ECOR 1010
Introduction to Engineering

Lecture 2

What is Engineering?

- How does Engineering differ from Science?
- Engineers design the “stuff” that society uses (including scientists and other engineers)!
  - Problem solving & critical thinking (applied analysis)
  - Design (synthesis)
  - Professionalism (formal organization, ethics)

“A scientist can discover a new star, but he cannot make one. He would have to ask an engineer to do that.”

— *Gordon L. Glegg, American Engineer, 1969*

What is an Engineer?

- *Ingenium* (Latin)
  - innate quality, especially mental power, capable of clever invention
- First used to describe those who had ability to invent / operate weapons of war – *military engineer*
- The word became associated with design / construction of works
  - Ships, roads, canals, and bridges.
  - People skilled in these fields were non-military or *civil* engineers.

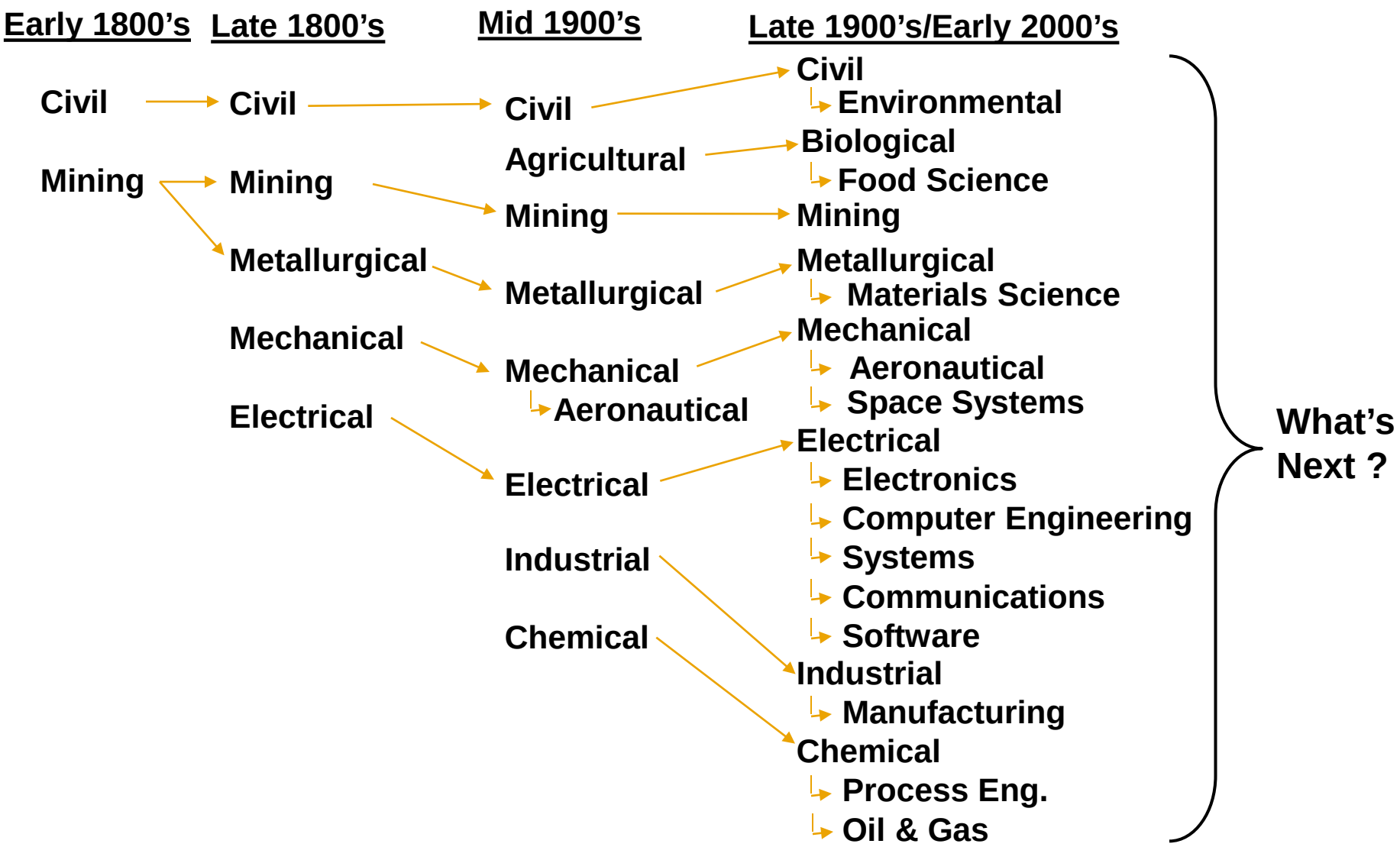
Definition of an Engineer

- An engineer is: (from textbook)
  - A person who uses science, mathematics, experience, and judgement to create, operate, manage, control, or maintain devices, mechanisms, processes, structures, or complex systems. Does this in a rational and economic way with human, societal, and natural resources and environmental constraints.

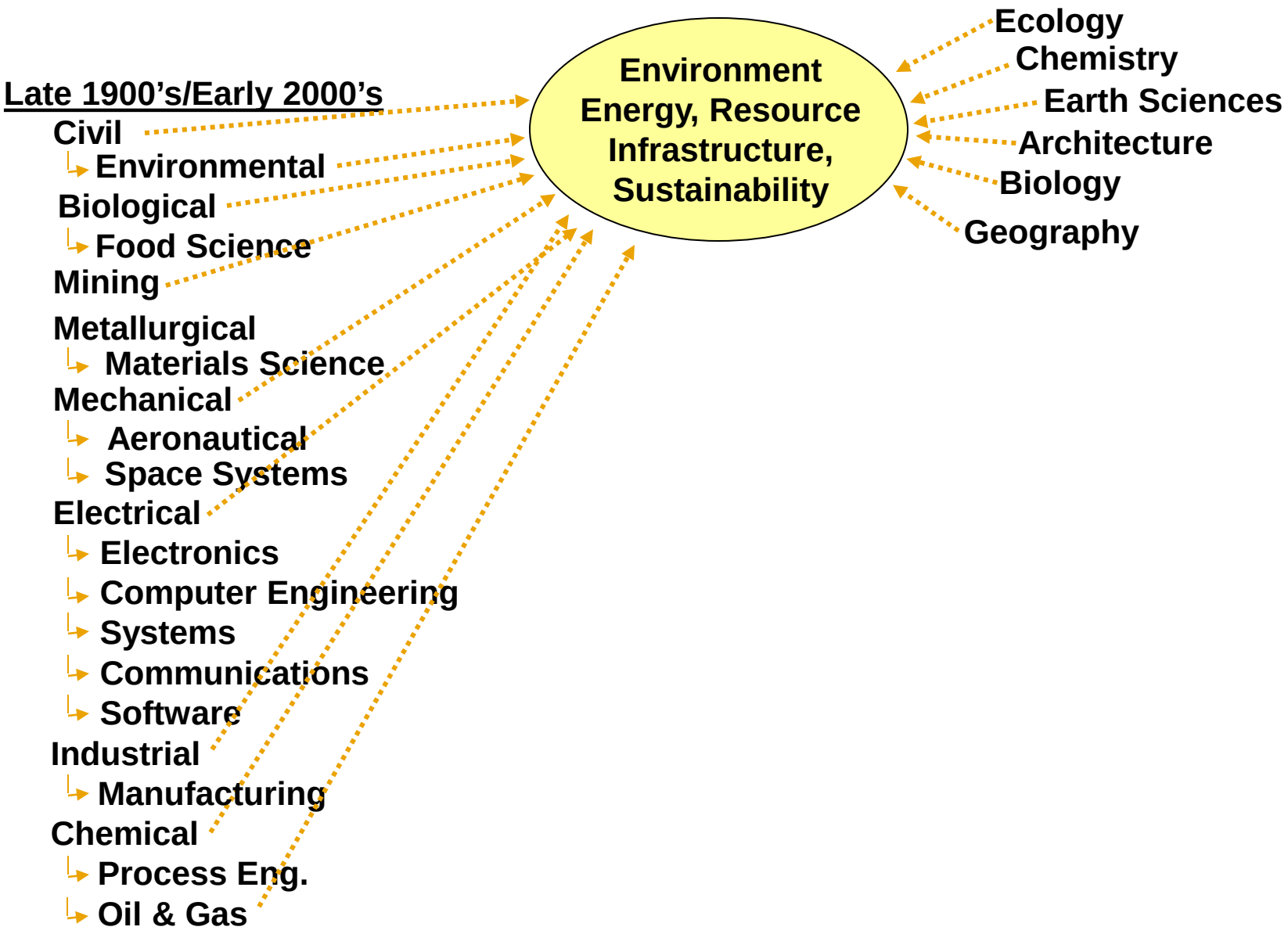
Definition of Engineering

- Definition of Engineering: (from American Engineers Council for Professional Development)
  - The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination;
  - or to construct or operate the same with full cognizance of their design;
  - or to forecast their behaviour under specific operating conditions;
  - all as respects an intended function, economics of operation and safety to life and property

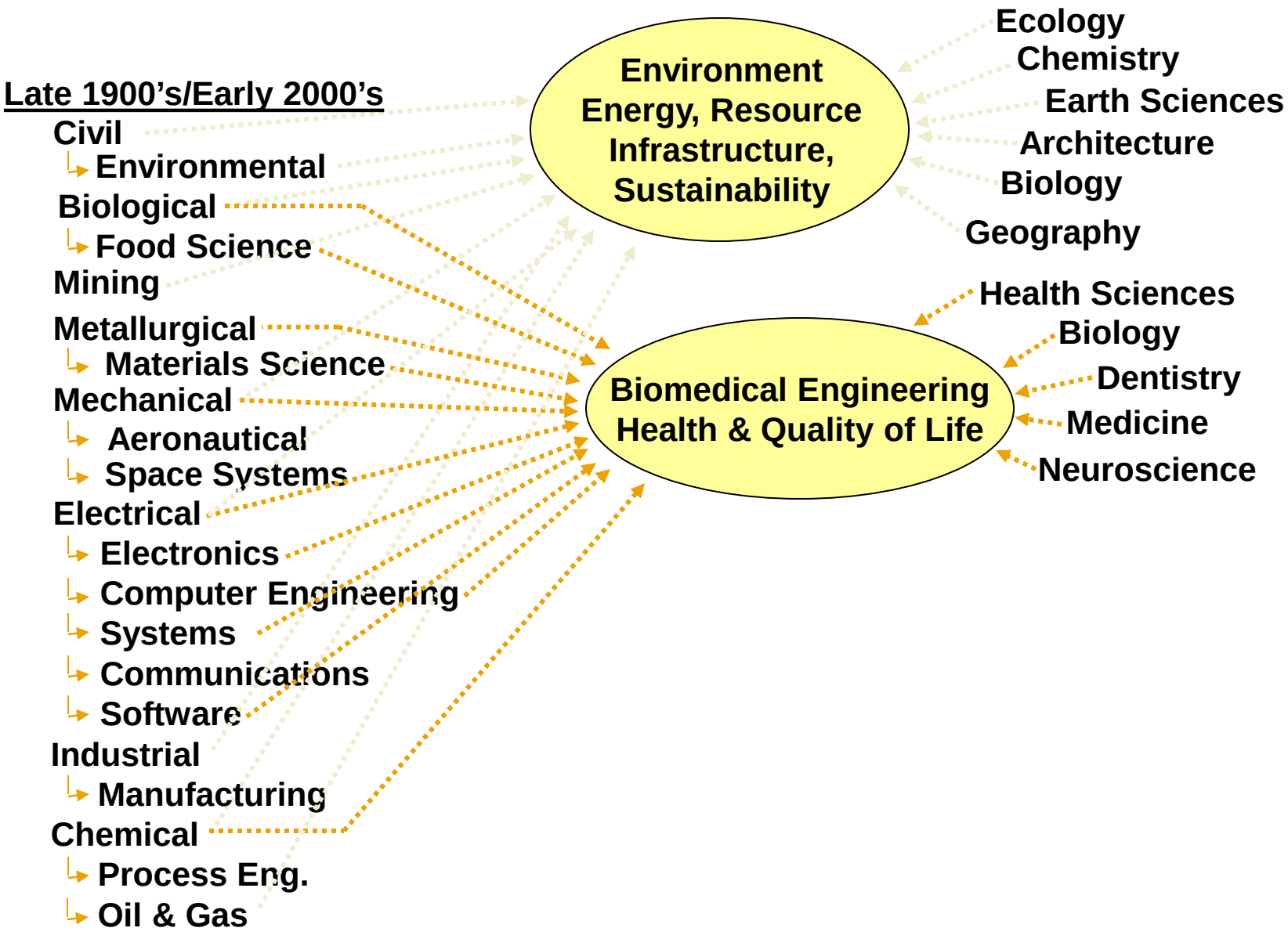
Engineering Disciplines



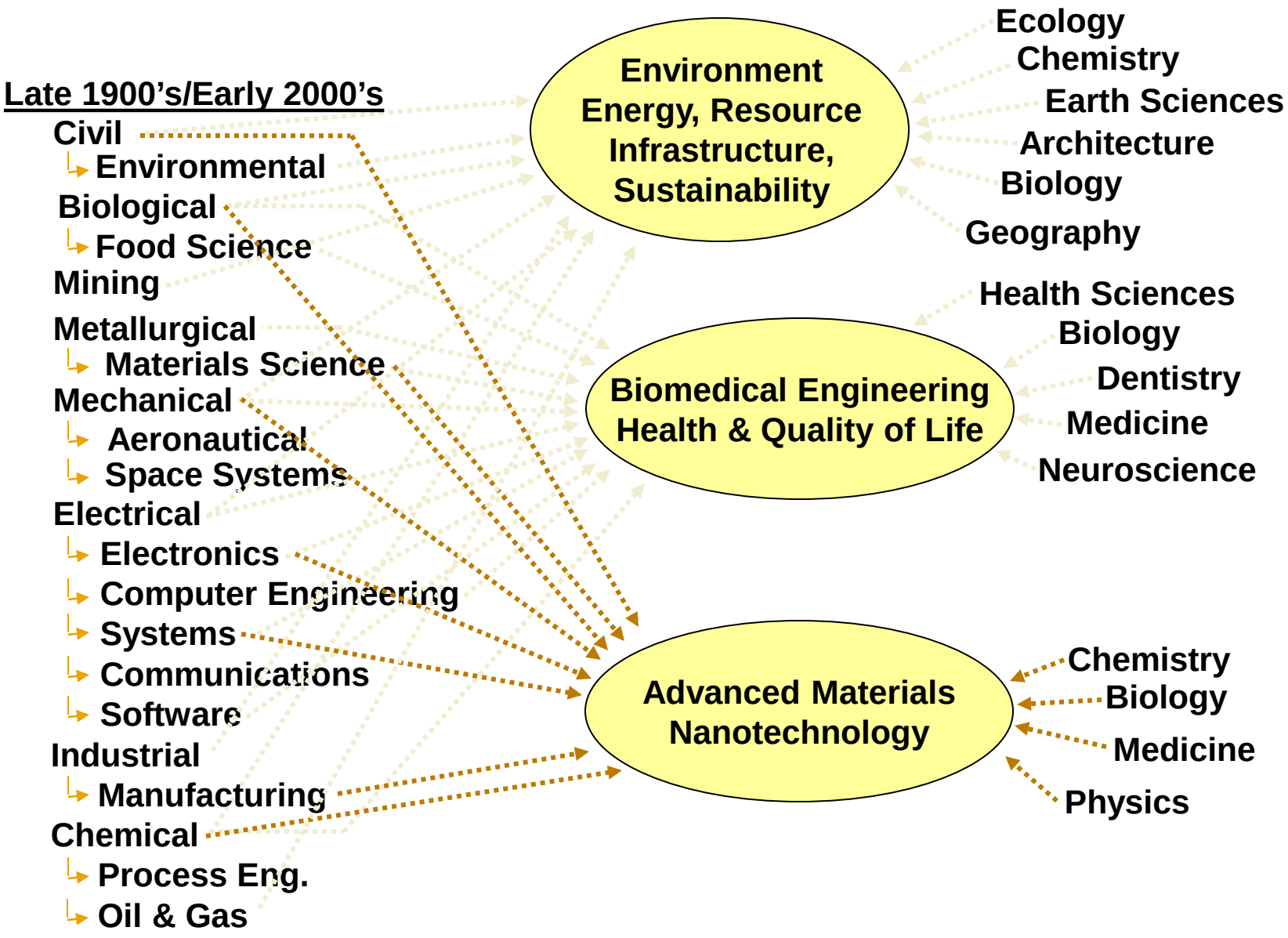
Interdisciplinary Approaches - 1



Interdisciplinary Approaches - 2



Interdisciplinary Approaches - 3



The Role of Engineers

- Engineering is a team activity.
  - Engineering teams involve individuals with widely different abilities, interests and education who cooperate to advance the project.
  - A typical technical team might consist of
    - engineers,
    - scientists,
    - technologists,
    - technicians,
    - social scientists,
    - skilled workers.

Engineer

- Provides the key link between theory and practical applications.
  - Extensive theoretical knowledge,
  - Ability to think creatively,
  - Ability to lead a team towards a common goal.
  - Knack for obtaining practical results,
- Education
  - Basic requirement is a bachelor’s degree.
  - Master’s or PhD is useful and sometimes preferred.

Professional Engineer

- In Canada, the title “professional engineer” is restricted by law.
  - Only those persons who have
    - Demonstrated competence
    - Been licensed by provincial professional engineering licensing association.

Professional Engineers
Ontario

J. Smith, B.Eng., P.Eng.

In Canada it is against the law to call yourself a “professional engineer” if you are not a licensed Professional Engineer

Canadian Engineering Accreditation Board (CEAB)

- PEO & other provincial/territorial associations rely on CEAB to evaluate & accredit engineering programs in Canada
- CEAB conducts regular & rigorous reviews of engineering programs
- Publishes list of accredited programs in Canada
- All Carleton engineering programs accredited for maximum available time (6 years)

CEAB Academic Requirements

- Mathematics (linear algebra, differential and integral calculus, differential equations, probability and statistics, and numerical analysis)
  - about 1/8th of the program
- Basic Sciences (physics, chemistry, biology or geoscience)
  - about 1/8th of the program
- Engineering sciences (ES)
  - minimum of 1/8th the program
- Engineering design (ED)
  - minimum of 1/8th the program

ES plus ED must be ½ of the program

- Complementary studies (TSE, etc.) is about 1/8th of the program

Why Conform to CEAB?

- If you want to become a professional engineer, then one of the principal requirements is that you graduate from an accredited program
- Other Requirements:
  - Practical Experience (4 years)
  - Professional Practice Examination
  - Character attested to by references
  - ~~Canadian Citizen or Permanent Resident~~

Two years ago

Technologist

- Works under direction of engineers
  - Applies engineering principles and methods to complex technical problems.
- Education
  - Completion of three year technology program from community college.
- Often supervises work of others and is encouraged to have qualifications recognized by technical society.
- Difference between engineering and technologist education
  - Engineering education typically provides greater theoretical depth
  - Technology diploma usually provides more hands-on experience.

Technician

- Works under the supervision of an engineer or technologist in the practical aspects of engineering,
  - e.g., making tests and maintaining equipment.
- Education
  - Completion of two-year technician program in a community college.
- Association may confer title of Certified Engineering Technician on those qualified.
  - Certification is not necessary to work as a technician.

Skilled Worker

- Skilled in a trade such as electrician, welder, plumber, carpenter, machinist, millwright, etc.
  - Typically carries out the designs and plans of others.
- Has great expertise acquired through formal apprenticeships and/or years of experience.
- Most trades have a trade organization and certification procedure.

Open-Ended Problems

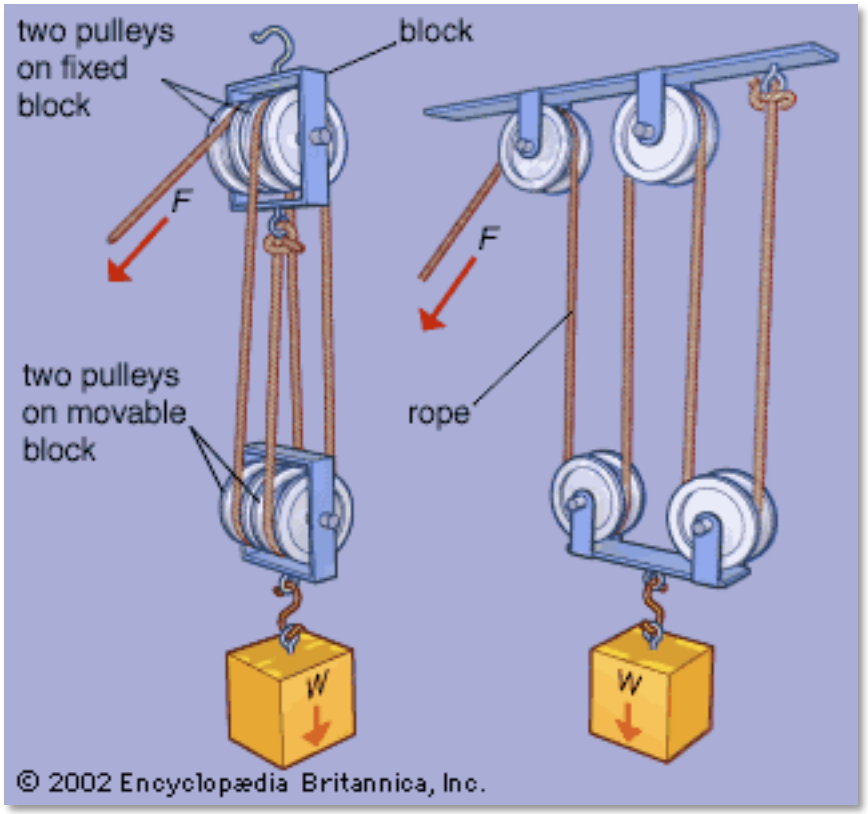
- Most engineering problems are open-ended
  - They don't have a single solution
- Just because there is more than one solution does not mean the problem is easier to solve
  - Actually, it can be the opposite!
  - New students sometimes find open-ended problems frustrating
  - What skills are needed to solve such problems?
    - Broad base of engineering knowledge
    - Critical thinking skills
    - Innovation
    - Perseverance

Engineering Skills

- How to represent a design problem
- How to make assumptions
- How to generate possible ideas for designs
- How to conduct an effective search for a solution
- How to plan and schedule activities
- How to make efficient use of resources
- How to organize the components and activities of a team design project

Ingenuity

- Engineers often find clever ways to “skirt” the laws of nature
  - the “block & tackle”
- Innovation
- Critical thinking
- Problem solving



Canadian Engineering Accomplishments

- Transcontinental Railway
  - Canadian Pacific Railway linked Canada from coast to coast in 1885.

Canadian Engineering Accomplishments

- De Havilland Beaver 1947

Canadian Engineering Accomplishments

- St Lawrence Seaway
  - Series of canals / waterways that opened Great Lakes to ocean going ships in 1959.

Canadian Engineering Accomplishments

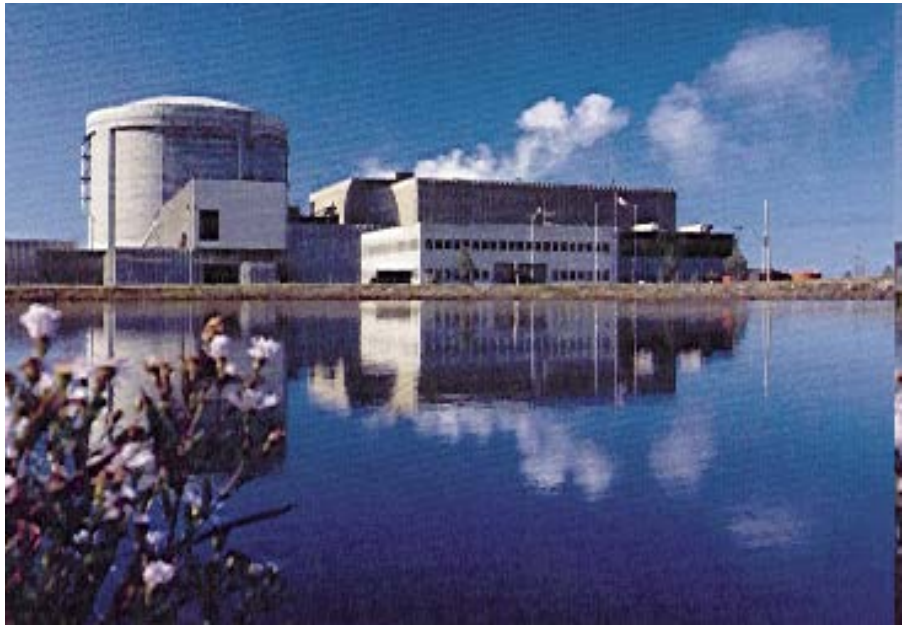
- Athabasca Oil Sands
  - Commercial oil sands development showed the feasibility of recovering oil from the oil sands.

Canadian Engineering Accomplishments

- Very-High-Voltage Transmission
  - Hydro-Québec was first electrical utility to develop transmission lines at very high voltage for long-distance power transmission.

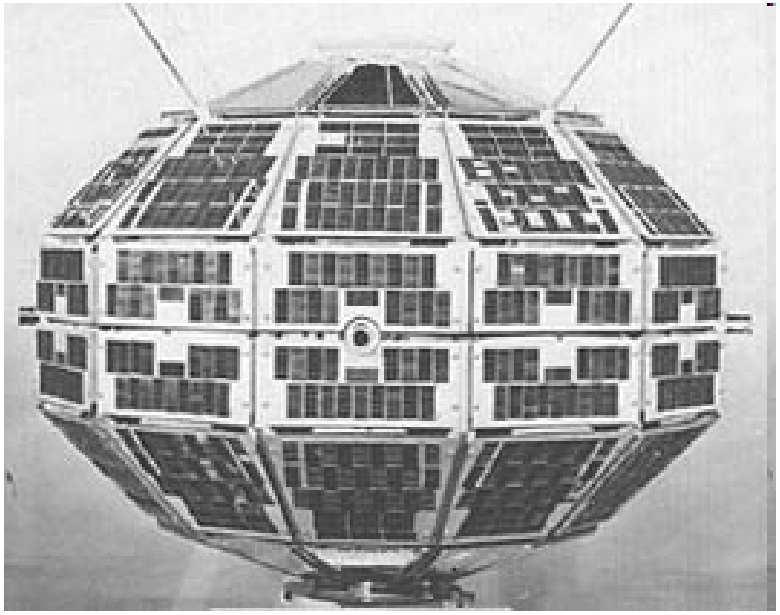
Canadian Engineering Accomplishments

- Nuclear power
  - CANDU nuclear power system produces electric power using natural uranium fuel and heavy-water for moderation and cooling.
  - No need for expensive fuel enrichment.



Canadian Engineering Accomplishments

- Alouette Satilite
  - 3rd country into space – September 1962

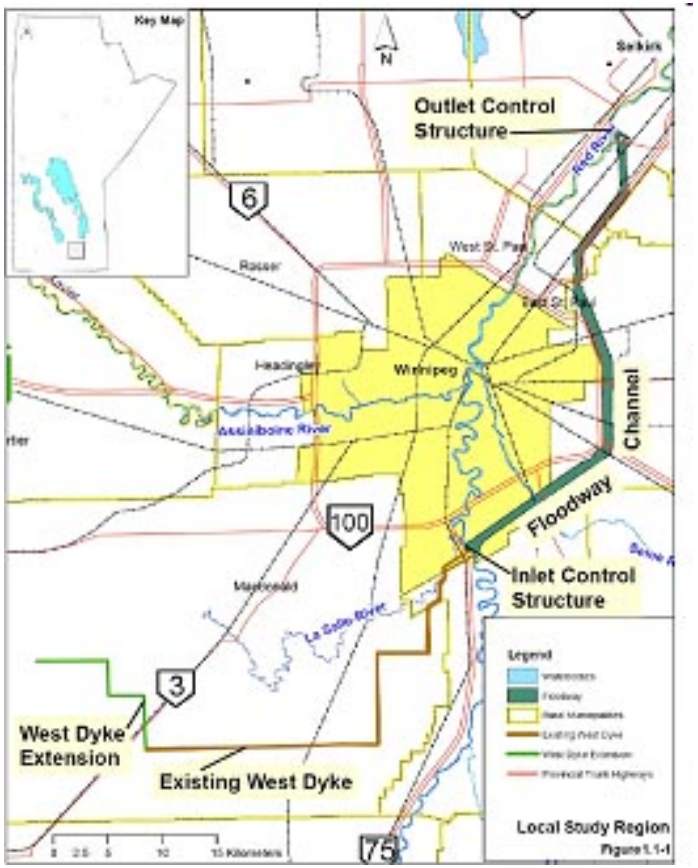


Canadian Engineering Accomplishments

- Trans-Canada Telephone Network
  - Completed in 1958 as world's longest microwave network.

Canadian Engineering Accomplishments

- Winnipeg Floodway – 1963-1968



Canadian Engineering Accomplishments

- The Canadarm

Canadian Engineering Accomplishments

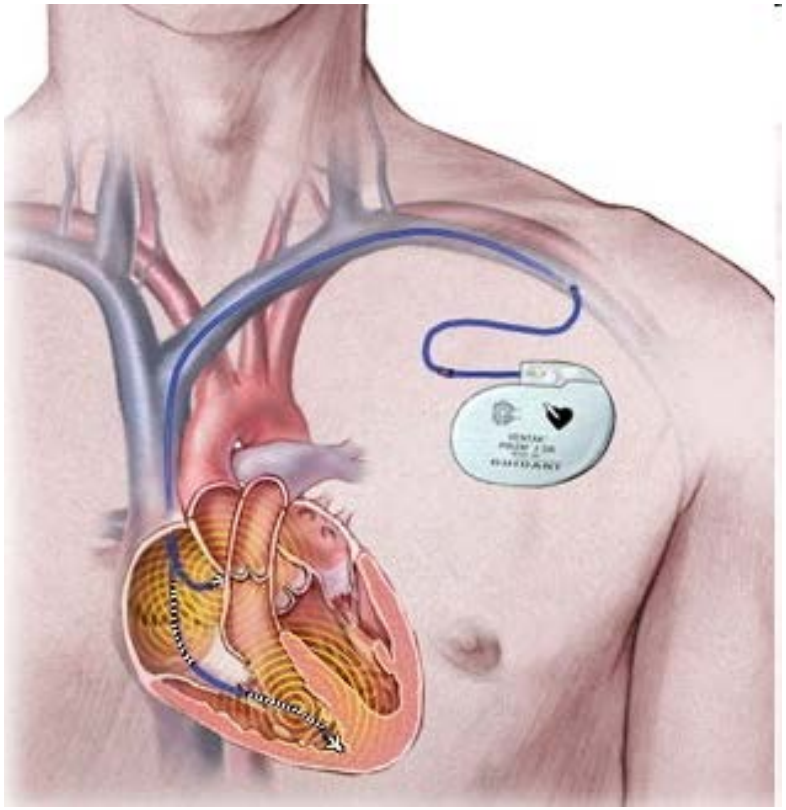
- Confederation Bridge
  - Longest bridge in the world crossing salt water subject to winter ice hazards.

Canadian Engineering Accomplishments

- IMAX

Canadian Engineering Accomplishments

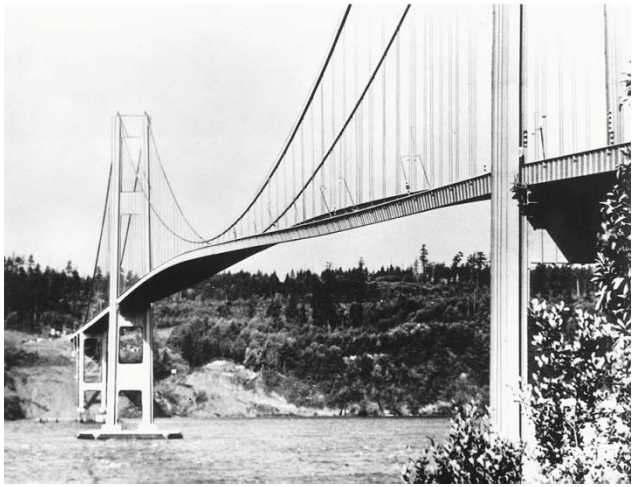
- Pacemaker
  - Developed by John A Hopps in 1949.



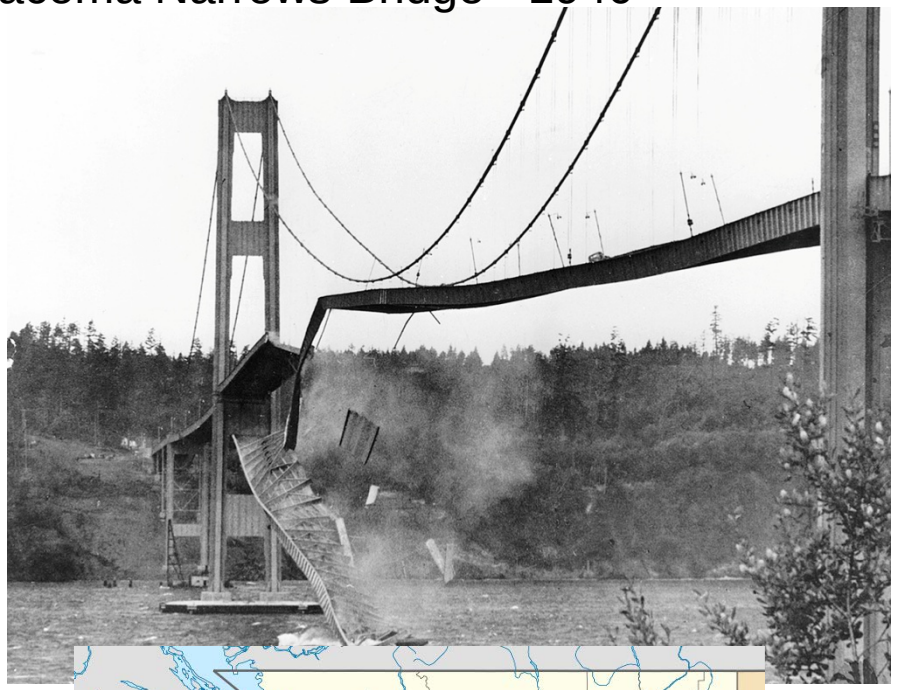
Canadian Engineering Accomplishments

- CN Tower
  - Built in 1976 as world's tallest free-standing structure.
  - American Society of Civil Engineers listed CN Tower as one of seven wonders of modern world.

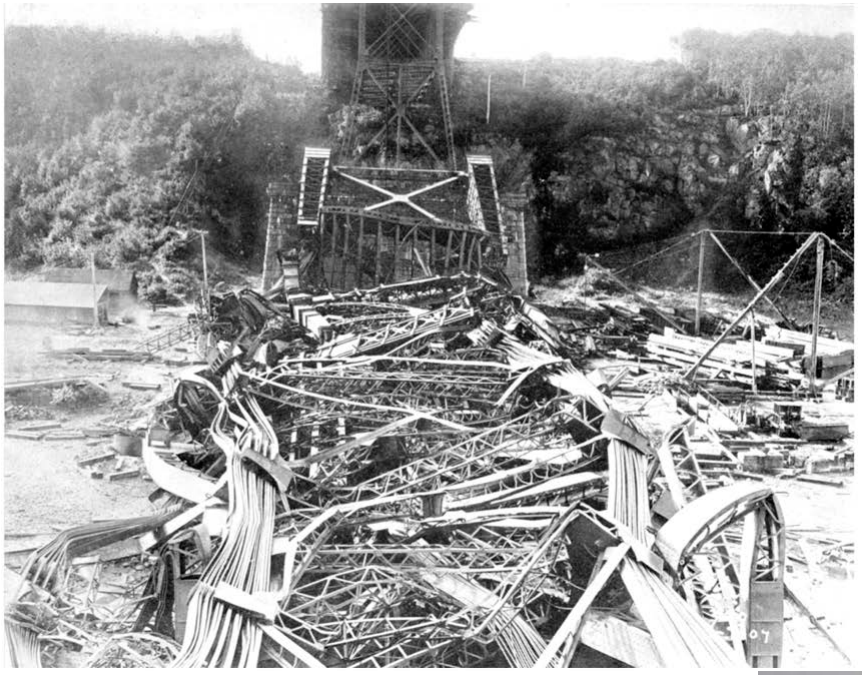
Engineering Requires Diligence



Tacoma Narrows Bridge - 1940



Quebec Bridge 1907



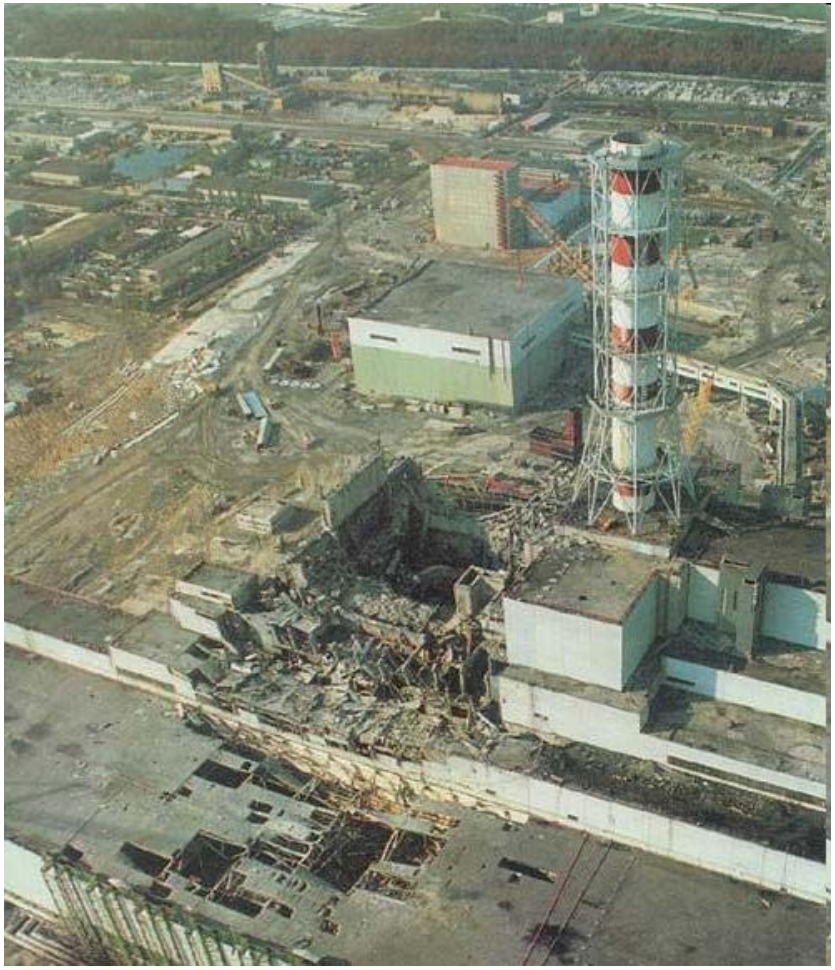
- longest cantilevered span in the world
- collapse during construction killed 75

Space Shuttle

Challenger

Columbia

Chernobyl Nuclear Reactor 1986



All Engineering Is Interdisciplinary

Many engineering disasters are rooted in inadequate interdisciplinary knowledge.

A ***FEW*** examples:

- No mechanical or civil engineer ever knows enough about electric motors
- Electrical engineers never know enough about heat transfer
- Biomedical engineers will always need more medical knowledge
- Systems engineers need to know more about mechanics
- All engineers need to know more chemistry
- All engineers need to know more about societal reaction to technology
- All engineers need better imaginations !

But … we only have you here for four years,

So maximize your learning for the next four years !

ECOR 1010
Lecture 3

Engineering Reporting & Measurements, Dimensions and Units

Engineers – Do We Have to Write?

Ing Lishmajor

“The Gender Stereotypes of Petruchio and Bianca in Shakespeare's The Taming of the Shrew”

Term Essay for ENGL 2109 - Gender, Sexuality and Literature

Essays – No … But … *Reports* – Yes

J. Beddoes, H. Lagacé

“Calorimetric and Microstructural Study of an Al-Zn-Mg-Si Alloy”

Alcan International Ltd., KR-83/049, 2 Aug. 1983 (proprietary)

Introduction – Engineering Reporting

- You Will Be Judged By Ability To Write Well
  $\Rightarrow$ In this engineering program and throughout your career
- Career Advancement Depends Partly On Writing Ability
- Not Literary Writing
  $\Rightarrow$ Communications Skills In A Technical & Business Environment
- Never Too Soon to Refine Your Written Skills
  $\Rightarrow$ You will never have adequate writing skill !

Reporting Topics - Formats

- Current Work:
  - Assignments
  - Laboratory Reports (for ECOR 1010 or other courses)
  - Resumé
  - Job Applications

- Early Career
  - Internal Memos
  - Progress Reports
  - Internal Technical Reports
  - Contribute To External Reports

- Later Career
  - Proposal Preparation
  - Technical Reports
  - Patents
  - Budget / Staffing Forecasts
  - Business Letters

Before Writing – Think About …

- Who Is The Reader ?
- What Does Reader Already Know ?
- What Does Reader Want To Know ?
- What Do You Want Reader To Know ?

Your boss

Your “boss”

That you answer

That you know the answer

Whether you know the answer

Whether you know the answer

That you know the answer

That you know the answer

When Writing Remember …

- What is the message you are trying to convey?
  - Purpose of report
  - Scope of work
  - Technical detail
- Who is your audience?
- Start by sketching out a table of contents
- Be consistent in your formatting
  - Style and references

Universal Rules

- Date and Sign Everything Written
- Be Clear and Concise $\Rightarrow$
- Avoid Jargon and Fancy Words
- Plan Content – Outline – Several Drafts
- Spell Checkers Are Only An Aid $\Rightarrow$
- Do NOT Leave Writing to the Last Minute
- **PROOF READ OVER AND OVER**

Be Concise and Clear

- Minimize Number Of Words $\Rightarrow$

- Avoid Verbs Turned Into Nouns

"Determination of procedure occurs at the committee level."

"The committee determines procedure."

- Use Strong Subjects

"The decision was made by the supervising engineer."

"The supervising engineer made the decision."

- Useless Adverbs

"The project was completed really well."

"The project was completed well."

Minimize Number of Words

"Objective consideration of contemporary phenomena compels the conclusions that success or failure in competitive activities exhibits no tendency to be commensurate with innate capacity, but that a considerable element of the unpredictable must inevitably be taken into account."

"The race is not to the swift,
nor the battle to the strong,
neither bread to the wise,
nor riches to those of understanding,
or favour to those of skill;
but time and fate happens to all."

Ecclesiates, chap. 9, verse 11.

You have to be lucky!

Spell Checkers

I have a spell checker

It came with my PC

It plainly checks *four* my *revue*

Mistakes I cannot *sea.*

I've run this poem *threw* it,

I'm sure *your please too no*

Its letter perfect in *it's weigh*,

My checker *tolled* me *sew*.

- Vigorous writing is concise. A sentence should contain no unnecessary words [and] a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts. This requires not that the writer make all his sentences short, or that he avoid all detail and treat his subjects only in outline, but that every word tell.

Elements of Style, William Strunk, Jr. - 1918

Qualities of a Good Engineering Report

- Clear statement of purpose
- Concise presentation of detail
- Logical development of data and ideas
  - Analyze, explain, conclude, recommend
- Objective separation of fact and opinion
- Organized layout
  - Well-spaced headings and visuals
- Has adequate references
  - No plagiarism or “forgotten” references
- Has no spelling or grammatical errors
  - No slang or jargon

Comprehensive Engineering Report

- Title Page
- Executive Summary, Abstract
- Table of Contents, List of Figures, List of Tables
- Introduction
  - Any necessary background information
  - Reasons for writing the report
  - Concise statement of the objective of the laboratory
- Method
  - Detail the method used to fulfil the objective of the laboratory
  - What steps were taken?
  - What tools were used to solve the problem?

Comprehensive Engineering Report

- Results and Discussion
  - Present the findings of your work
  - Tables, graphs, and drawings can support this section, but must be accompanied by descriptive text (caption)
  - Only describe results that relate to the objective
  - Discuss any difficulties/anomalies that were encountered
  - Significance of your results
- Conclusions
  - Was the objective achieved?
  - Either paragraph or organized in point form

Comprehensive Engineering Report

- Acknowledgements
- References
- Appendices
  - Data tables
  - Graphs
  - Drawings

Not required to directly understand Results, Analysis, Discussion or Conclusions

Resumé

- Purpose $\rightarrow$ To Get Interview
- Content
  - Who Are You / Where Are You
  - Your Education
  - Your Work Experience
  - Technical Interests & Achievements
  - Volunteer & Community Activities - Leadership
- Personal Details Not Necessary (Age, Gender, Birthplace, Photograph)
- Academic Marks & Standing
- References - Available On Request
- Customize For Different Jobs

Covering Letter

- Concise, Formal, Respectful But Confident
- Confined To Specific Job
  - Indicate Knowledge of Job / Company
  - Why Hire Me ?
- Contact Details On Letter
- **PROOF READ OVER AND OVER**

Internal Memos

- Rapid Transfer Of Information
- Variety of Formats → Organization Specific
- Often Formal & Archival
- Usually Internal → Immediate Supervisor + Distribution
- Concise, But Not Necessarily Short
- Proper Grammar → Even In E-mail
    - Technical Information
    - Meeting / Trip Report
    - Production Summaries
    - Monthly, Quarterly Progress Reports

PRATT & WHITNEY AIRCRAFT OF CANADA LTEE LTD.

MEMO

2780-80-80-30600

To: Mr. W. Abdel Messeh

12 March 1980

From: J.C. Beddoes, Dept. 2788, Ext. 7611

cc: Messrs. D.L. Cook
F.C. Desrochers
H.B. Dunthorne
N. Khemchandani
H. Lavery
I. McCormick
U. Okapuu
A.D. Strelshik
K. Wilson/C. Briggs/ B.Plitz

C.F. #S-3373
S.S.F. #S-3168
S.S.F. #S-3168T

Distribution Including archival files

Re: PT7A-1 Low Pressure Shroud Housing

Ref: 1) Memo from J. Beddoes to W. Abdel Messeh, "PT7A-1, HPT Shroud Housing", dated 14 February 1980.

Introduction

The PT7 low pressure shroud housing was analysed to determine its acceptability from a stress point of view. Additionally, tip clearance for three operating conditions (ground idle, cruise, take-off) was determined. This memo summarizes the analysis and results thus obtained.

Clear statement of content

Conclusions & Recommendations

1) Steady-state cruise tip clearance is 0.015", based on an initial clearance of 0.033" and a pinch point of 0.006", see Figure 1.

2) The variation in tip clearance from leading to trailing edge is less than 0.001".

3) Shroud ring stress levels are well below the 0.2% yield stress of IN-718, the recommended material.

4) Shroud segment stress levels are high, but at no location exceeding the 0.2% yield stress of IN-792 MOD 5A, the recommended material.

Outcome of work

Shroud Housing Design

Details

The LPT shroud housing consists of two parts, the shroud segments and the shroud housing ring. Both these parts are cooled by T_3 air, bled from the cooling duct around the combustion chamber liner. A schematic of the cooling scheme is shown in Figure 2. A total of 0.5% cooling air is bled for the shroud housing. After air impinges on the shroud segment, it will join the hot gas by leakage between the shroud segments. The design and analysis of the LPT shroud segment is similar to that for the HP shroud segment. The HP shroud design is summarized in another memo (Ref. 1).

Project Proposals

- Development of Future Work
  - Marketing Proposal
  - Production Capability
  - Product Development
  - New Design
- Compete For Internal Capital Funds
- Compete For External Work
- Proposal Can Be Costly To Produce
- Contains:
  - Rationale For Expenditure
  - What Is To Be Done
  - Schedule
  - Risks
  - Capability Of Project Group
  - How Will It Be Done
  - Budget
  - Major Potential Problems
- REMEMBER - You May Have To Do What You Propose !

Technical Research Papers

- Concise Summary of a Significant Technical Advance
- Structured Format:

  Abstract, Introduction, Procedural Details, Results, Discussion
  Conclusions, Acknowledgements, References

- Information Becomes Public
  - Free Of Commercialism
  - Cannot Directly Criticize Competitors Product or Process

- Corporate Policy For Release Of Information
  - Internal Technical Reports
  - Frequently Confidentiality Agreements

JOURNAL OF MATERIALS SCIENCE: MATERIALS IN MEDICINE 10 (1999) 389–394

The influence of surface condition on the localized corrosion of 316L stainless steel orthopaedic implants

J. BEDDOES, K. BUCCI
Department of Mechanical and Aerospace Engineering, Carleton University, 1125 Colonel By Drive, Ottawa, K1S 5B6, Canada

Abstract
< 200 words.
Statement of contents and significance.

The localized corrosion of austenitic stainless steel 316L intended for use as orthopaedic implants is determined as a function of the surface condition and metallurgical state. From the examination of samples exposed to a ferric chloride solution, at both 22 and 37 °C, the independent contribution of crevice and pitting corrosion to localized corrosion is determined. Both forms of localized corrosion occur to a greater extent at the higher temperature. The results indicate that weight loss measurements may not be sufficient to determine the extent of crevice corrosion separately from the influence of pitting corrosion. More importantly, the surface conditions required for the best resistance to crevice or pitting corrosion differ. Electropolished surfaces provide the best resistance to crevice corrosion, while "bead blasted" surfaces provide the best resistance to pitting corrosion. The implication of this result in terms of the serviceability as orthopaedic implants is discussed. The current results indicate the cold-worked state exhibits improved resistance to pitting corrosion. However, the influence of the metallurgical state could not be separated from a possible compositional effect.
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Background information to put report into context

1. Introduction

Type 316L stainless steel is the most popular metal for use as osteosynthesis plates for orthopaedic applications. This popularity stems from a satisfactory combination of good mechanical properties and reasonable cost. However, during exposure to physiological environments the protective surface oxide inherent to 316L is not stable [1], causing both crevice and pitting corrosion to occur [1–3]. Analysis of retrieved implants reveals that even after exposure times as short as 2 months crevice corrosion is evident [4]. While it is uncommon for the pitting and crevice corrosion to be sufficiently extensive that mechanical failure occurs, corrosion releases metallic ions into surrounding tissue leading to inflammation and possible loosening of the implant [5]. Furthermore, there is concern regarding the accumulation of metallic ions, released by corrosion, within internal organs [6]. Pitting and crevice corrosion have resulted in the premature removal of 316L implants [4].

In light of the foregoing, the localized corrosion of 316L for orthopaedic applications has been extensively studied. It is well established that the initiation of both pitting and crevice corrosion is associated with the presence of sulfides [7, 8]. As a consequence the maximum sulfur content of 316L for implant applications is 0.01 wt % [9]. The surface condition of the implant also has a major influence on the resistance to localized corrosion. Generally, reducing the average crevice gap increases the susceptibility to crevice corrosion [10]. However, surface grinding may be detrimental to crevice initiation [11], since it produces residual surface stresses, while electropolishing improves corrosion due to the reduced surface area, removal of the disturbed layer left by grinding, removal of imbedded contaminants, and development of a protective surface film [1, 2, 11].

Type 316L bone fixture plates can be implanted in either the cold-worked or annealed condition. The former provides higher strength, but during surgical procedures the latter is more easily formed to bone contours. Previous investigations suggest that the cold-worked condition is more susceptible to crevice corrosion [2, 12], probably due to an increase in the internal stress.

The purpose of the work presented in this paper is to determine the susceptibility to pitting and crevice corrosion at 22 and 37 °C of 316L surfaces prepared according to industrial practices for bone fixture plates. Accordingly, the results for five surface conditions are presented for both the cold-worked and annealed states. A limited number of samples of 304 are included for comparison.

Clear statement of purpose

2. Materials and experimental procedure

Approximately 50 316L samples with dimensions of 25 × 50 × 5.5 mm were supplied by a manufacturer of orthopaedic bone fixture plates. The samples were prepared from either annealed or cold-worked stock,

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Long term creep of TiAl + W + Si with polycrystalline and columnar grain structures

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Received 5 September 2004; received in revised form 2 December 2004; accepted 13 December 2004

Abstract < 50 words. Statement of contents and significance.

Abstract

The long term creep properties at 207 MPa and 760 °C of TiAl + W + Si with a fully lamellar microstructure and either polycrystalline grains or a columnar grain structure are compared. The results indicate that the columnar grain structure reduces the primary creep strain and delays the onset of tertiary creep, with only 1.2% creep strain after 10,000 h.
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Keywords: Bridgman technique; Directional solidification; Titanium aluminides; Creep

Background Information to put report into context

1. Introduction

Compositions based on the TiAl intermetallic exhibit a desirable combination of strength, oxidation resistance, density and creep properties. This combination of properties makes them potential candidates for several elevated temperature applications in reciprocating and gas turbine engines. All of the envisaged applications are within a temperature and stress domain in which creep can be expected to occur and, therefore, the creep resistance of TiAl has been the subject of considerable attention. It is well established that maximum creep resistance of TiAl compositions is developed through heat treatment to the fully lamellar structure of alternating plates of the α_2 and γ phases [1]. Further, if the α_2 and γ lamellae are aligned with the loading direction an improved combination of mechanical properties can result [2,3]. The creep properties of nickel base superalloys can be improved through directional solidification that eliminates grain boundaries transverse to the loading direction [4,5]. Therefore, directional solidification of TiAl to produce a columnar grain structure combined with heat treatment to the fully lamellar microstructural condition may serve to maximize creep resistance, particularly if lamellae are aligned in the load direction. By comparing the long term creep properties of polycrystalline and columnar grained fully lamellar TiAl + W + Si structures this paper refines the definition of the microstructural characteristics necessary for maximum creep resistance and further elucidates the microstructural factors controlling creep of TiAl intermetallics.

Clear statement of purpose

The addition of W to TiAl can improve creep performance [6–8], however creep properties are sensitive to the presence of the W-rich β phase. In W containing TiAl compositions aging the fully lamellar structure in the $\alpha_2 + \gamma$ binary phase field (approximately 850–950 °C) causes β precipitates/particles to form along lamellar interfaces/grain boundaries. Comparison of the creep properties of aged and unaged fully lamellar structures demonstrates that β phase formation lowers the primary creep strain, but reduces the creep rupture life

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Patents

- Legal Document - Significant Initial and Ongoing Costs
- Provides Protection of Intellectual Property
  - Do You Need Or Want Protection ?
  - Usually Strict Corporate Policies In Place
- Must Divulge Technical Details
  - Product Patents More Common - WHAT
  - Process Patents Less Useful & Desirable - HOW
- Structured Format

  Field of Invention, Background of Invention, Summary of Invention, Description of Invention, Examples of Use, Claims
- Usual To Enlist Advice of Patent Attorney
- Lengthy Process - about 2 years from application to patent

United States Patent [19]

Saxena et al.

[11] **Patent Number: 5,897,922**

[45] **Date of Patent: Apr. 27, 1999**

[54] **METHOD TO MANUFACTURE REINFORCED AXI-SYMMETRIC METAL MATRIX COMPOSITE SHAPES**

[75] Inventors: **Pawan Saxena**, Gloucester; **Jonathan C. Beddoes**, Ottawa; **Ashok K. Koul**, Gloucester, all of Canada

[73] Assignee: **National Research Council of Canada**, Ottawa, Canada

[21] Appl. No.: **08/826,672**

[22] Filed: **Apr. 7, 1997**

[51] **Int. Cl.**^{6} **C23C 4/08**; B22D 11/00

[52] **U.S. Cl.** **427/455**; 164/465; 427/422; 427/425; 427/427; 427/576; 427/177; 427/178

[58] **Field of Search** 427/576, 422, 427/455, 425, 427, 199, 200, 203, 205, 206, 180, 177, 178; 164/465

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,401,539 3/1995 Coombs et al. 427/422

5,480,676 1/1996 Sonoparlak et al. 427/180

Primary Examiner—Janyce Bell

Attorney, Agent, or Firm—Juliusz Szereszewski

[57] **ABSTRACT**

A composite part consisting of a metallic matrix and reinforcing fibers is fabricated by the simultaneous winding of the fiber and plasma spraying of the matrix onto a rotating mandrel, wherein an axi-symmetric part is produced with multiple layers of the fibers aligned in the circumferential direction. Single or multiple fiber strands are wound onto a mandrel and simultaneously sprayed with the heated powder matrix material using a thermal spray process. Rotation and translation of the mandrel produces an axi-symmetric composite part. The content of the fiber material in the plasma sprayed matrix is typically up to 40% by volume. The light-weight composite part is produced in a single processing step. The part may be used either directly, or as an insert in other components with or without further densification.

11 Claims, 4 Drawing Sheets

ECOR 1010 Lab Reports

- One page of text, plus front (title page) and back matter (appendices)
- Typed and neatly formatted
- Use Course Template: 12 point font size with fixed margins all around
- Drawings, tables, and graphs should be attached to the report as Appendices
- Drawings, tables and graphs should be supported by a short statement describing purpose and content (i.e., a caption)

Title Page

ECOR 1010 – INTRODUCTION TO ENGINEERING

FULL AUTHOR'S NAME

ASSIGNMENT #1

Assignment Title: ...

TO:

Marking TA Name: ...

Marking TA Email: ...

Lab Section: A1

Room: ME2556 – Carleton University

FROM:

Author's Email: ...

Student Number: ...

Word Count*: 278

Number of Figures and Tables: ...

Last Date and Time of Revision: DD/MM/YYYY @ HH:MM (AM/PM)

* Word Count is of all pages, including Title Page, Figures and Tables if applicable (it shows on the left-bottom corner of the MS Word status bar as "Words: ..."). It is just for the part of assignment prepared in MS WORD.

One Page of Text

- Introduction
  - background information, concise statement of technical objective
- Method
  - procedure to investigate objective
- Results & Discussion
  - present results related to objective clearly, refer to graphs, tables or drawing as required
  - details in Appendix
  - discuss difficulties or anomalies and significance of results
- Conclusions
  - list specific significant conclusions
  - state if objective achieved

Figures and Tables

- All Figures and Tables referred to in one page of text must be numbered and have a caption
- Immediately follow text (they are not part of Appendix)

Figure 1: Carleton engineering students at CFB Trenton.

Table 1: 1st Year Full-time Engineering Enrolment 2012

Program	Enrolment
Aerospace	131
Architectural C & S	50
Biomedical & Electrical	35
Biomedical & Mechanical	47
Civil	167
Communications	40
Computer Systems	64
Electrical	144
Engineering Physics	2
Environmental	56
Mechanical	156
Sustainable & Renewable Energy (A&B)	22 & 23
Software	57
Total	994

Appendices

- Sketches, drawings, tables, calculations, etc. and supporting text that provide additional detail to results.
- Each Appendix referred to individually in Results section
- But, each sketch, drawing, table, etc. in the Appendix does not have to be referred to individually in Results section.

Laboratory Reports – Other Courses

- PHYS 1004, CHEM 1101, CHEM 1000
- Make sure you are familiar with reporting requirements

A Couple of Web Resources

- Writing Guidelines for Engineering and Science Students: http://www.writing.engr.psu.edu/
  - Lots of links and examples
- Engineering Communication Centre (UofT): http://www.ecf.utoronto.ca/~writing/handbook.html

Summary

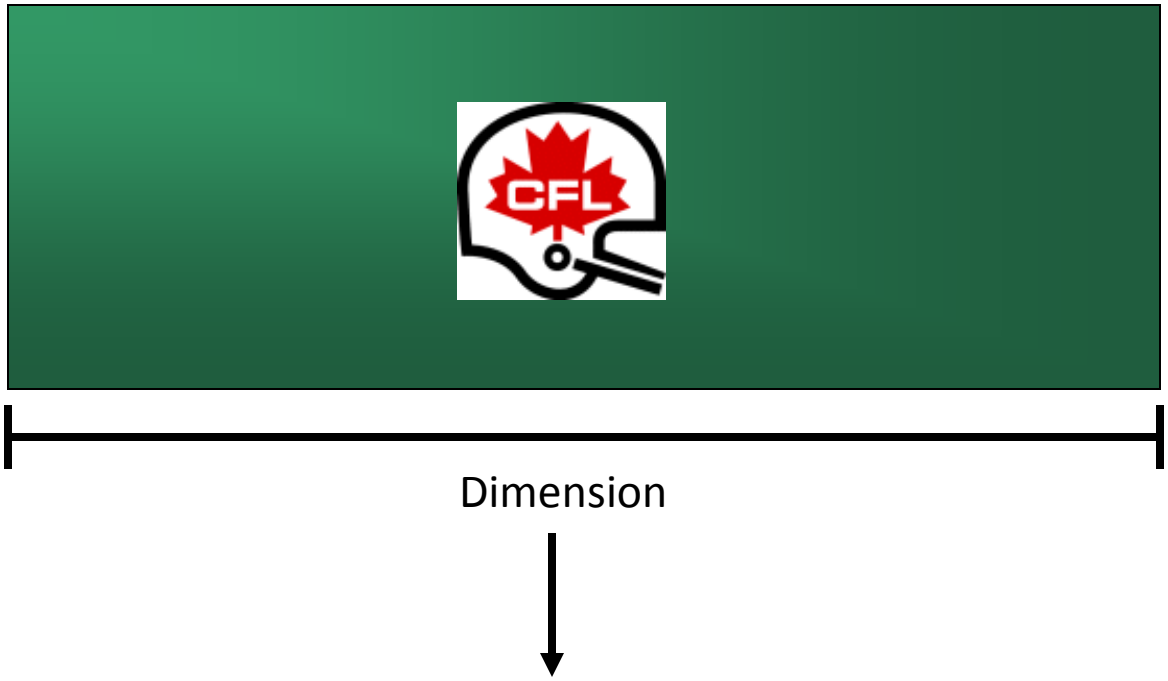
- Poor writing & reporting skills will impede your advancement at university & in your career
- Good writing & reporting requires practice
- **PROOF READ OVER AND OVER**
- There are many forms of technical writing, but always
  - Clarity
  - Conciseness
  - Accuracy
  - Courtesy
- Pay attention in CCDP 2100 - Communication Skills for Engineering Students

Measurements

- Physical quantity that has been observed.
  - Measurement compared to a standard quantity.
    - Standard quantity is called a unit.
    - Example: 1 kg is a standard unit.
      - e.g., mass of an object is 5 times greater than the standard unit, thus its mass is 5 kg.
  - A measurement consists of two parts:
    - A numerical magnitude and
    - A name, symbol, or combination of symbols that define the reference standard.

Measurements, Dimensions, and Units

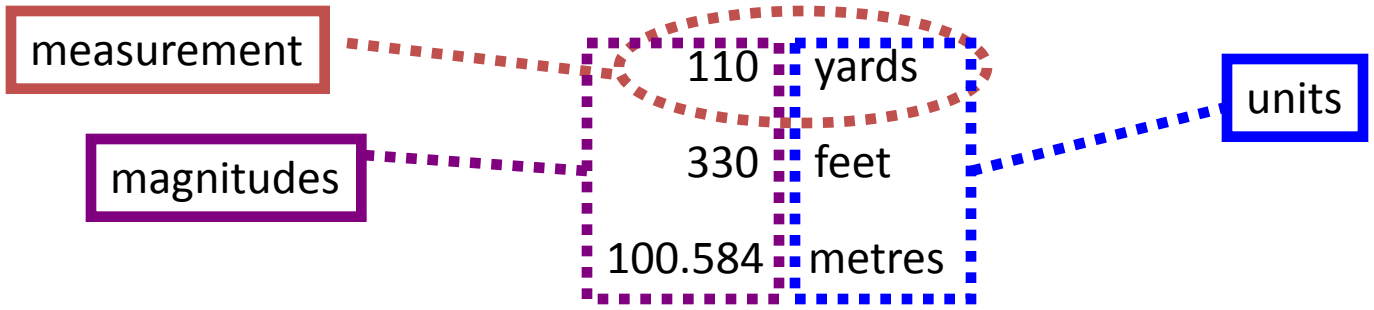
To explain these definitions, consider a CFL Football Field:



The physical length of a CFL football field. The actual length of the field is constant, and does not change.

Measurements, Dimensions, and Units

The length of the field can be represented by various measurements:



Changing the unit changes the magnitude of a measurement, not the physical dimension!

Base and Derived Units

- Derived Unit
  - Derived in terms of base units
    - e.g. 1 Newton = 1 kilogram times metre per second squared
      - (N = Kg m/s^2)
- Base Units
  - Fundamental units from which all other units are derived.

Système International d'Unités (SI)

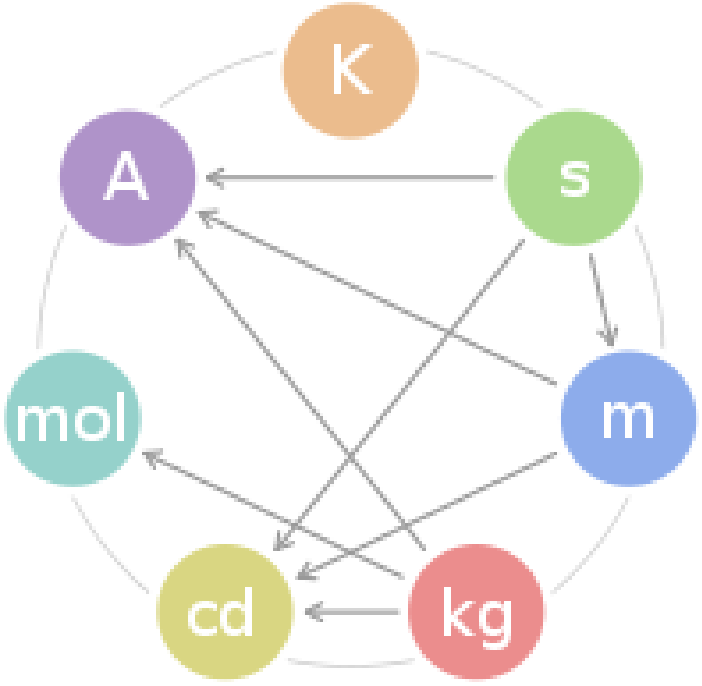
- Adopted by almost all countries
  - United States is a notable exception.
- Metric system introduced as measurement system "for all people, for all time".
- Metre was originally chosen to be one ten millionth of distance between north pole and equator.

Since 1983 the metre is the length of the path travelled by light in vacuum during a time interval of 1⁄299,792,458 of a second.

7 Base Units in SI

The International System of Units (SI) defines seven units of measure as a base set from which all other SI units are derived:

- metre for length
- kilogram for mass
- second for time
- Ampere for electric current
- Kelvin for temperature
- candela for luminous intensity
- mole for the amount of substance.



1 metre is practically = 1,579,800.762042(33) wavelengths of helium-neon laser light in a vacuum

Base and Derived SI Units - 1

TABLE 10.1 Base and derived SI units

Symbol	Unit Name	Quantity	Definition
~~M~~ →m	metre, meter	length	base unit
kg	kilogram	mass	base unit
s	second	time	base unit
K	kelvin	temperature	base unit
°C	degree Celsius	temperature	(kelvin temperature) − 273.15
N	Newton	force	$m \cdot kg \cdot s^{-2}$
J	joule	energy	$N \cdot m = m^2 \cdot kg \cdot s^{-2}$
W	watt	power	$J/s = m^2 \cdot kg \cdot s^{-3}$
Pa	pascal	pressure	$N/m^2 = m^{-1} \cdot kg \cdot s^{-2}$
Hz	hertz	frequency	s^{-1}

Base and Derived SI Units - 2

Electrical and Electromagnetic Units

A	ampere	current	base unit
C	coulomb	charge	$A \cdot s$
V	volt	potential	$J/C = m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Ω	ohm	resistance	$V/A = m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
S	siemens	conductance	$1/\Omega = m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
F	farad	capacitance	$C/V = m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Wb	weber	magnetic flux	$V \cdot s = m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
T	tesla	flux density	$Wb/m^2 = kg \cdot s^{-2} \cdot A^{-1}$
H	henry	inductance	$Wb/A = m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$

Base and Derived SI Units - 3

Dimensionless Quantities			
rad	radian	plane angle	$m/m = 1$; $1/(2\pi)$ of a circle
sr	steradian	solid angle	$m^2/m^2 = 1$; $1/(4\pi)$ of a sphere
mol	mole	particle count	base unit ($\simeq 6.02 \times 10^{23}$)
Light			
cd	candela	intensity	base unit
lm	lumen	flux	cd · sr
lx	lux	illuminance	lm/m^2

Absolute and Gravitational Unit Systems

- SI unit system
  - *Absolute* system
    - Mass is a fundamental unit
    - Newton's second law (force = mass × acceleration) is invoked to derive force due to gravity.
- FPS unit system
  - *Gravitational* system
    - Force is a fundamental unit
    - Mass is derived from Newton's second law.
    - Distance, force, and time are fundamental dimensions, measured in units of **feet, pounds, and seconds**.

Comparison of Unit Systems

Table 10.2 Comparison of unit systems

	Dimensions	Absolute		Gravitational	Hybrid
		SI	CGS	FPS	American
Fundamental	Force [F]	–	–	lb	lbf
	Length [L]	m	cm	ft	ft
	Time [T]	s	sec	sec	sec
	Mass [M]	kg	g	–	lbm
Derived	Force [F]	newton ($kg \cdot m/s^2$)	dyn ($g \cdot cm/sec^2$)	–	–
	Mass [M]	–	–	slug ($lb \cdot sec^2/ft$)	–
	Energy [LF]	joule ($N \cdot m$)	erg ($cm \cdot dyne$)	$ft \cdot lb$	$ft \cdot lbf$
	Power [LF/T]	watt ($N \cdot m/s$)	erg/sec	$ft \cdot lb/sec$	$ft \cdot lbf/sec$
	Pressure [F/L^2]	pascal (N/m^2)	$dyne/cm^2$	lb/ft^2	lbf/ft^2

Forces and Gravity

- The application of gravity in Newton's Second Law (F = ma) presents several problems
- It is treated differently in each system of units

Comparison of Unit Systems

- Newton's Second Law: $F = ma$
- SI: $1\ \text{N} = 1\ \text{kg} \cdot 1\ \text{m/s}^2$
- American: $1\ \text{lbf} \neq 1\ \text{lbm} \cdot 1\ \text{ft/sec}^2$ → Does not work!

Re-write Newton's 2nd Law:

$$F = \frac{ma}{g_c} \qquad \text{where } g_c = 32.17 \frac{\text{ft} \cdot \text{lbm}}{\text{lbf} \cdot \text{sec}^2}$$

Comparison of Unit Systems

Example:

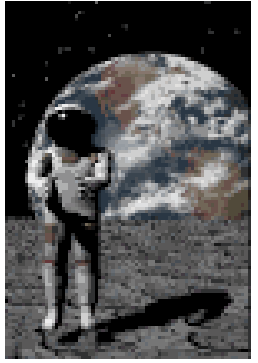
- Your mass is 120 lbm (54 kg). You jump off a cliff. What force pulls you to earth?
  - American:

$$F = \frac{ma}{g_c} = \frac{120\ \text{lbm} \cdot 32.17\ \text{ft/sec}^2}{32.17\ \frac{\text{ft} \cdot \text{lbm}}{\text{lbf} \cdot \text{sec}^2}} = 120\ \text{lbf}$$

  - SI:

$$F = ma = 54\ \text{kg} \cdot 9.81\ \text{m/s}^2 = 530\ \text{N}$$

Comparison of Unit Systems



- What about on the moon ? (Acceleration due to gravity is 0.2 that on earth)
  - American:

$$F = \frac{ma}{g_c} = \frac{120\ \text{lbm} \cdot (0.2) \cdot 32.17\ \text{ft/sec}^2}{32.17\ \frac{\text{ft} \cdot \text{lbm}}{\text{lbf} \cdot \text{sec}^2}} = 24\ \text{lbf}$$

  - SI:

$$F = ma = 54\ \text{kg} \cdot (0.2) \cdot 9.81\ \text{m/s}^2 = 106\ \text{N}$$

A metric lunch: 1 N = 0.2248 lbf

From *Introduction to Engineering Analysis* by K. D. Hagen, p. 30, 3rd Edition, 2008. Artwork by Kathryn Hagen.

Units !

- Your mass is: 77 kg = 170 lbm = 5.28 slugs = 12 stones & 2 pounds
- You weigh: 755 N = 170 lbf
- Just A Few Other Units !!

- 1 ton = 2 000 pounds (except in UK where it is 2240 lb, because a *hundred weight* is 112 pounds and 1 ton = 20 hwt !!)
- 1 tonne = 1 000 kg (or 1 Mg)
- 1 mile = 0.868 nautical miles = 8 furlongs = 80 chains = 860 fathoms = 1 720 yards = 5280 ft = 15 840 hands = 63 360 inch
- 1 BTU (British Thermal Unit = heat 1 pound of water from 60 to 61°F) = 778 ft·lbf
- 1 ton of cooling = 12,000 BTU/h (power to melt 1 ton of ice in 1 hour)
- 1 acre = 4 480 square yards
- Canadian tablespoon (teaspoon) ≠ US tablespoon ≠ Imperial tablespoon ≠ metric tablespoon
- 1 gallon US ≠ 1 Imp. gallon = 4 quarts = 8 pints = 160 fluid ounces = 153 shots = 102 jiggers
- 1 horsepower = 550 ft·lbf/sec = 2544 BTU/h = 746 W
- bushels, pecks, ångström, mil, rods, drop, dash, pinch, troy once, beer gallon (1.016 gallon), barrel, carrot, kip, fortnight, erg, dyne, bar, torr, calorie, etc., etc.

- Get Good Conversion Tables !!

How to Convert Units

Adding Apples and Oranges:

- You can only add things if they have the same units
- You cannot add 5 apples and 3 oranges
  - (unless you are making fruit salad)
- You must convert to common units

How to Convert Units

For arguments sake:

- 1 apple = 1 PoF and 1 orange = 1 PoF
- So, you can write the first conversion as:

$$1 = \frac{1\text{PoF}}{1\text{apple}}$$

- Multiplying something by 1 does not change it, so number of apples times 1 PoF/apple gives the equivalent Pofs for the number of apples
- In the same way, oranges can be converted to PoFs

How to Convert Units

$$5\ \text{apples} \times \frac{1\text{PoF}}{1\text{apple}} + 3\ \text{oranges} \times \frac{1\text{PoF}}{1\ \text{orange}} = 8\ \text{PoF}$$

- Be a fanatic about units
- Take the time to write out and cancel units
- It is a very good habit to have
- If the units do not work out then you know you are doing something wrong
- Students who do not know how to convert units typically get 10% fewer marks on exams

Learn to be careful and neat

- Mistakes are easy to make if you are sloppy
- Engineering students can make mistakes, but engineers cannot
- Engineers work in teams in which they review each other's work
- If your work is a mess and difficult to follow, people will not want to work with you
- If your work is difficult to follow, then people who assess your work might not see how brilliant you really are!

Reading Assignment

- Read Chapter 10

ECOR 1010
Lecture 4

Measurements, Units and Errors

SI Magnitude Prefixes

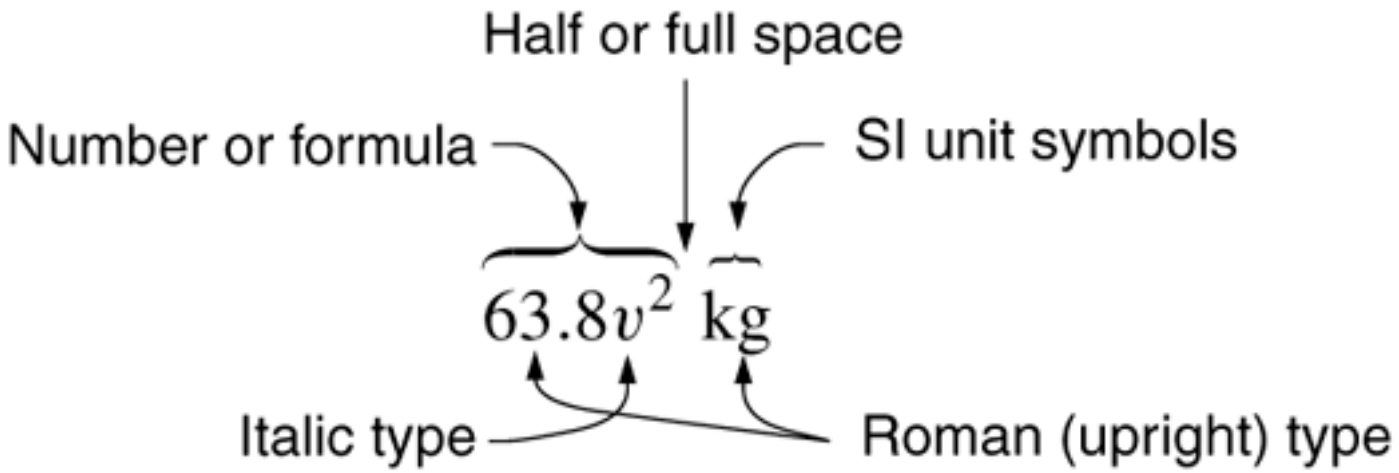
- The unit may be preceded by a magnitude prefix;
  - The prefix is regarded as an inseparable part of the symbol.

Table 10.3 Magnitude prefixes in the SI unit system by symbol, name, and numerical value.

Y	yotta	10^{24}	M	mega	10^{6}	f	femto	10^{-15}
Z	zetta	10^{21}	k	kilo	10^{3}	a	atto	10^{-18}
E	exa	10^{18}	m	milli	10^{-3}	z	zepto	10^{-21}
P	peta	10^{15}	μ	micro	10^{-6}	y	yocto	10^{-24}
T	tera	10^{12}	n	nano	10^{-9}			
G	giga	10^{9}	p	pico	10^{-12}			

Writing Quantities With Units

- Standardized rules for correctly representing quantities with units:



A physical quantity is written as a number or a formula representing a number, followed be unit symbols.

Rules for Writing With Units - 1

- Always a space between numeric value and unit:
  - 23.67 kg not 23.67kg
- Unit symbols are treated like algebraic factors that can be multiplied or divided with numbers or other unit symbols:
  - Multiplication between units is indicated by a centred dot or a half-space,
  - Division by a slash or a negative superscript:
    - 27 kg·m/s^2 or 27 kg m/s^2 or 27 kg·m·s^{-2}

Rules for Writing With Units - 2

- Unit symbols are not modified with subscripts:
  - V_{max} = 200 V not V = 200 V_{max}.
- Relation between numerical quantity and unit symbols must be clear:
  - 3.7 km × 2.8 km for an area; not 3.7 × 2.8 km
  - 87.2 g ± 0.4 g or (87.2 ± 0.4) g; but not 87.2 ± 0.4 g

Rules for Writing With Units - 3

- Unit symbols not mixed with unit names in sentences:
  - Use kg/m^2 or kilogram per square metre, but not kilogram/m^2.
- Long numbers, written in groups of 3, the groups should be separated by a non-breaking half space rather than a comma or period:
  - 93 000 000 miles not 93,000,000 miles
  - 21 298.046 83 m not 21298.04683 m

Common Units

	SI	FPS
Force	newton (N) $= 1\ kg \cdot m/s^2$	pound (lb)
Length	metre (m)	foot (ft)
Mass	kilogram (kg)	slug = $1\ lb \cdot sec^2/ft$
Time	s	sec
Pressure	pascal (Pa) = $1\ N/m^2$	psi (lbs/in^2) or lbs/ft^2
Work & Energy	joule (J) = N·m	ft·lb
Power	watt (W) = N·m/s	horsepower HP = 550 ft·lb/sec
Temperature	K $T(K) = T(°C)+273.15$	°F $T(°F) = 9/5\ T(°C)+32$

Fixed, Scientific and Engineering Notation

- Fixed notation
  - Ordinary decimal notation
    - e.g. 30140.0,
- Scientific notation
    - 3.014×10^4,
- Engineering notation
  - Exponent of 10 is a multiple of 3 to correspond to SI prefixes
    - e.g. 30.14×10^3.

Unit Algebra - 1

- Algebra can be performed on units,
  - with restriction that only quantities with same units can be equated, added, or subtracted.
- Consider conversion from one unit to another
  - 20 000 ft·lb/min = ? HP

$$20\,000\,\frac{\text{ft}\cdot\text{lb}}{\text{min}}\times\frac{1\,\text{min}}{60\,\text{s}}\times\frac{1\,\text{HP}}{550\,\text{ft}\cdot\text{lb/s}}=0.606\,\text{HP}$$

Unit Algebra - 2

- Consider the equation $s = vt + (1/2)at^2$, where
  - v is the initial velocity in m/s,
  - t is time in s,
  - a is acceleration in m/s^2.
- Then s has units $(m/s)s + (m/s^2)s^2 = m + m$
  - Since we can add quantities with same units,
    - s has units m.
    - s is a measure of length.

Dimensions

- Dimensions differ slightly from units
  - e.g., Speed
    - Dimensions = distance / time.
    - Units may be km/hr, or mm/s, etc.
- Fundamental dimensions
  - Distance, time, mass etc.

Derived Dimensions

- Products or ratios of basic dimensions

Acceleration: $$a = \frac{[l]}{[t]^2}$$

Force: $$f = ma = \frac{[m][l]}{[t]^2}$$

Dimensional Homogeneity: The dimensions on either side of an equation must be the same

↳ Dimensions of f = dimensions of m times a

Derived Dimensions with Units (Pressure)

Pressure = Force per area $\rightarrow \dfrac{[f]}{[l^2]}$

Units :

$\dfrac{\mathrm{N}}{\mathrm{m}^2}$ = Pascal (Pa) in the SI system

$\dfrac{\mathrm{lb}}{\mathrm{in}^2}$ = psi in the FPS system

Derived Dimensions with Units (Work)

Work = force 'dot' displacement = $f \bullet d$

$\rightarrow [f][l]$

Units:
$N \cdot m$ = Joules (J)

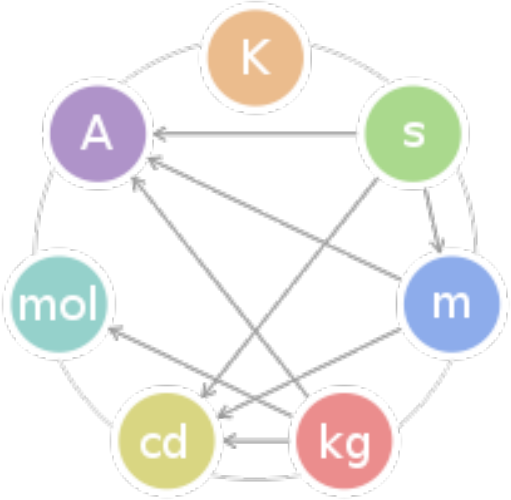
Derived Dimensions with Units (Power)

$$\text{Power} = \frac{\text{work}}{\text{time}} \rightarrow \frac{[\,f\,]\,[l]}{[t]}$$

Units:

$$\frac{\text{N} \cdot \text{m}}{s} = \text{J/s} = \text{Watts (W)}$$

Derived Dimensions with Units (Charge)



$$Q = \int I \; dt$$

$$\textit{Units} : \text{Coulomb} = \text{Ampere} \bullet \text{second}$$

6.241506×10^{18} electrons

Non-Dimensional Numbers

- Ratios where the numerator has the same dimension as the denominator

$$\text{Aspect Ratio } (\text{AR}) \text{ of an aircraft wing } = \frac{(\text{Wing Span})^2}{\text{Wing Area}}$$

$$AR = \frac{[l]^2}{[l]^2} = [1]$$

Unit Consistency (Dimensional Analysis)

- When performing calculations, numbers should always be written with correct units
- Units should be carried throughout the problem
- Very useful check!

The Gimli Glider

"If a Boeing 767 runs out of fuel at 41,000 feet, what do you have? A 132 ton glider …"

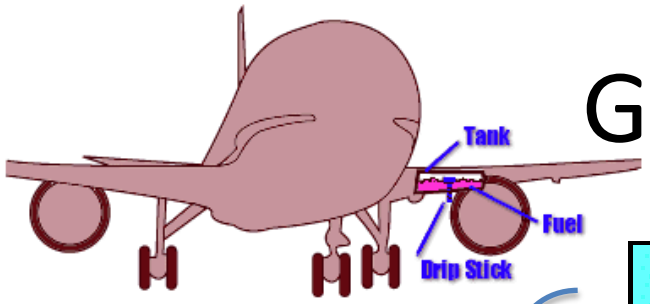
- Wade H. Nelson (Soaring Magazine, 1997)

Air Canada Flight 143: The Gimli Glider

The Scenario

- There was a problem with the fuel gauges, so they calculated the volume of fuel they needed *by hand*
- Previously there was a flight engineer on board, but not on these new planes.
- Among other things, the specific gravity of fuel is needed to make the proper calculations
  - They used 1.77 lb/L as the constant
  - They should have used 0.8 kg/L for this all-metric 767 aircraft!

Recall 2.2 lb =1 kg



Gimli Glider: What Happened

What they did

7,682 L x 1.77 = 13,597 kg of fuel remaining on board

22,300 kg needed – 13,597 kg on board = 8,703 kg to be added

8,703 kg ÷ 1.77 = 4,916 L of fuel to be added

If they had kept track of the units and verified that the units canceled properly, they could have calculated:

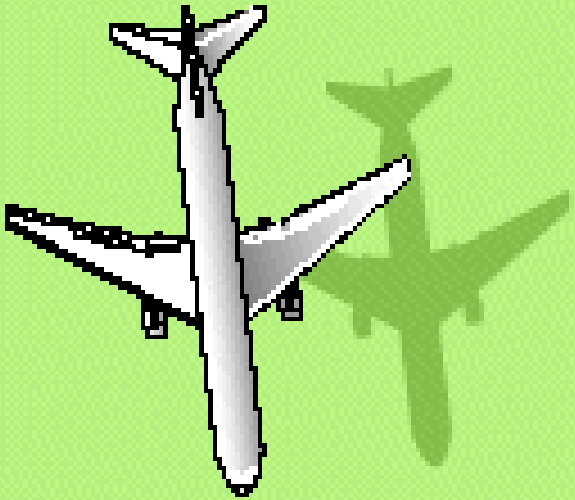
What they should have done

$$7{,}682\ \text{L} \times \frac{0.803\ \text{kg}}{\text{L}} = 6{,}169\ \text{kg remaining on board}$$

22,300 kg needed – 6,169 kg on board = 16,131 kg to be added

$$16{,}131\ \text{kg} \times \frac{\text{L}}{0.803\ \text{kg}} = 20{,}163\ \text{L of fuel to be added}$$

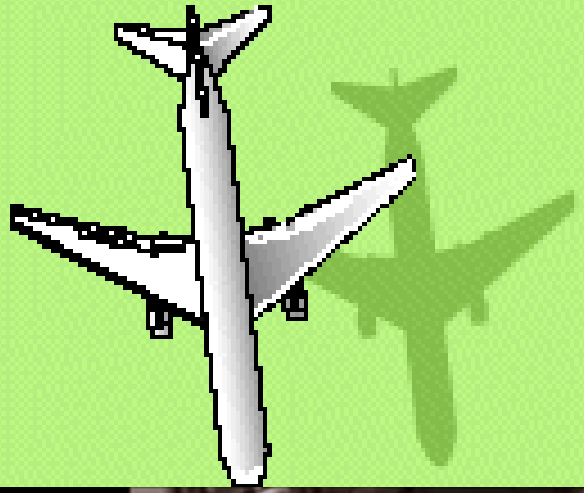
Sideslipping a 767



Aircraft too high. Speed slowed to 180 knots

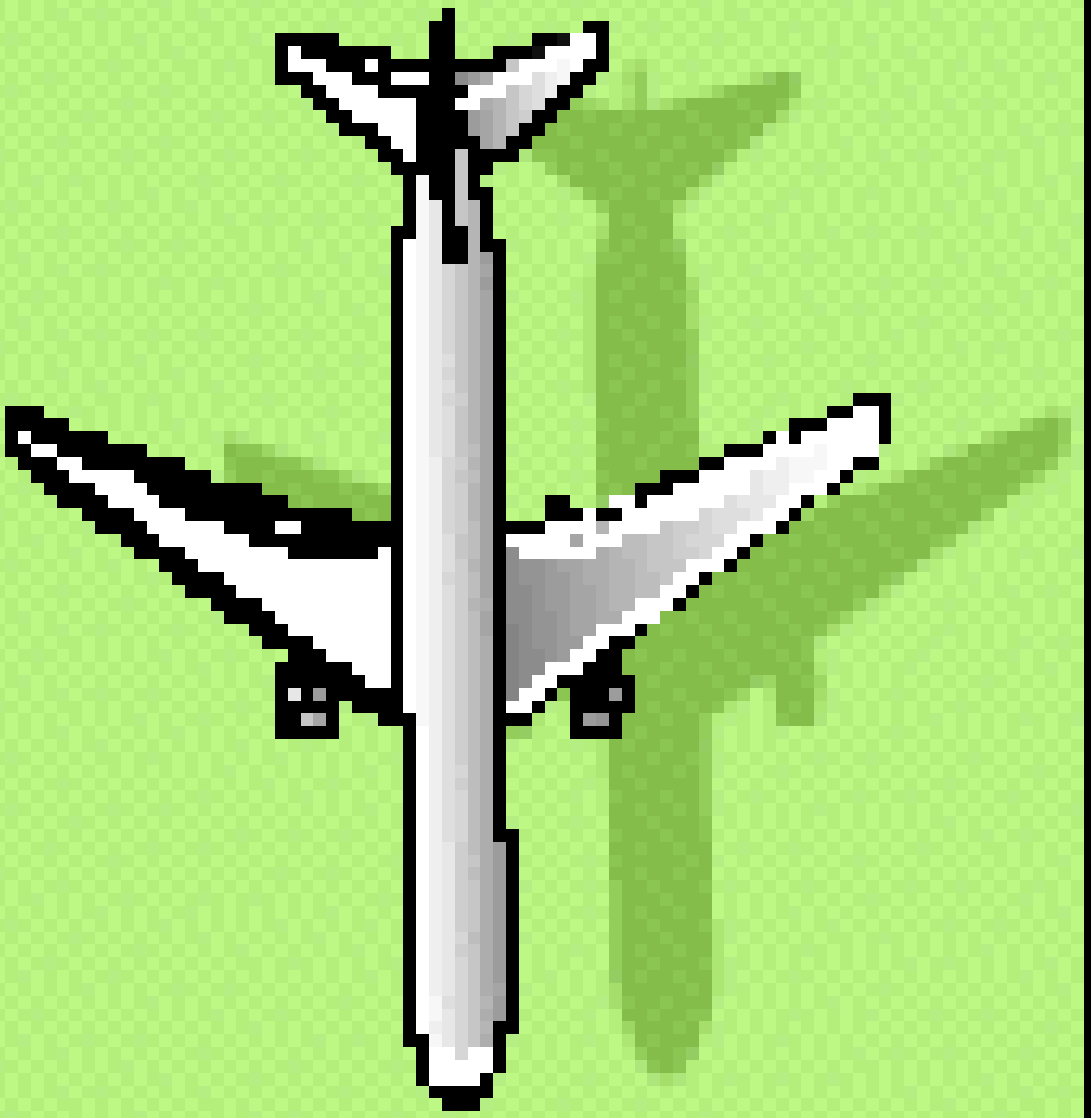
Pilot initiates sideslip: left rudder pedal pushed while he turns the yoke to the right. Aircraft manoeuvred into a steep angle. Aircraft rapidly loses altitude.

Sideslipping a 767

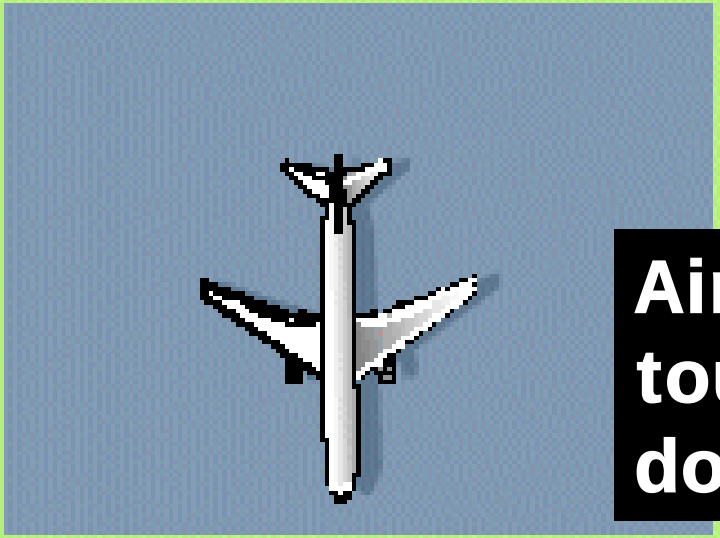


Aircraft too high. Speed slowed to 180 knots

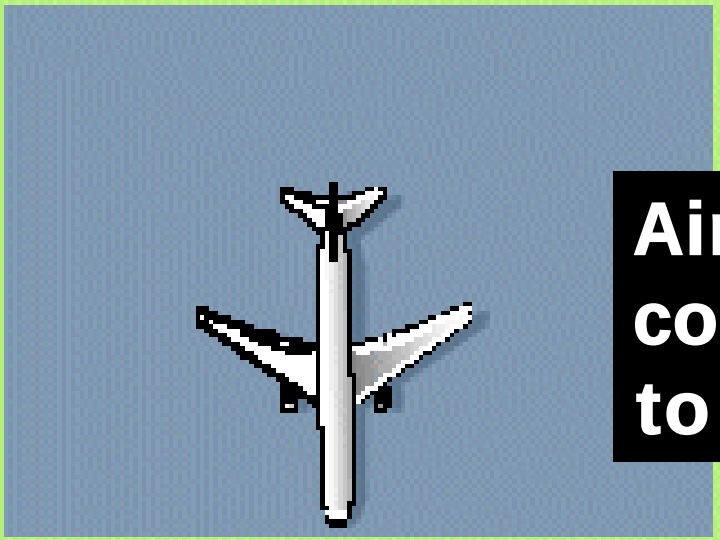
Pilot initiates sideslip: left rudder pedal pushed while he turns the yoke to the right. Aircraft manoeuvred into a steep angle. Aircraft rapidly loses altitude.



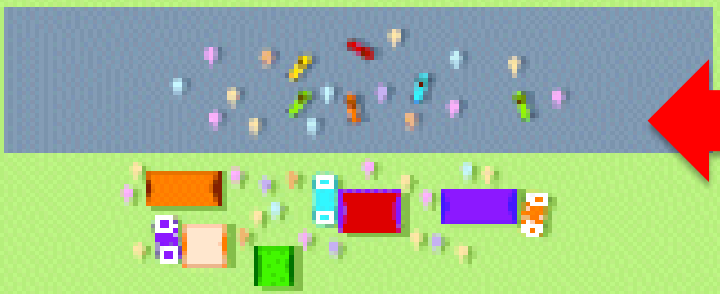
Aircraft straightens out at an altitude of 40 feet.



Aircraft touches down.



Aircraft comes to rest.



Lots of people

Gimli Glider

Measurements

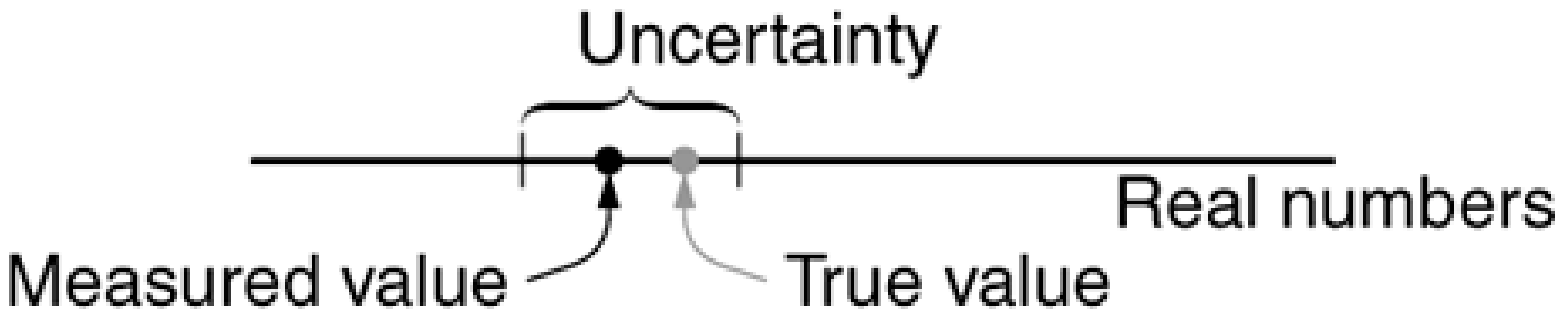
- Engineering students should know
  - Definition of traceable measurement;
  - Classification of uncertainties into systematic and random effects;
  - Correct use of words *accuracy, precision, bias;*
  - How to write inexact quantities using engineering and other notation;
  - The correct use of significant digits.

Measurement

- Measurement:
  - Property of a physical object that can be represented using a real number.
    - As opposed to counting, measurement is not exact.
  - Quantities usually measured with an instrument.
    - Calipers, scale, measuring cup etc.

Uncertainty

- Measuring instruments are not perfect;
  - Measurements typically yield
    - Estimate of true value, and
    - An interval around estimate in which true value lies.
    - This is called the uncertainty interval.



Illustrating a true (exact) value, which is a point on the line of real numbers, and its measured estimate, together with an interval of uncertainty.

True value – measured value = measurement error.

Systematic Errors

- Consistent deviation from the true value;
  - also called a *bias* or an *offset.*
- Error has same magnitude and sign when repeated measurements are made under same conditions.
- Can be detected by
  - Calibration,
  - Comparison with results obtained with an independent method

Three Types of Systematic Errors

- Natural Error
  - From environmental effects;
    - e.g. temperature changes affect electronic components and measuring instruments.
  - Correction factor can be applied to compensate if possible.
- Instrument Error
  - Also called *offset*.
  - Caused by imperfections in adjustment or construction of instrument.

Types of Systematic Errors

- Personal Error
  - Result from habits of the observer.
  - Can be reduced by proper training.

Random Errors

- Result of small variations in measurements
  - e.g. in repeated measurements, an observer may
    - exert slightly different pressures on a micrometer
    - connect voltmeter leads in slightly different locations.
- Random errors do not bias measurement,
  - They produce both positive and negative errors with zero mean value.
- If several measurements are made, their mean is normally a better estimate of true value than any single measurement.

Precision and Accuracy - 1

- Precision of a measurement
  - Repeatability.
    - Precise measurements have small random error
    - Discrepancies between repeated measurements taken under the same conditions are small.
- Accuracy
  - Accurate measurements are close to true value
    - Some authors use term to describe total error
    - Others to describe systematic error.
      - Accurate measurement has little bias.

Precision and Accuracy - 2

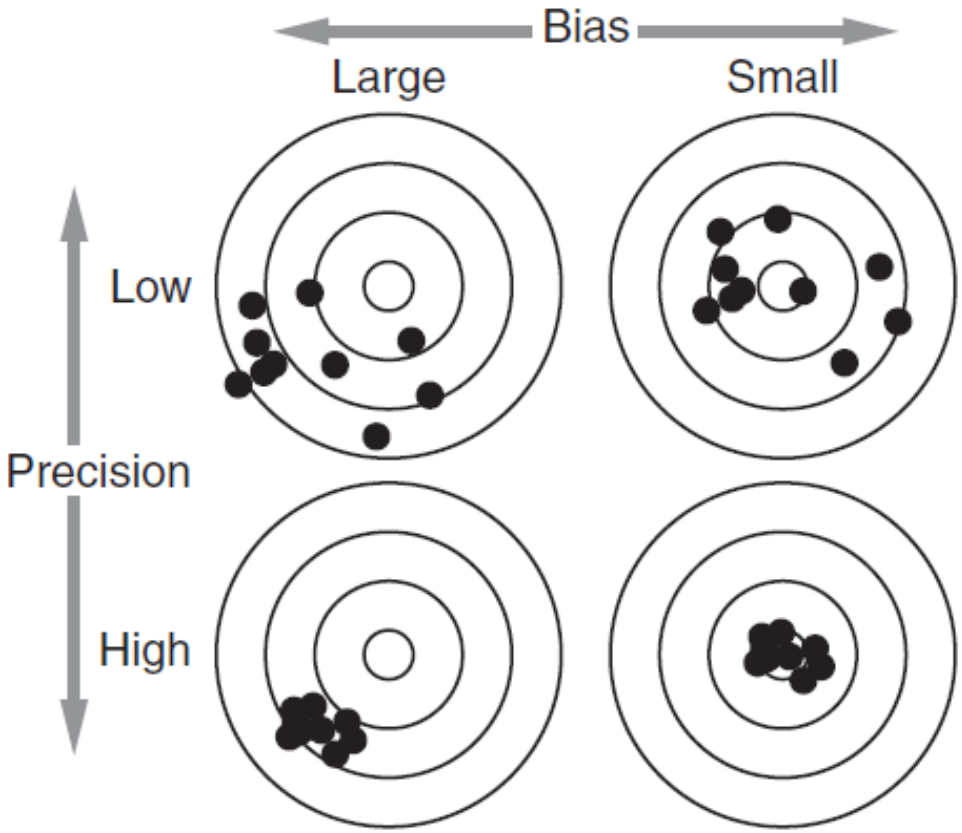


Figure 11.3 Precision, bias, and accuracy: The two right patterns have small bias (small systematic error); the two bottom patterns have high precision (small random error). The lower right pattern is accurate; ~~less commonly~~ the two right patterns would be said to be accurate.

Estimating Measurement Error - 1

- When systematic errors are quantified, the measurement can be corrected to remove bias.
  - The offset is subtracted from measurement, or
  - The instrument is recalibrated.
- Random error remains
  - Must be estimated and quoted with measurement.

Estimating Measurement Error - 2

- Source of random errors
  - Technical specifications of instrument
  - Reading errors.
    - e.g., Estimating position of needle of a gauge or meter requires interpolation between scale markings,
      - Precision of measurement is limited by ability of observer to resolve small distances.
      - Precision of the readings will be a fraction of the amount between scale markings, typically one-tenth.

How to Write Inexact Quantities

- Measurement is complete only when a statement about its uncertainty is included.
- Uncertainty is normally expressed as an estimated range;
  - Can be stated explicitly or implicitly.

Explicit Uncertainty Notation

- Measurement may be expressed in fixed, scientific, or engineering notation, and
- Uncertainty may be given in either absolute or relative form.
  - Fixed notation with error in absolute form
    - v_s = 343.5 m/s ± 0.9 m/s = (343.5 ± 0.9) m/s
  - Fixed notation with error in relative form
    - v_s = 343.5(1 ± 0.26%) m/s.

Implicit Uncertainty Notation

- If a quantity is written without explicit uncertainty, uncertainty is taken to be ±5 in digit immediately to the right of least significant digit.
- Suppose measured speed is 94 km/h
  - Without more information, the error is ±0.5 km/h
- Indicated speed is 94 km/h
  - Error from speedometer graduations is ±1 km/h
  - >100 km/h error is ±2.5 km/h

Significant Digits

- Determine the precision of the number.
  - Should not use more significant digits than justified by the measurement.
- Significant digits are identified as follows:
  - All non-zeros are significant,
  - All zeros between significant digits are significant.
  - Leading zeros are not significant.
  - Trailing zeros are significant in fractional part of number.

Significant Digits

- Examples
  - 0.0350 oz has 3 significant digits
  - 90 000 000 miles has 1 significant digit, (ambiguous)
  - 92 900 000 miles has 3 significant digits, (ambiguous)
  - (92 900 000 ± 500) miles has 5 significant digits

Significant Digits

- In scientific notation, integer part is normally one non-zero digit,
  - Number of significant digits is one more than number of digits after decimal point.
    - 9×10^7 = 1 significant digit
    - 9.3×10^7 = 2 significant digit
    - 9.290×10^7 = 4 significant digits
- In engineering notation, all digits except leading zeros are significant
    - 0.09×10^9 miles = 1 significant digit
    - 93×10^6 miles = 2 significant digits
    - 92.90×10^6 miles = 4 significant digits

Rounding Numbers

- Rounding is used to reduce number to the appropriate significant digits.
  - When leftmost discarded digit is less than 5, then retained digits are unchanged;
    - 3.234 → 3.23 or 3.2
  - When leftmost discarded digit greater than 5, or is 5 with at least one nonzero digit to its right, increase rightmost retained digit by one;
    - 3.256 → 3.26 or 3.3
    - 9.747 → 9.75 or 9.7 *not 9.8*

Rounding Numbers

- When the leftmost discarded digit is 5 and all following digits are 0, then rightmost retained digit unchanged if it is even; otherwise it is increased by one.
  - 3.25 → 3.2
  - 3.250 → 3.2
  - 3.350 → 3.4
    - This rule avoids introducing a bias into the mean of a set of rounded numbers.

Effect of Algebraic Operations

- Computations performed using inexact measured quantities yield inexact results.
  - Final computed value should not have more significant digits than are justified;
    - Must be rounded to imply correct interval of uncertainty.

Absolutely NEVER give all the digits you get out of your calculator or a program such as Excel:
unless you can defend all of them!!

Addition and Subtraction of Inexact Quantities

- $(x \pm \Delta x) + (y \pm \Delta y)$
  - Max: $(x + \Delta x) + (y + \Delta y) = (x + y) + (\Delta x + \Delta y)$
  - Min: $(x - \Delta x) + (y - \Delta y) = (x + y) - (\Delta x + \Delta y)$
- Therefore

  $(x \pm \Delta x) + (y \pm \Delta y) = (x + y) \pm (\Delta x + \Delta y)$
- Similarly

  $(x \pm \Delta x) - (y \pm \Delta y) = (x - y) \pm (\Delta x + \Delta y)$

Addition and Subtraction of Inexact Quantities

- For addition or subtraction, we add absolute uncertainties.
  - (3.5 ± 0.4) m + (1.22 ± 0.03) m = (4.72 ± 0.43) m becomes (4.7 ± 0.4) m.
  - (3.93 ± 0.08) kg - (3 ± 0.1) kg = (0.93 ± 0.18) kg becomes (0.9 ± 0.2) kg.

Multiplication and Division Using Inexact Quantities

– For multiplication, we add relative uncertainties:

$$(x \pm \Delta x) \times (y \pm \Delta y) = xy \pm y\Delta x \pm x\Delta y + \Delta x \Delta y$$

$$= xy\left(1 \pm \frac{\Delta x}{x} \pm \frac{\Delta y}{y} + \frac{\Delta x}{x}\frac{\Delta y}{y}\right)$$

$$\approx xy\left(1 \pm \frac{\Delta x}{x} \pm \frac{\Delta y}{y}\right)$$

$\frac{\Delta x}{x}\frac{\Delta y}{y} \approx 0$

– Similarly, we add relative uncertainties for division.

Multiplication and Division Using Inexact Quantities

$$(4.0\pm0.5)\ \text{kg} \times (2.0\pm0.2)\ \text{m/s}^2 = 4(1\pm0.5/4.0)\ \text{kg} \times 2(1\pm0.2/2.0)\ \text{m/s}^2$$
$$= 4(1\pm0.125)\ \text{kg} \times 2(1\pm0.1)\ \text{m/s}^2$$
$$= 8(1\pm0.225)\ \text{N} + \text{higher order terms}$$
$$\approx (8\pm1.8)\ \text{N}$$
$$\approx (8\pm2)\ \text{N}$$

$$(4.0\pm0.5)\ \text{N} / (2.0\pm0.2)\ \text{m}^2 = 4(1\pm0.5/4.0)\ \text{N} / 2(1\pm0.2/2.0)\ \text{m}^2$$
$$= 4(1\pm0.125)\ \text{N} / 2(1\pm0.1)\ \text{m}^2$$
$$= 2(1\pm0.225)\ \text{Pa} + \text{higher order terms}$$
$$\approx (2\pm0.45)\ \text{Pa}$$
$$\approx (2\pm0.5)\ \text{Pa}$$

Multiplication and Division Using Inexact Quantities

Product of 1.1, 1.2, 1.3, 2.4 ? (Implied uncertainty is ±0.05)

Calculator product: 1.1×1.2×1.3×2.4 = 4.1184

Product rounded to two significant digits = 4.1

Product rounded with uncertainty is between 4.05 and 4.15

But, what if all errors are -0.05 ? Product = 3.5470

or, what if all errors are +0.05 ? Product = 4.7545

Worst case is much worse than 4.05 to 4.15 !

Should you give the answer as 4, with implied uncertainty of ±0.5?

Multiplication and Division Using Inexact Quantities

Product of 1.1, 1.2, 1.3, 2.4 ? (Implied uncertainty is ±0.05)

Consider propagation of errors from multiplying:

$(1.1\pm0.05)\times(1.2\pm0.05)\times(1.3\pm0.05)\times(2.4\pm0.05)$

$=1.1(1\pm0.05/1.1)\times1.2(1\pm0.05/1.2)\times1.3(1\pm0.05/1.3)\times2.4(1\pm0.05/2.4)$

$= 4.1184\ (1\pm0.05/1.1)\times(1\pm0.05/1.2)\times(1\pm0.05/1.3)\times(1\pm0.05/2.4)$

$= 4.1184\ (1\pm0.05/1.1\pm0.05/1.2\pm0.05/1.3\pm0.05/2.4) \ + \ ...$

$\approx 4.1184\ (1\pm0.146) = 4.1 \pm 0.6$

This is a worst case error estimate. Is this always justified?

Reading Assignment

- Read Chapter 11

ECOR 1010
Lecture 5

Engineering Graphics - 1

How Do Engineers Communicate?

- Engineers convey information in three principal ways
  - Written Documents
  - Oral Presentations
  - Graphically
- Sometimes a combination is needed

Importance of Engineering Graphics

- The majority of engineering information is transmitted by graphical means
- But unambiguous written and verbal communication is also central to successful engineering communication

Example – Describing an Object

- Written Communication
  - Made of metal, this tool has a handle and a heavy irregular shaped head
  - The handle has a rubber grip
  - The length of the head runs perpendicular to the handle
  - The head has a rounded blunt end for impact, along with two flattened stems formed by a tapered grove at the opposite end
  - The length of the tool is approximately 30 cm and it weighs about 1 kg

A Picture is Worth ...

- Graphical Communication

Figure 12.1 This picture is worth at least 75 words.

The Point

- Obviously, graphics can convey some information in an easier to understand way
- Imagine how difficult some things would be without graphical communication:
  - Advertising
  - Instructions
  - Education
  - Engineering!

Advantages of Graphical Communication

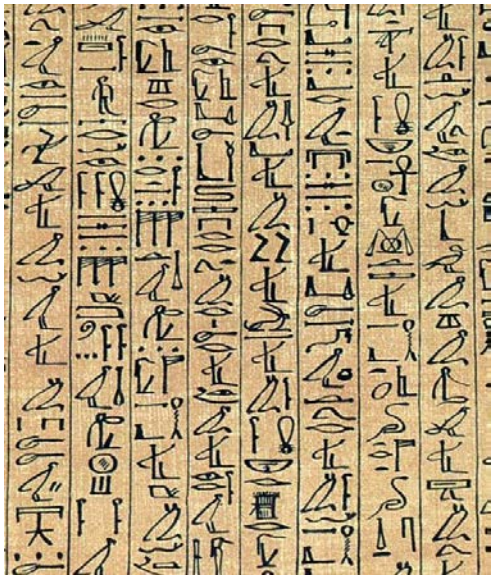
- Clear
- Concise
- Efficient
- Reduced Ambiguity

Graphical Representation

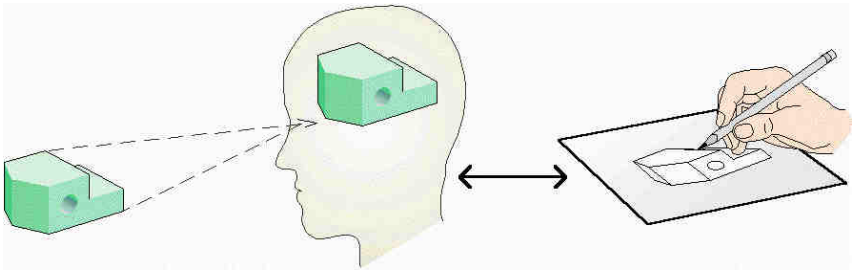
"Wait! Wait! … Cancel that, I guess it says 'helf.'"

Engineering Graphics

- Graphics is a universal language
- The earliest forms of written communication were pictorial
  - Egyptian Hieroglyphics
- Engineering graphics are directed towards graphical problem solving
- A good drawing is “worth a thousand words”
- Moreover, good engineering graphics are self explanatory!



Graphical Representation



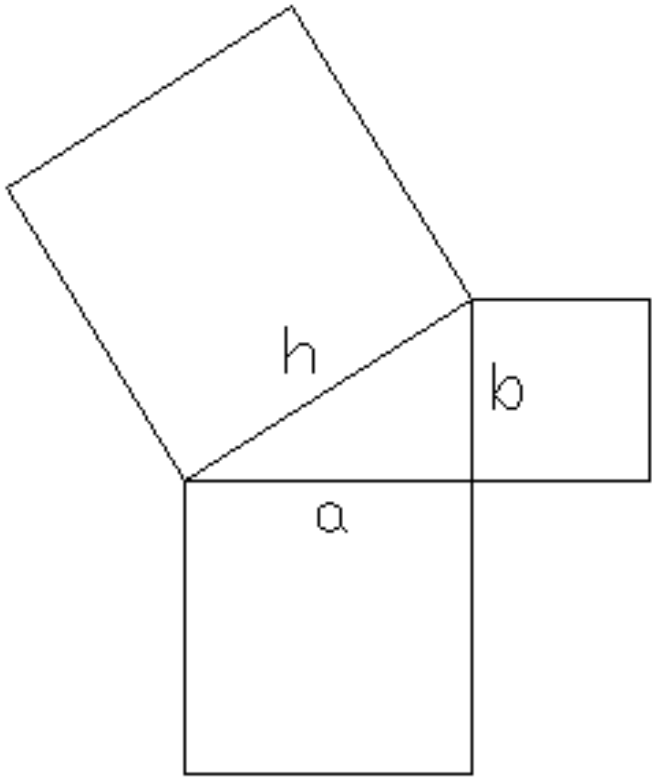
- Practical engineering problems stem from problems associated with the graphical representation of ideas that have to be turned into physical reality: parts
- A visual image is formed in the mind, reviewed, modified, and ultimately communicated to someone else in the form of graphics

Graphical Representation

- It is crucial that the graphical representation be clear and unambiguous
- The image must be precise and exact

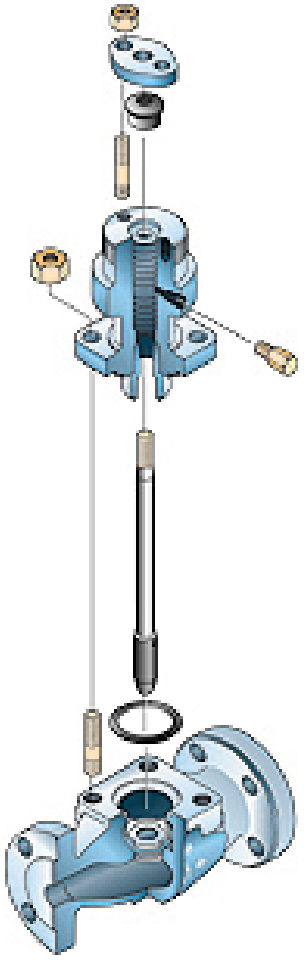
Engineering Graphics & Geometry

- The word geometry means “earth measure”
- Geometry as a science may have begun in Egypt, to measure the areas of fields to assess taxes
- Calculus and algebra are abstractions of geometry
  - e.g., Pythagorean theorem
- Ancient Indian, Chinese, Egyptian, Greek and Roman builders, among others, used graphics to solve complex design problems associated with large structures

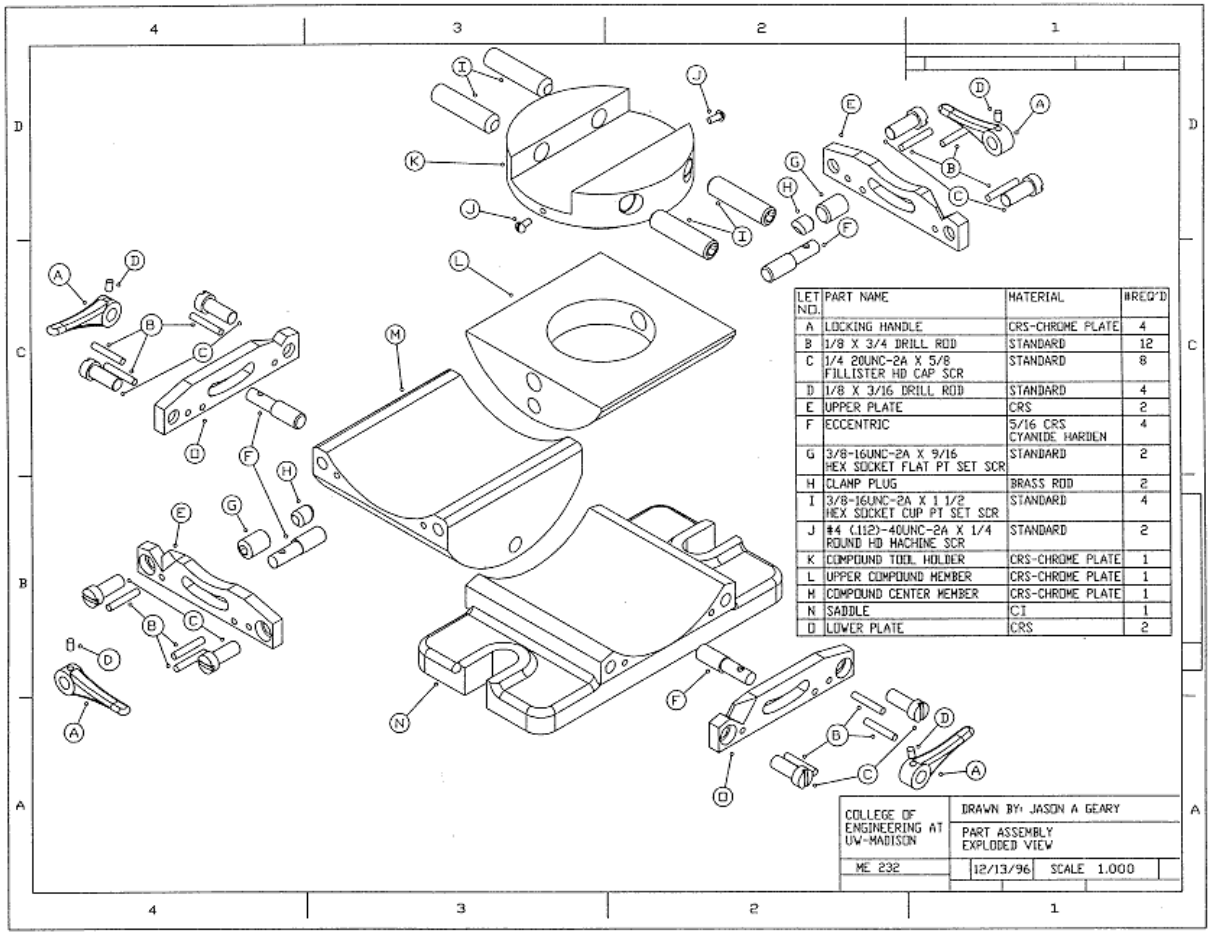


Technical Illustration

- Also called pictorial drawings, technical illustrations are used to describe products in catalogues, user, and maintenance manuals
- Pictorial sketching is an important engineering communication tool
- Useful to describe difficult to visualize components or assemblies
- How to put components together – NOT how to make them
- Three common types
  - Perspective
  - Oblique
  - Isometric (Axonometric)



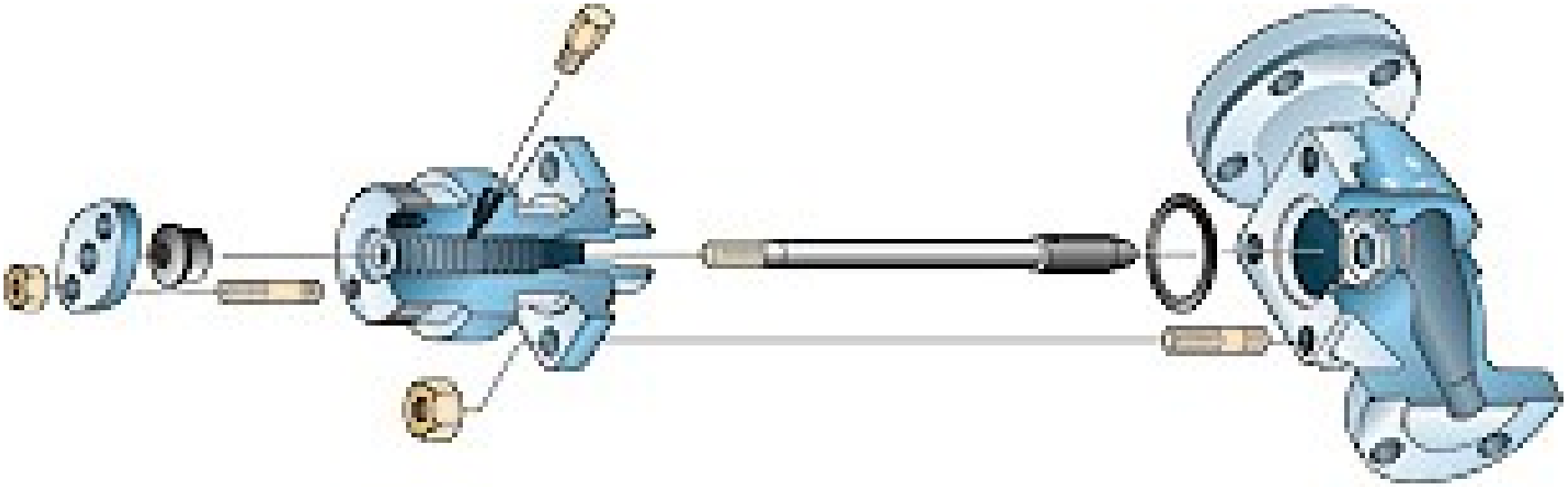
Production Assembly Drawings



LET NO.	PART NAME	MATERIAL	#REQ'D
A	LOCKING HANDLE	CRS-CHROME PLATE	4
B	1/8 X 3/4 DRILL ROD	STANDARD	12
C	1/4 20UNC-2A X 5/8 FILLISTER HD CAP SCR	STANDARD	8
D	1/8 X 3/16 DRILL ROD	STANDARD	4
E	UPPER PLATE	CRS	2
F	ECCENTRIC	5/16 CRS CYANIDE HARDEN	4
G	3/8-16UNC-2A X 9/16 HEX SOCKET FLAT PT SET SCR	STANDARD	2
H	CLAMP PLUG	BRASS ROD	2
I	3/8-16UNC-2A X 1 1/2 HEX SOCKET CUP PT SET SCR	STANDARD	4
J	#4 (.112)-40UNC-2A X 1/4 ROUND HD MACHINE SCR	STANDARD	2
K	COMPOUND TOOL HOLDER	CRS-CHROME PLATE	1
L	UPPER COMPOUND MEMBER	CRS-CHROME PLATE	1
M	COMPOUND CENTER MEMBER	CRS-CHROME PLATE	1
N	SADDLE	CI	1
O	LOWER PLATE	CRS	2

COLLEGE OF ENGINEERING AT UW-MADISON	DRAWN BY: JASON A GEARY
	PART ASSEMBLY EXPLODED VIEW
ME 232	12/13/96 SCALE 1.000

Pictorial Assembly Drawings



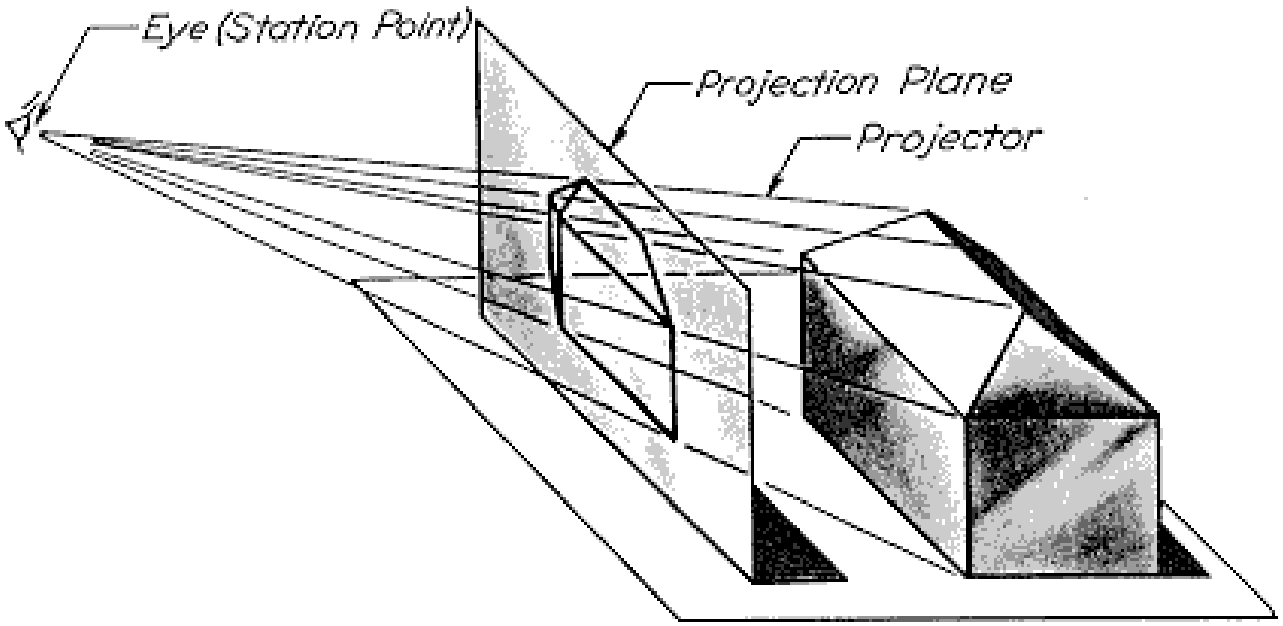
Pictorial assembly (exploded) drawing
Used to illustrate catalogues, user manuals, etc.

Perspective Projection

- In perspective projection the projectors intersect at finite points, called vanishing points (VP)
- The representation on the projection plane may be considered the view that would be seen by a single eye at a known point in space (station point)
- The picture is formed on the projection plane by the intersections of the projecting lines from the object to the focal point of the eye

Perspective Projection

- Perspective projection is used primarily by architects and commercial artists to describe the external appearance of an object



Perspective Projection

- One-Point Perspective
  - The projection plane is parallel to two principal axes. Receding lines along one of the principal axis converge to a vanishing point
  - A one-point perspective is used almost exclusively for interior-room views. It gives the observer the illusion of looking into the room

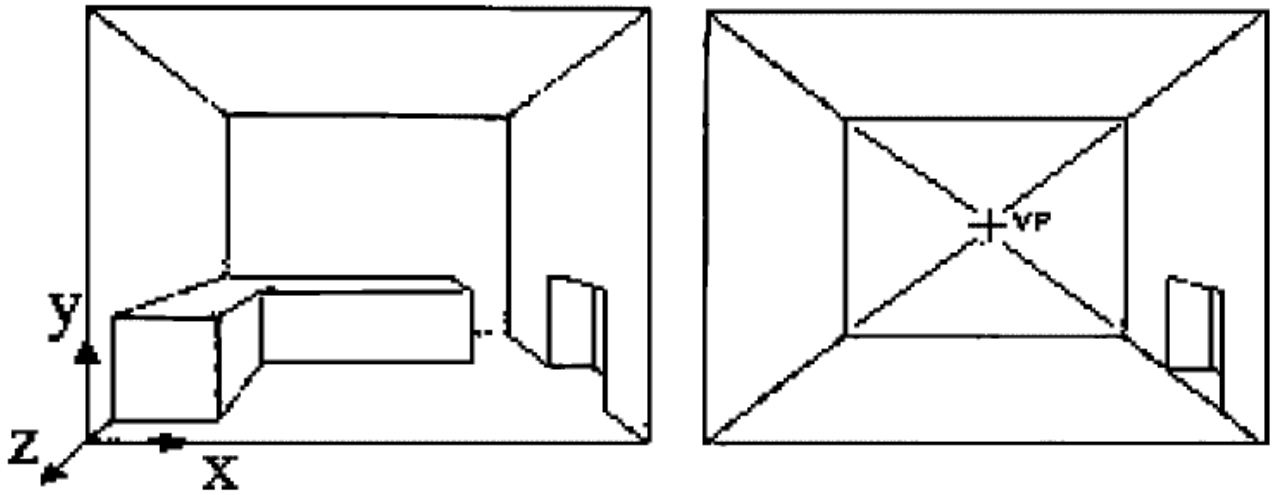
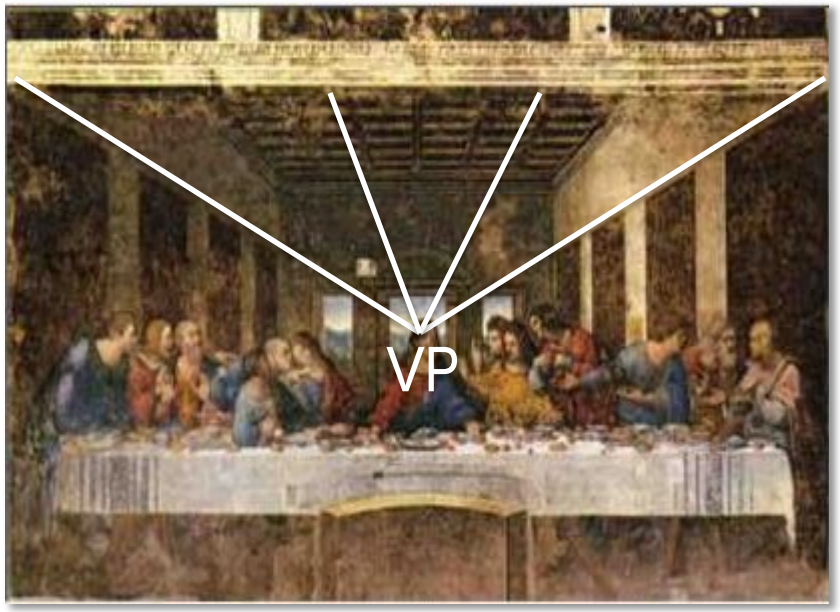


Figure 12.12 One-point perspective.

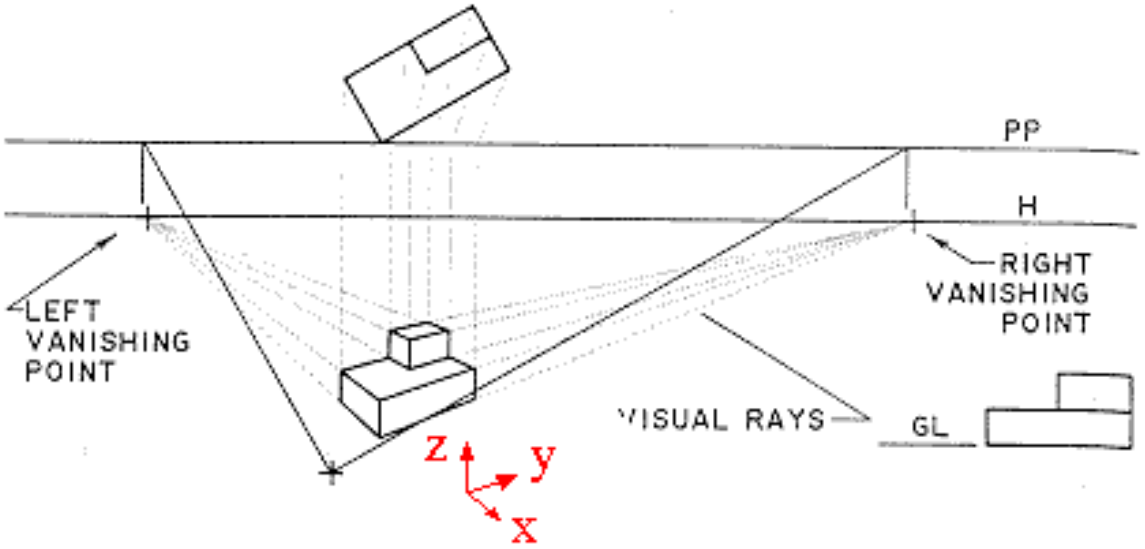
Perspective Projection

- LenardoDa Vinci: The Last Supper employed one-point perspective to focus the attention of the viewer to the vanishing point (VP)



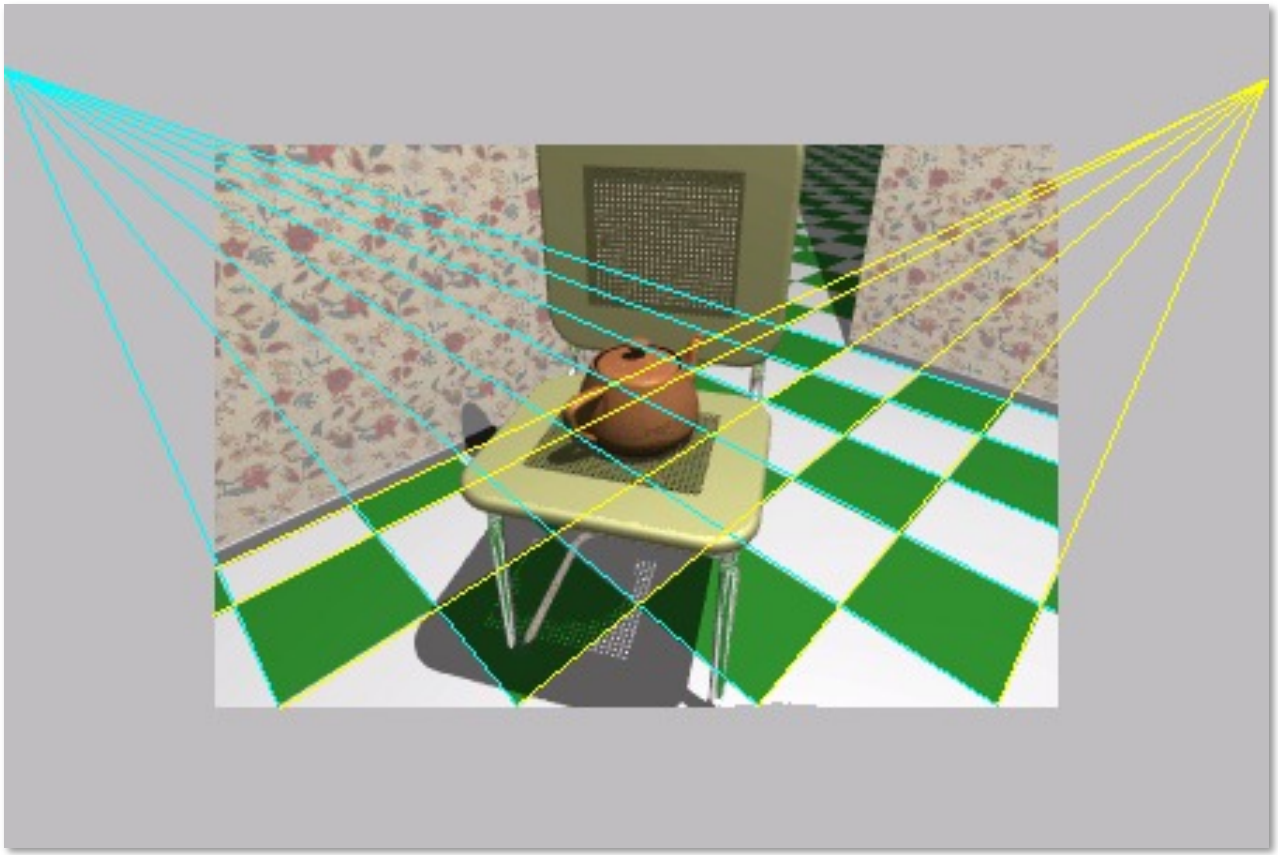
Two-Point Perspective

- Often used in architectural renderings
- If the projection plane intersects exactly two principal axes, a two-point perspective projection occurs
- In this perspective the visual rays converge at two vanishing points



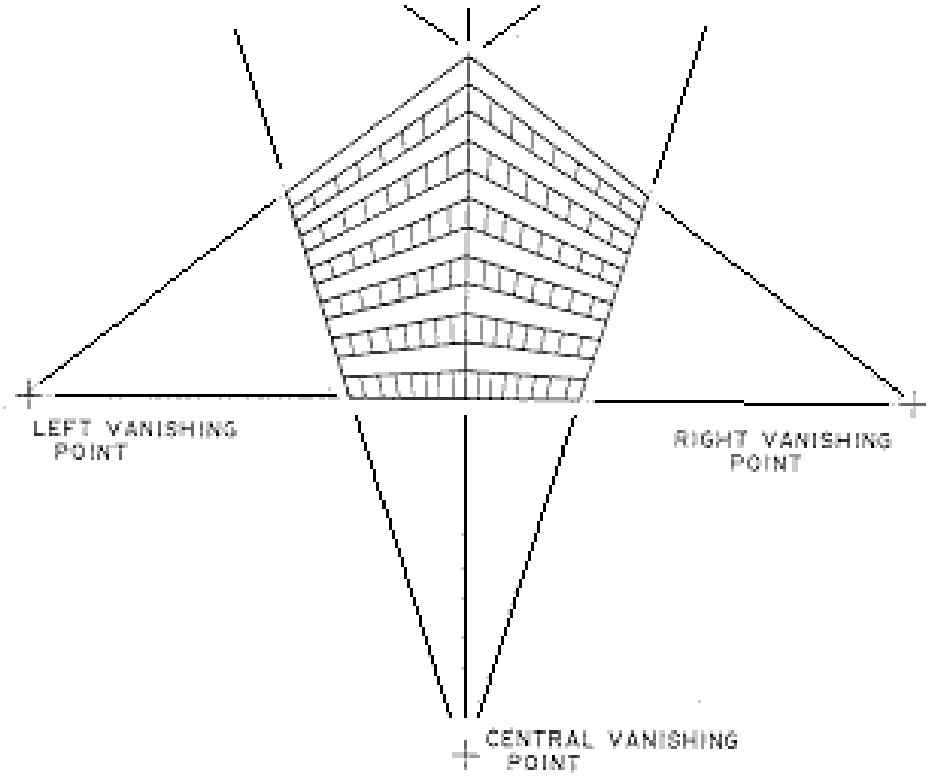
Perspective Projection

- Computer graphics two-point example



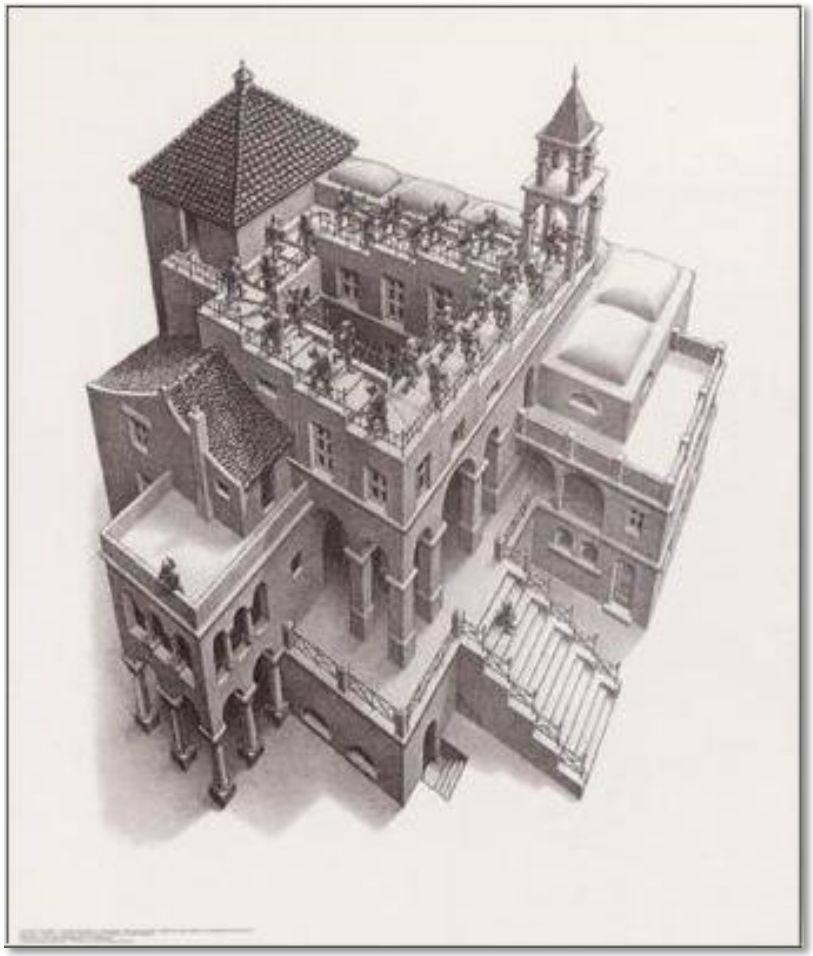
Perspective Projection

- If the projection plane is not parallel to any principal axis, a three-point projection occurs with the visual rays converging to three vanishing points

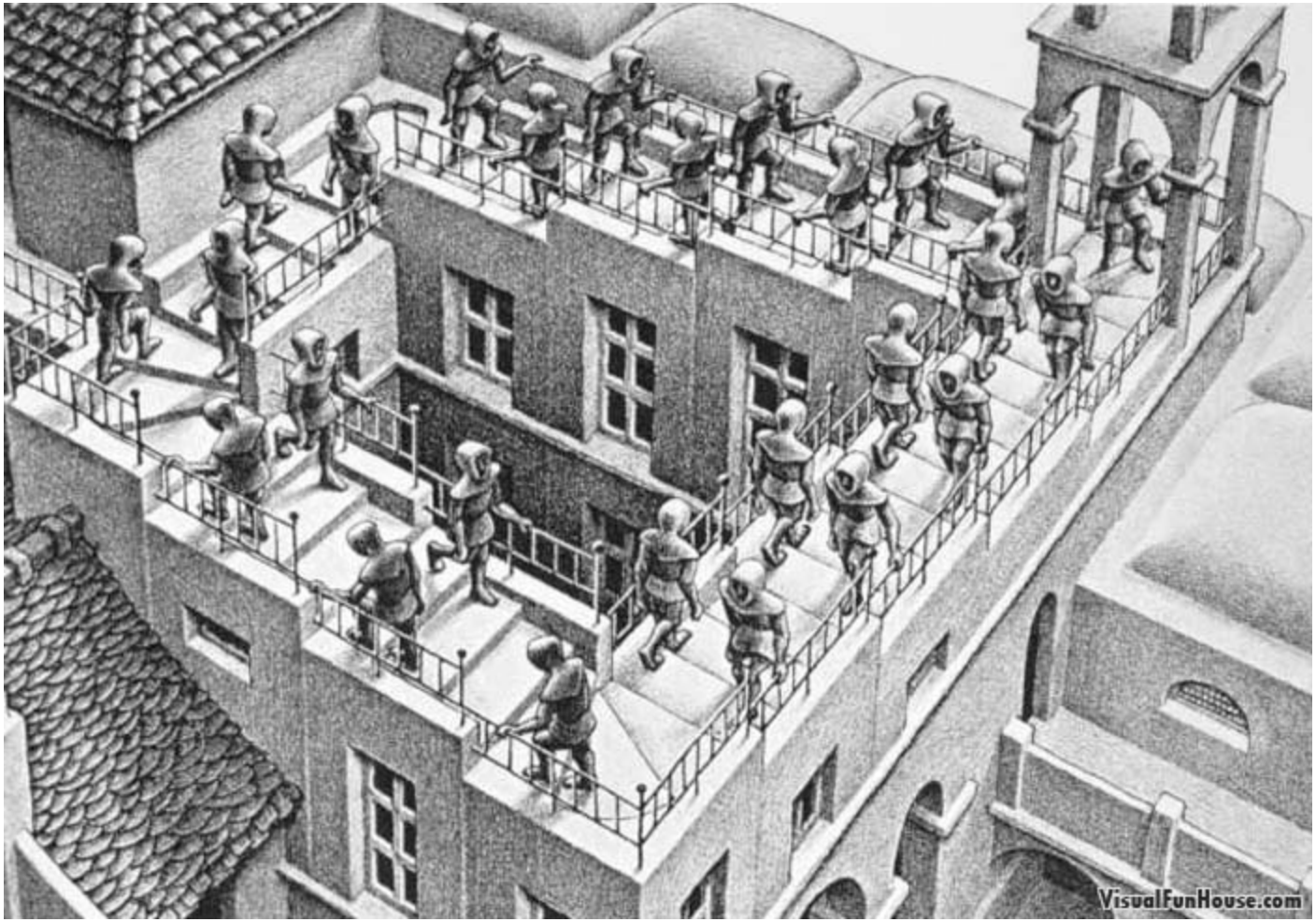


Perspective Projection

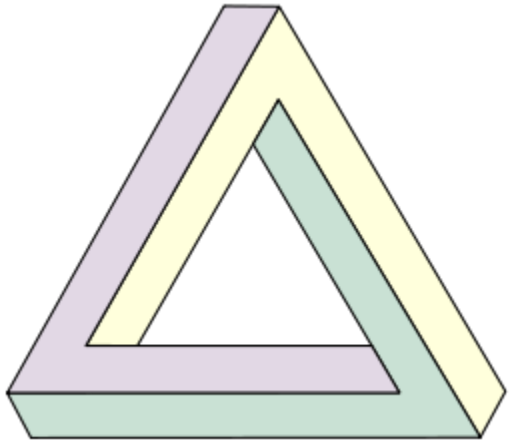
- M.C. Escher created optical illusions using three-point perspective in “Ascending and Descending”



Perspective Projection



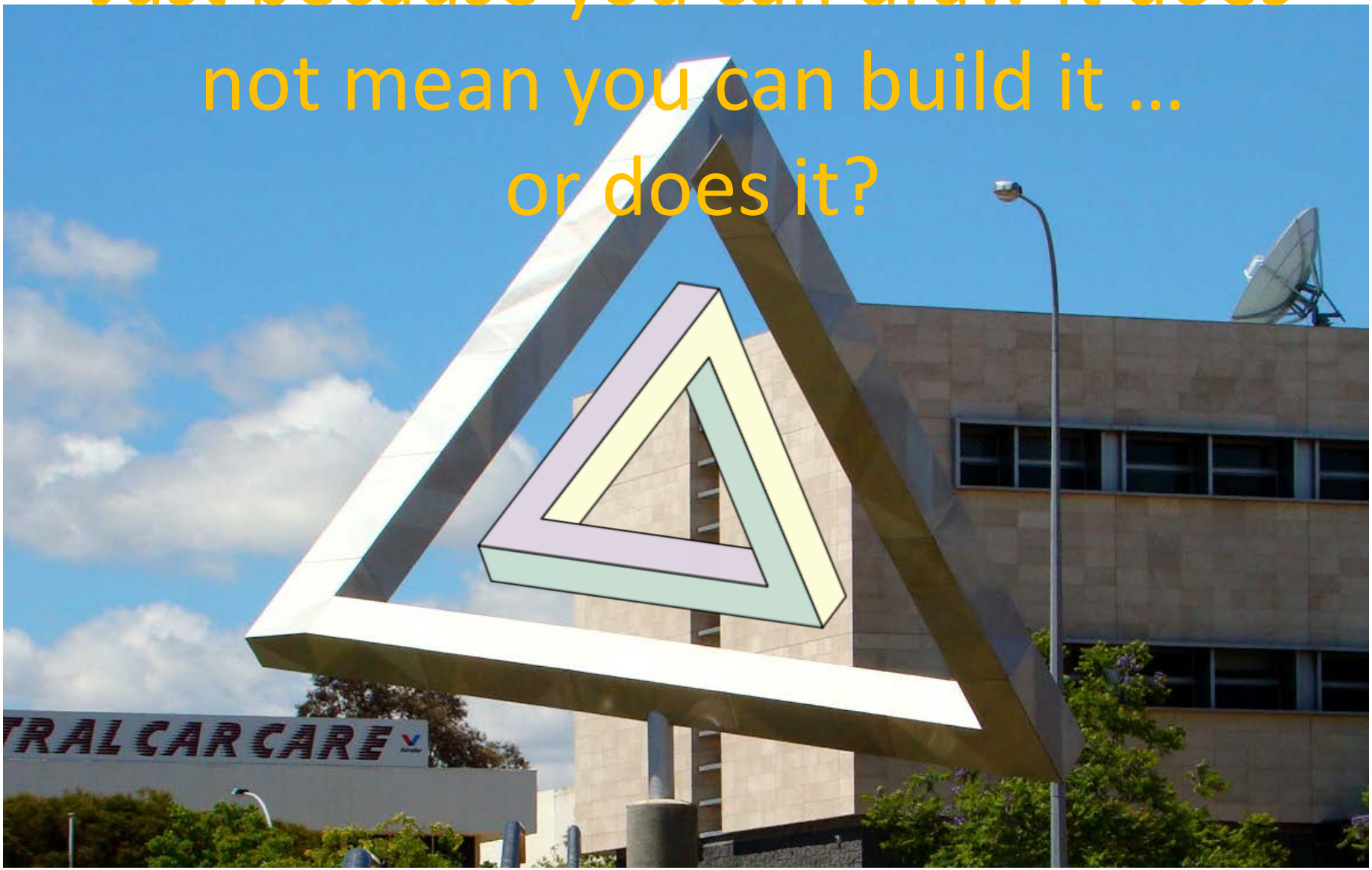
Just because you can draw it does not mean you can build it …



Penrose Triangle

Escher`s Waterfall

Just because you can draw it does not mean you can build it … or does it?

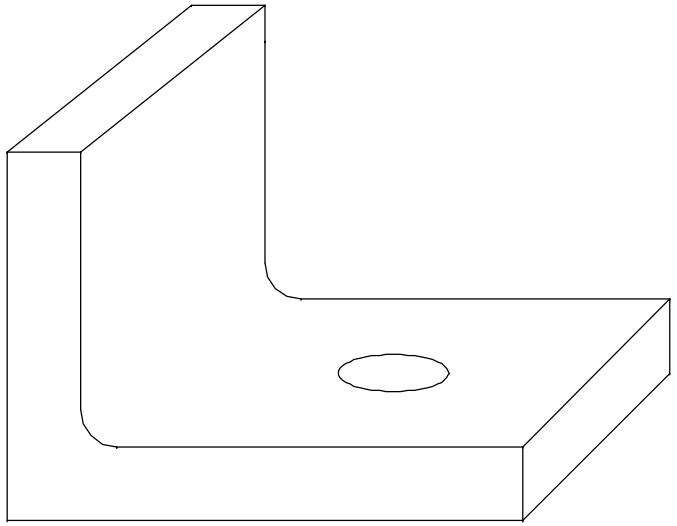


Brian McKay and Ahmad Abas in Perth Austrialia

CENTRAL CAR CARE

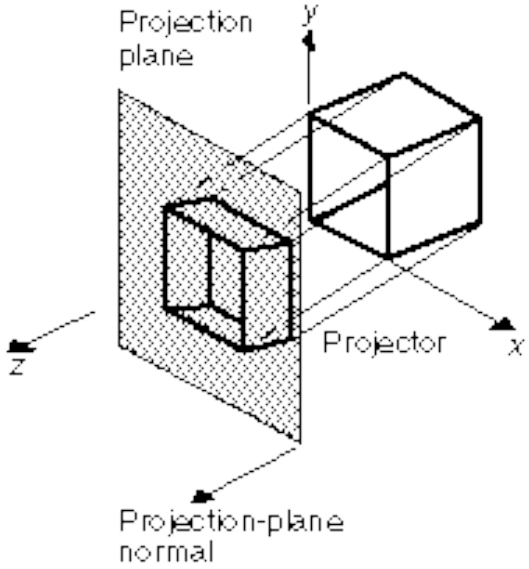
Oblique Projection

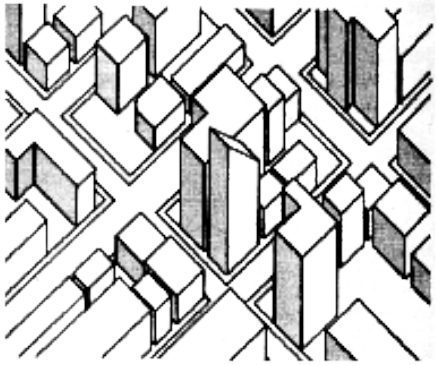
- Front face of object is parallel to the viewer, therefore that face is true size
- Projection lines do not converge to a vanishing point



Oblique Projection

- Parallel projectors are at an oblique angle (*i.e.,* not 90^{o}) to the paper plane
- Used to give an indication of depth
- Presents the exact shape of one face
- Lack of perspective foreshortening makes it easier to compare sizes

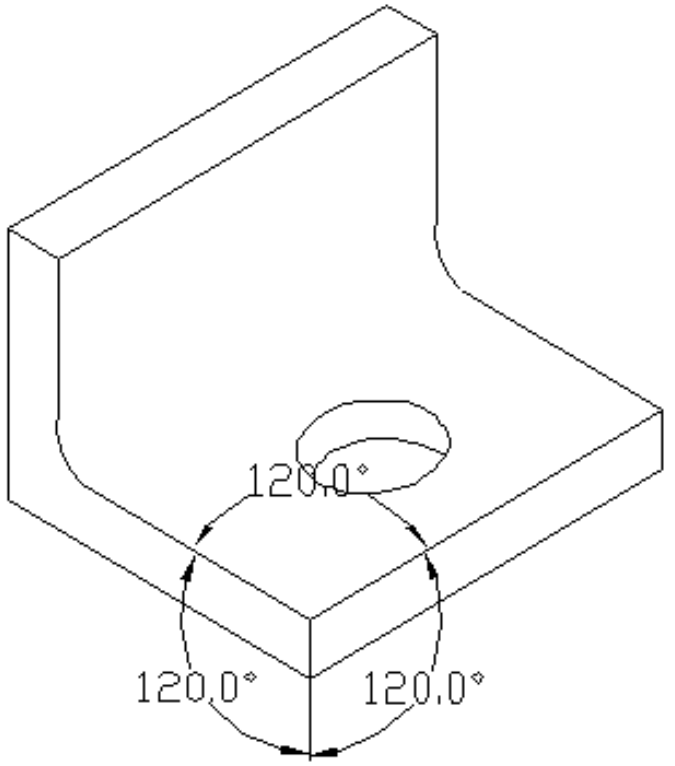




Foreshortening is a technique used in perspective to create the illusion of an object receding strongly into the distance or background.

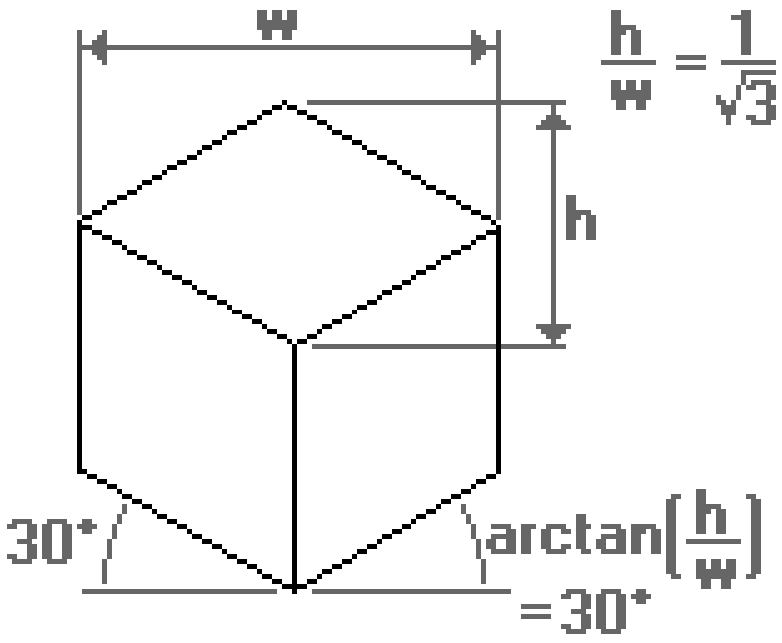
Isometric Projection

- Parallel lines remain parallel instead of converging to a vanishing point
- Axis are each 120 degrees apart
- Special case of *Axonometric* projection
  - Viewed so as to reveal more than one side



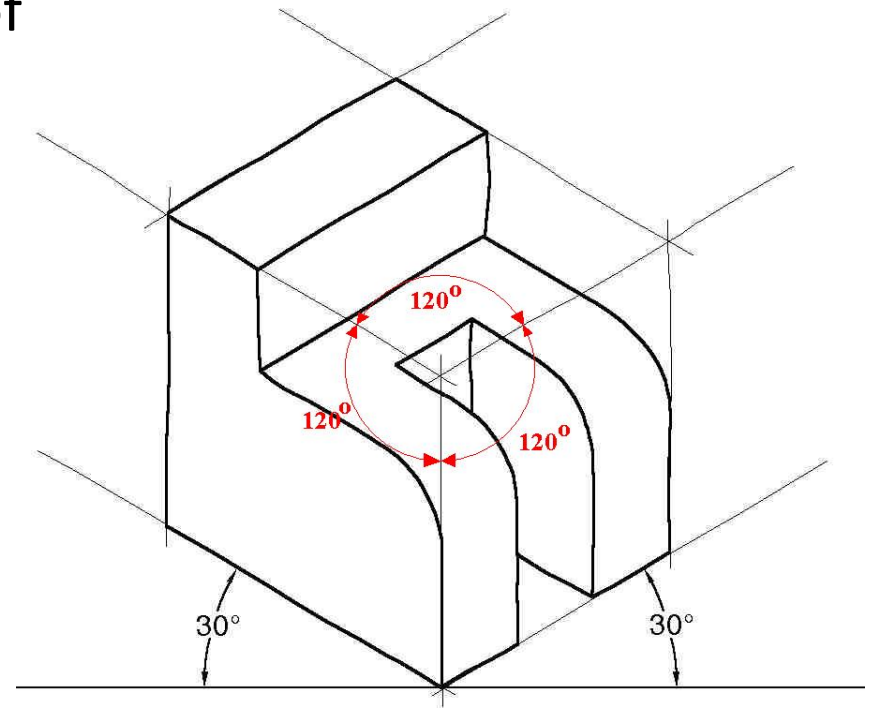
Isometric Projection

- Isometric projection uses parallel projectors (orthogonal projection), but it shows more than one face of the object (axonometric)
- The x-, y- and z-axes have the same metric: a unit (say, a cm) along the x-axis is equally long along the y- and z-axes
- In a cube, all edges in the 2D picture have the same length
- The projected cube is also symmetric; all sides are rhombuses (a rhombus is a parallelogram with sides that are equal in length)

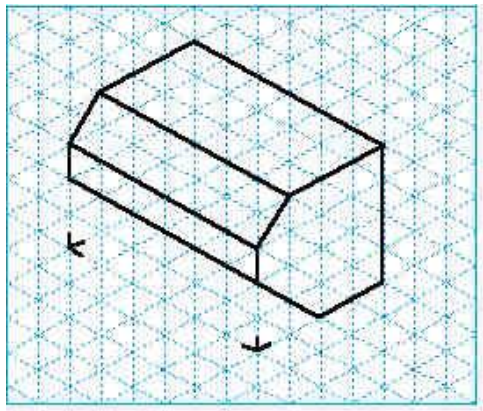


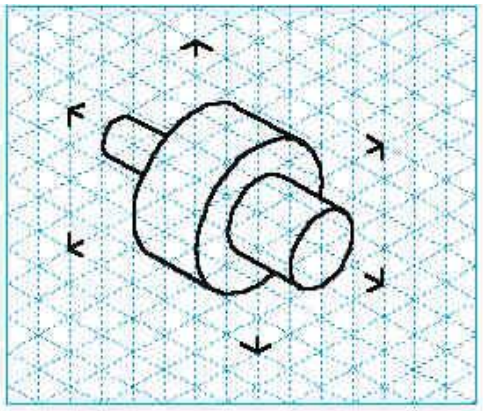
Isometric *Sketching*

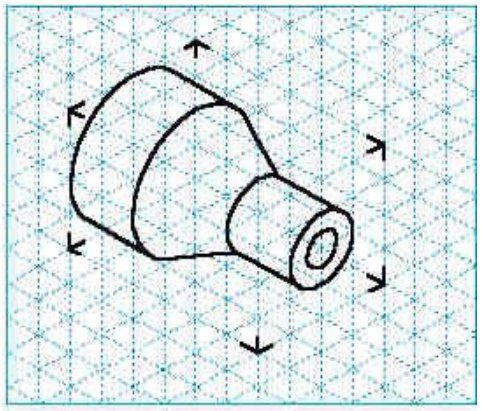
- Isometric projection uses parallel projectors (orthogonal projection), but it shows more than one face of the object (axonometric)
- The x-, y- and z-axes have the same metric: a unit (say, a cm) along the x-axis is equally long along the y- and z-axes
- In a cube, all edges in the 2D picture have the same length
- The projected cube is also symmetric; all sides are rhombuses (a rhombus is a parallelogram with sides that are equal in length)

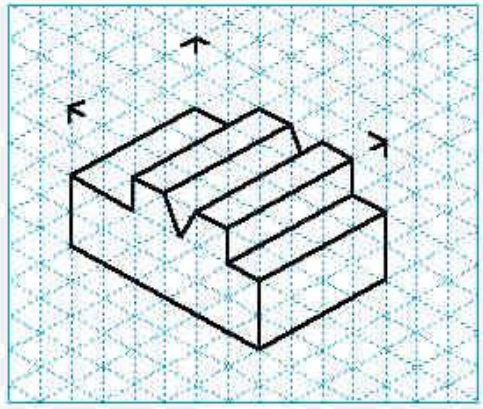


Isometric Sketch Paper









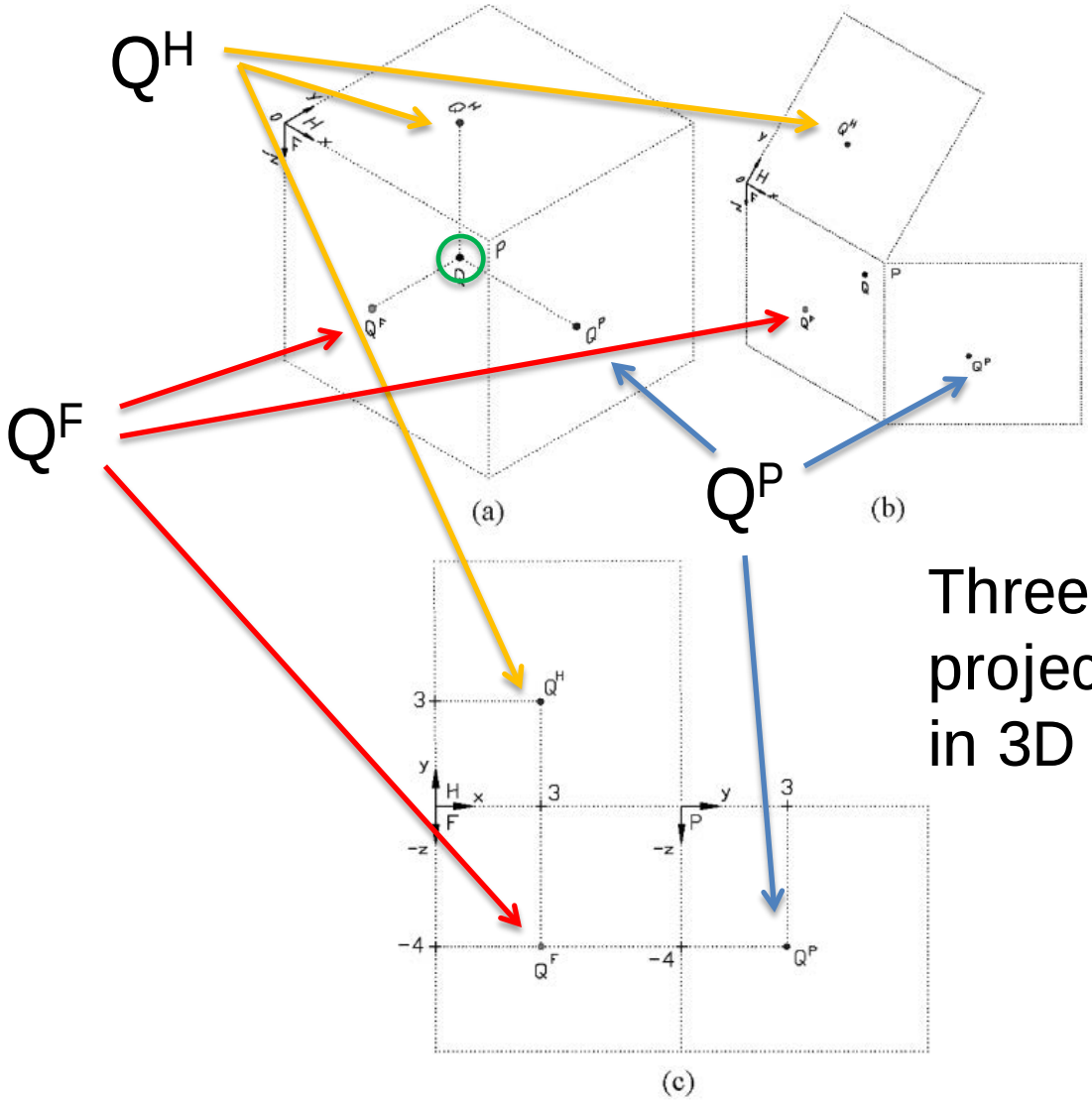
Orthographic Projection

- The most important graphical drawing method
- 2D representations of a 3D object
- Extensively used in Engineering
- Useful when technical information is needed
- They enable parts to be made
- Often an isometric view is included with the standard views

Orthographic Projection

- Orthographic projection is the geometric backbone of a technical drawing
- In order for the technical drawing to be useful, many conventions must be followed
  - The information in the drawing has to be clear and concise
  - Conventions apply to things like object placement, line types, and dimensioning

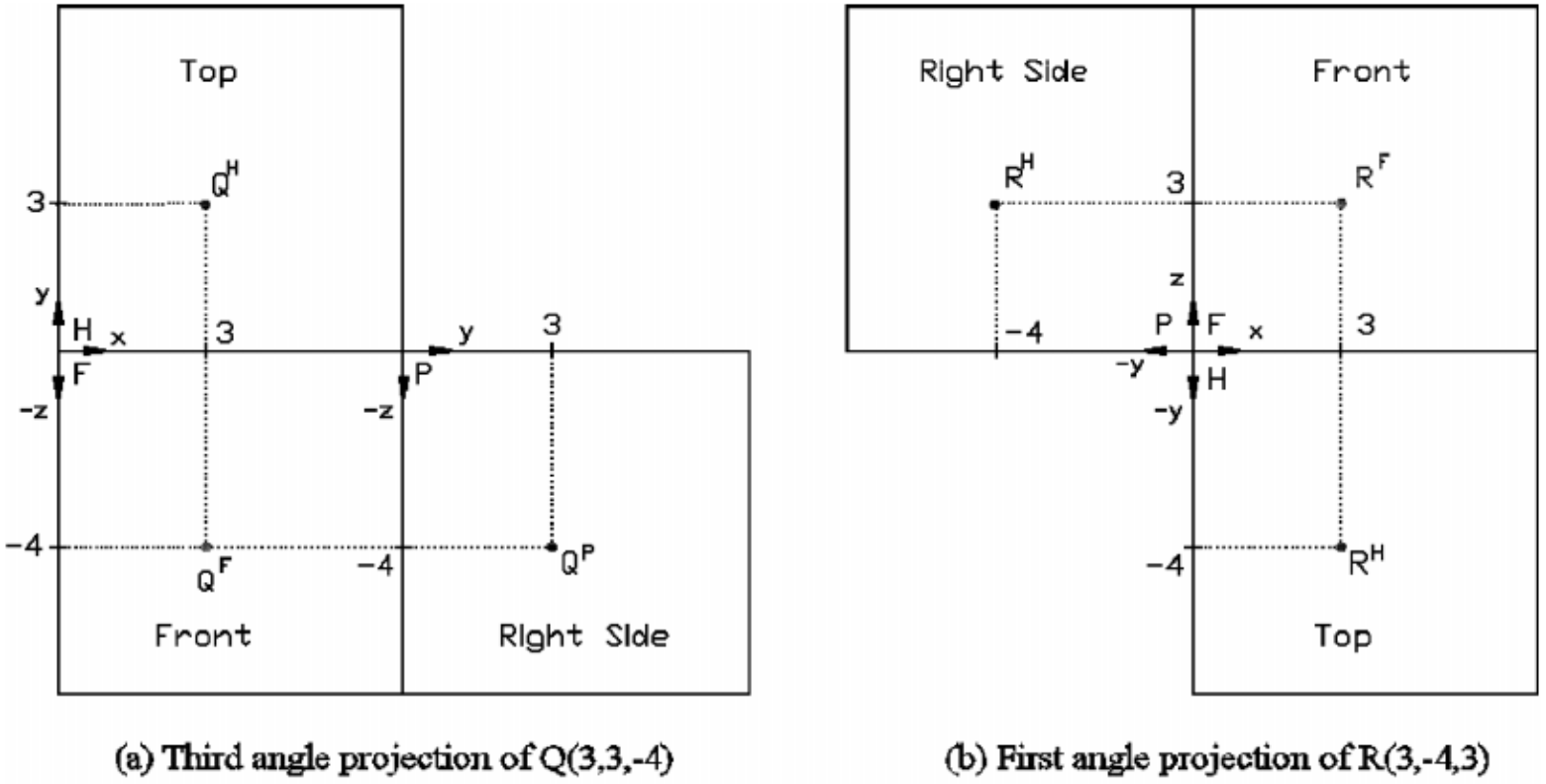
Orthographic Projection



Three orthographic projections of a point in 3D space

Figure 12.7 Three orthographic projections of a point in 3D space.

Orthographic Projection



(a) Third angle projection of Q(3,3,-4)

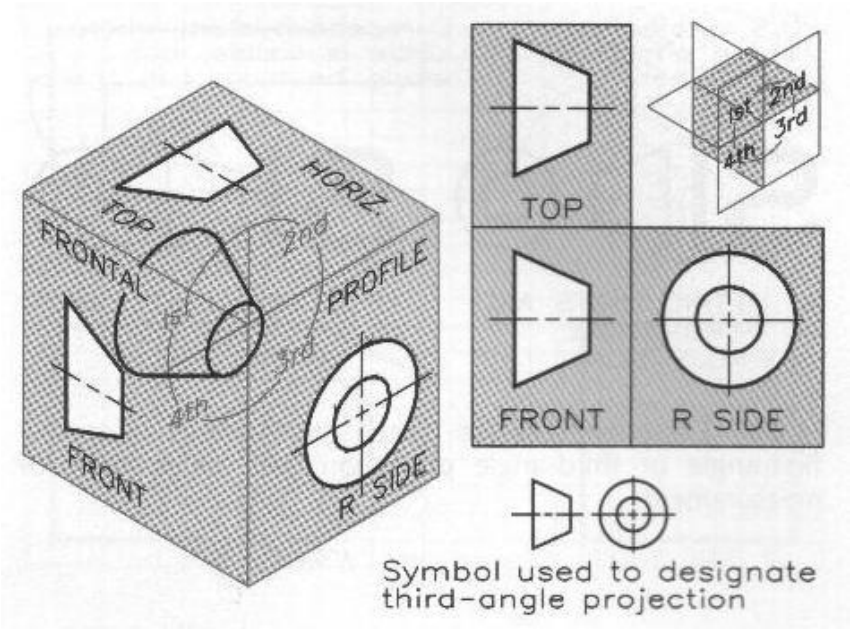
(b) First angle projection of R(3,-4,3)

Figure 12.8 Three relative positions of the principal planes in third and first angle projection.

Third-Angle Orthographic Projection

Third-Angle Projection

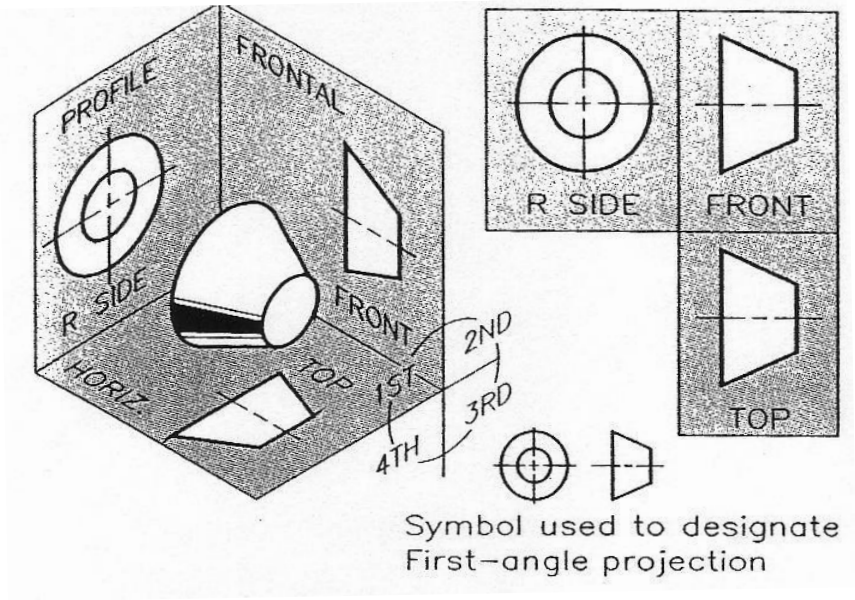
- The object is placed in the third quadrant and then viewed from the first quadrant
- Projection planes are between the observer and object
- Used in Canada, U.S., and Britain
- First-Angle Projection used in Europe
- The top view is placed over the front view; the right-side view is to the right of the front view



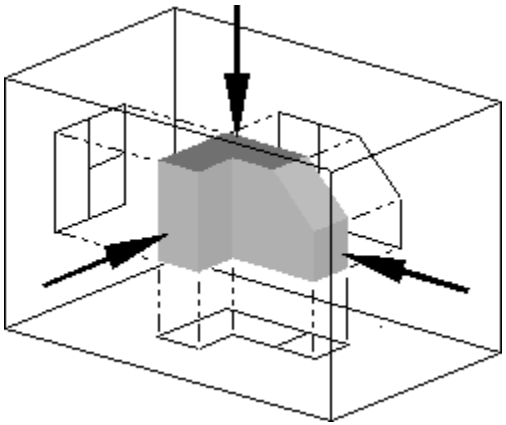
First-Angle Orthographic Projection

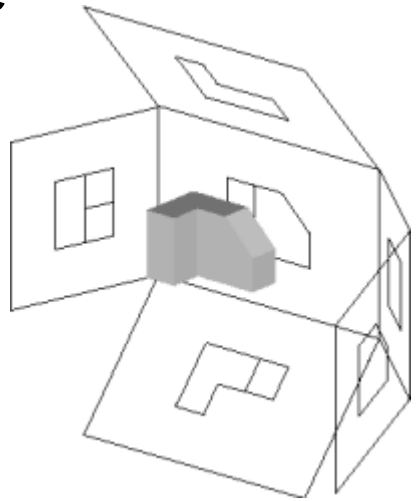
First-Angle Projection

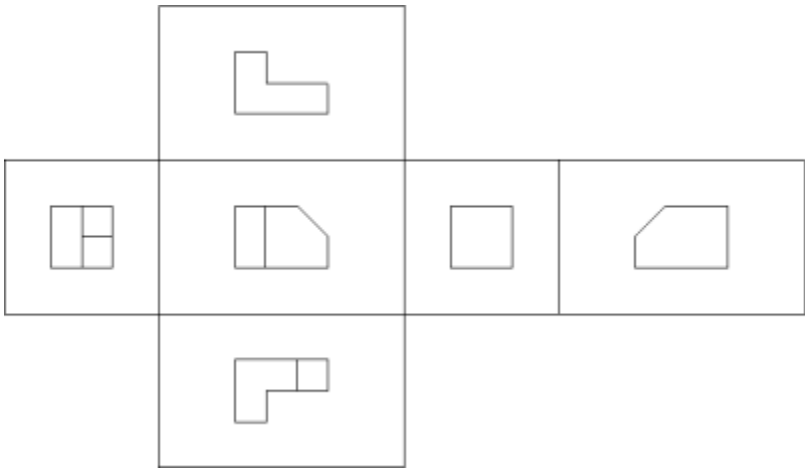
- The object is placed in the first quadrant and viewed from the first quadrant
- The object is between the observer and projection planes
- Used in most of the world
- The top view is placed below the front view. The right-side view is to the left of the front view

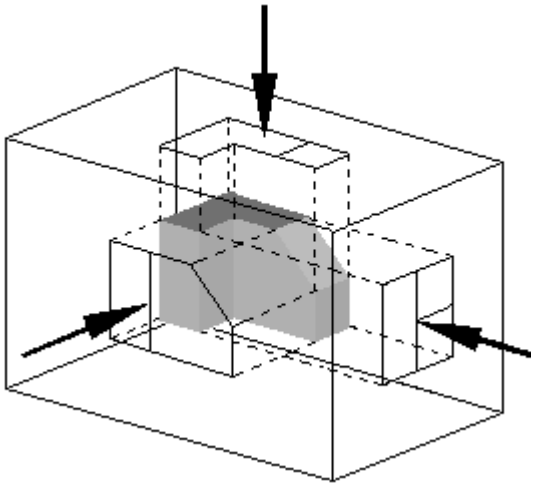


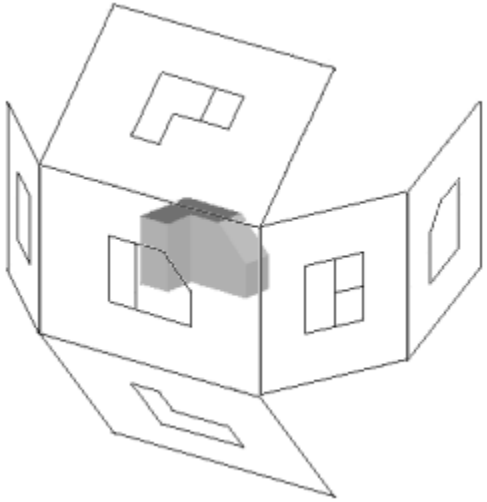
First Angle

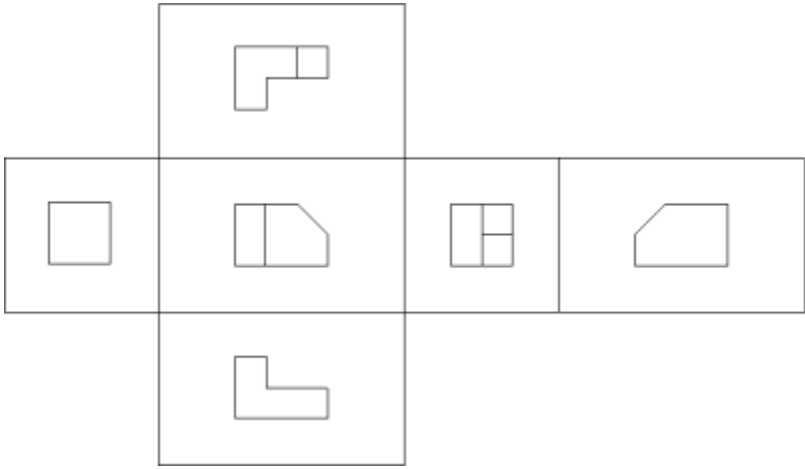




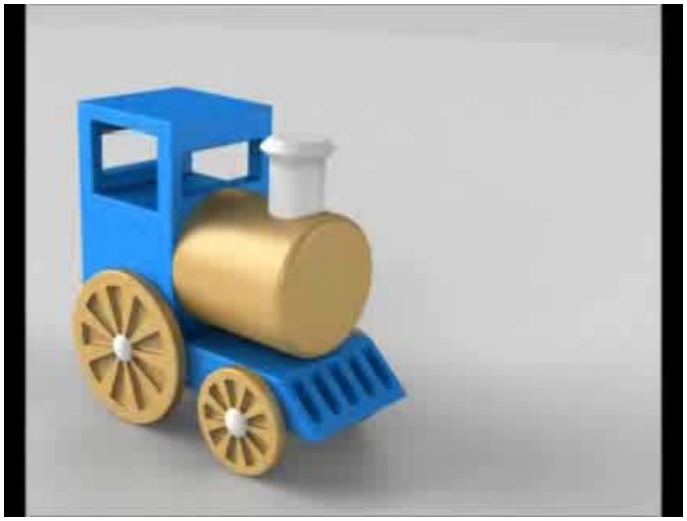


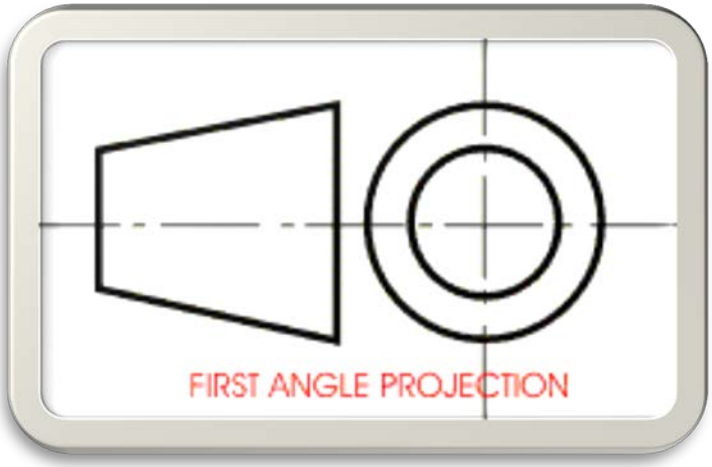






Third Angle



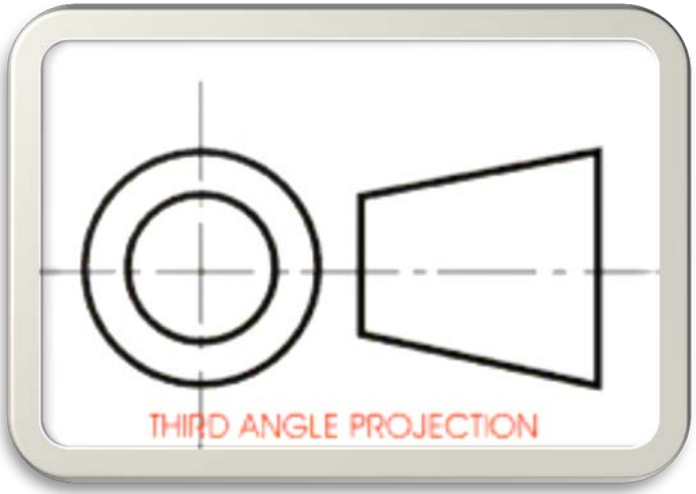


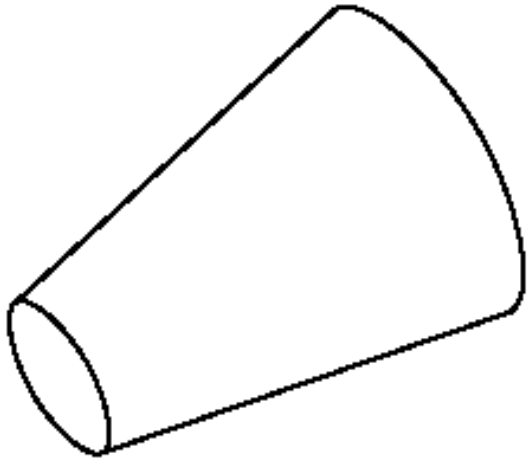
Symbol for FIRST ANGLE

- Wide end is next to the circle

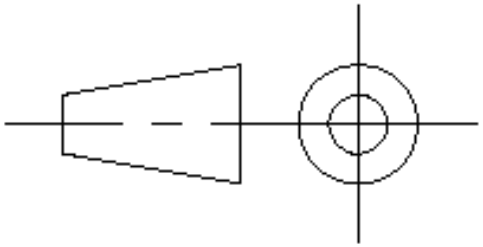
Symbol for THIRD ANGLE.

- Narrow end is next to the circle.

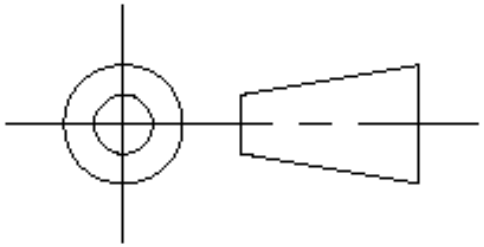




truncated cone

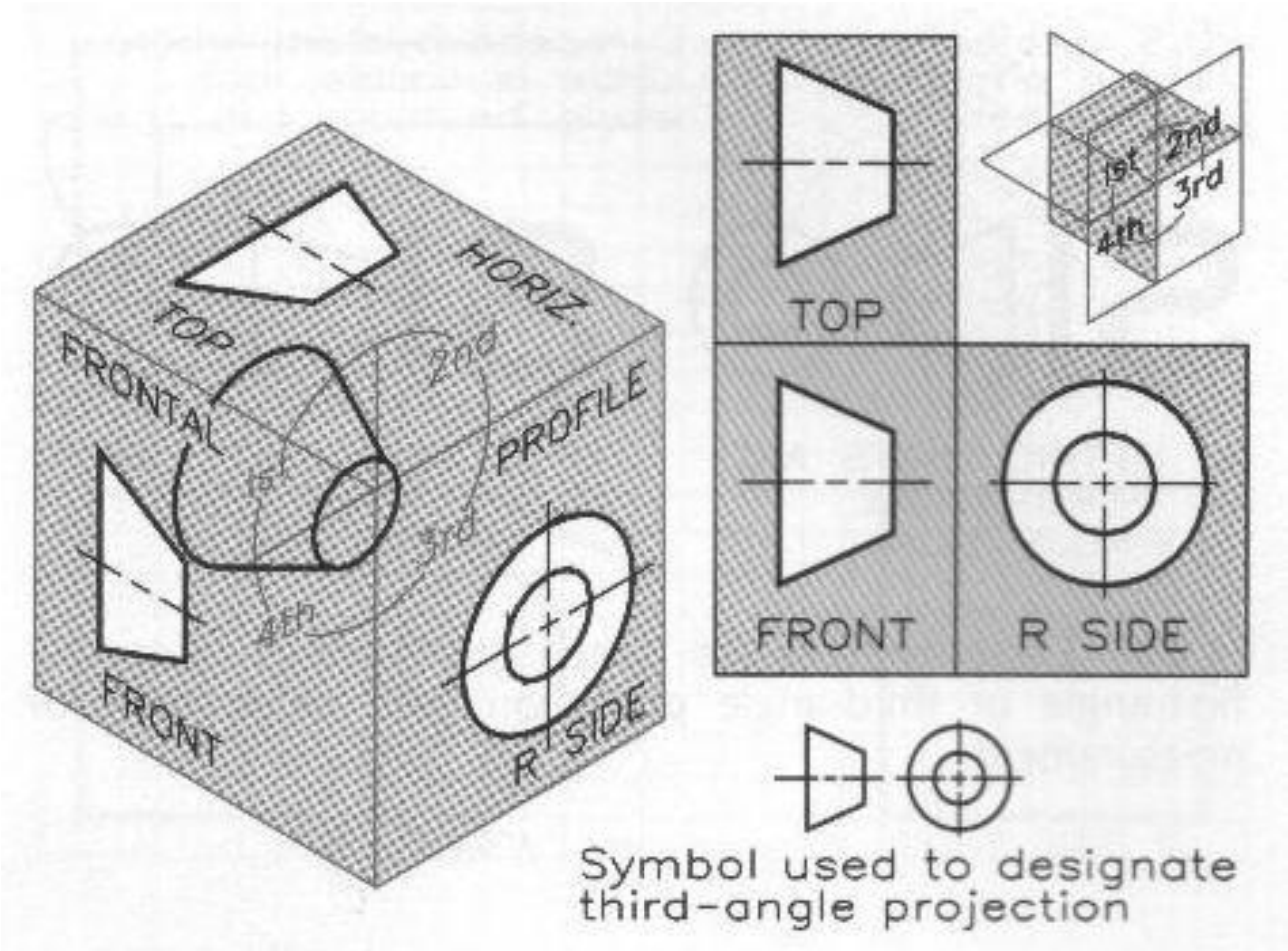


first-angle symbol



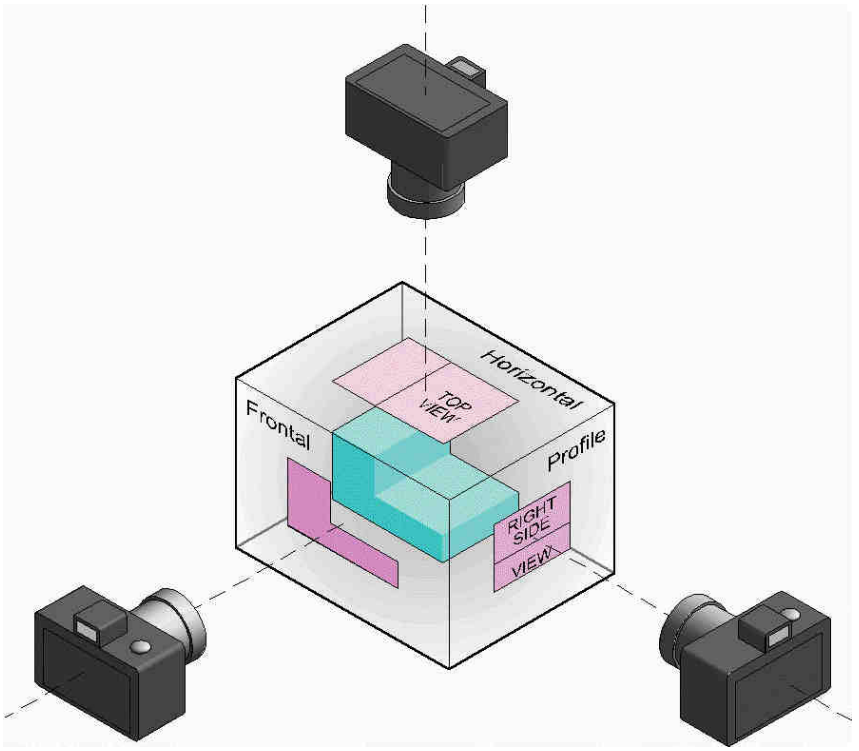
third-angle symbol

We use Third-Angle Projection



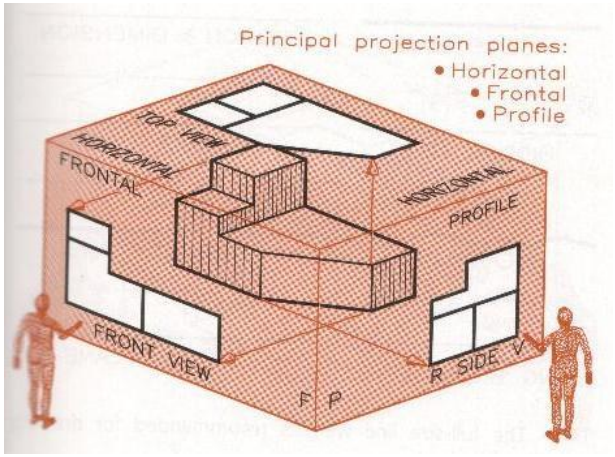
Orthographic Projection

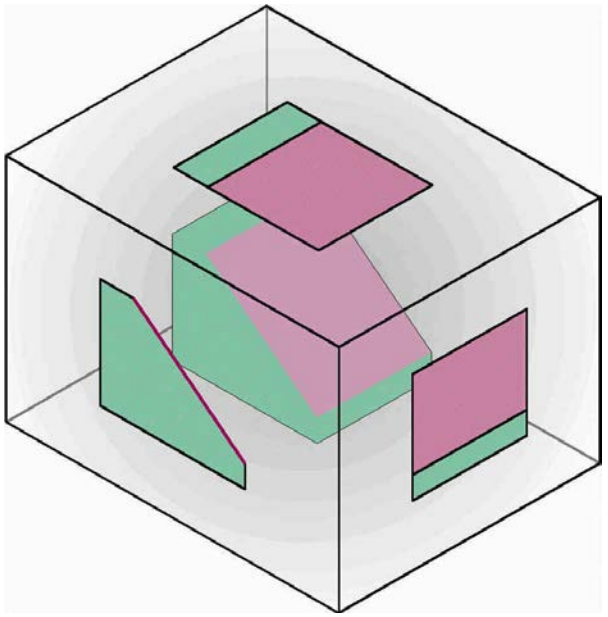
- The bracket in the figure is a simple part, but describing it with words is difficult
- Is it hard to make a 3D drawing of it?
- Not if you know how to project it *orthographically*!
- Orthographic projection represents different views separated by 90^{o} as the viewer moves around it



Orthographic Projection

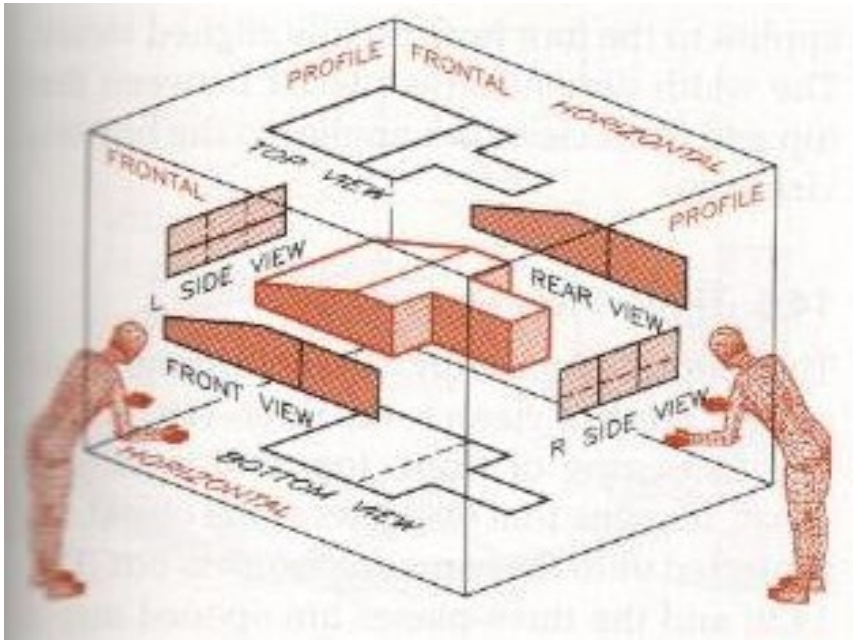
- Orthographic projection involves projecting views of an object onto the sides of an imaginary rectangular glass box
- The projectors in any one view are parallel to each other and perpendicular (orthographic, or orthogonal) to the projection planes (the sides of the rectangular glass box)

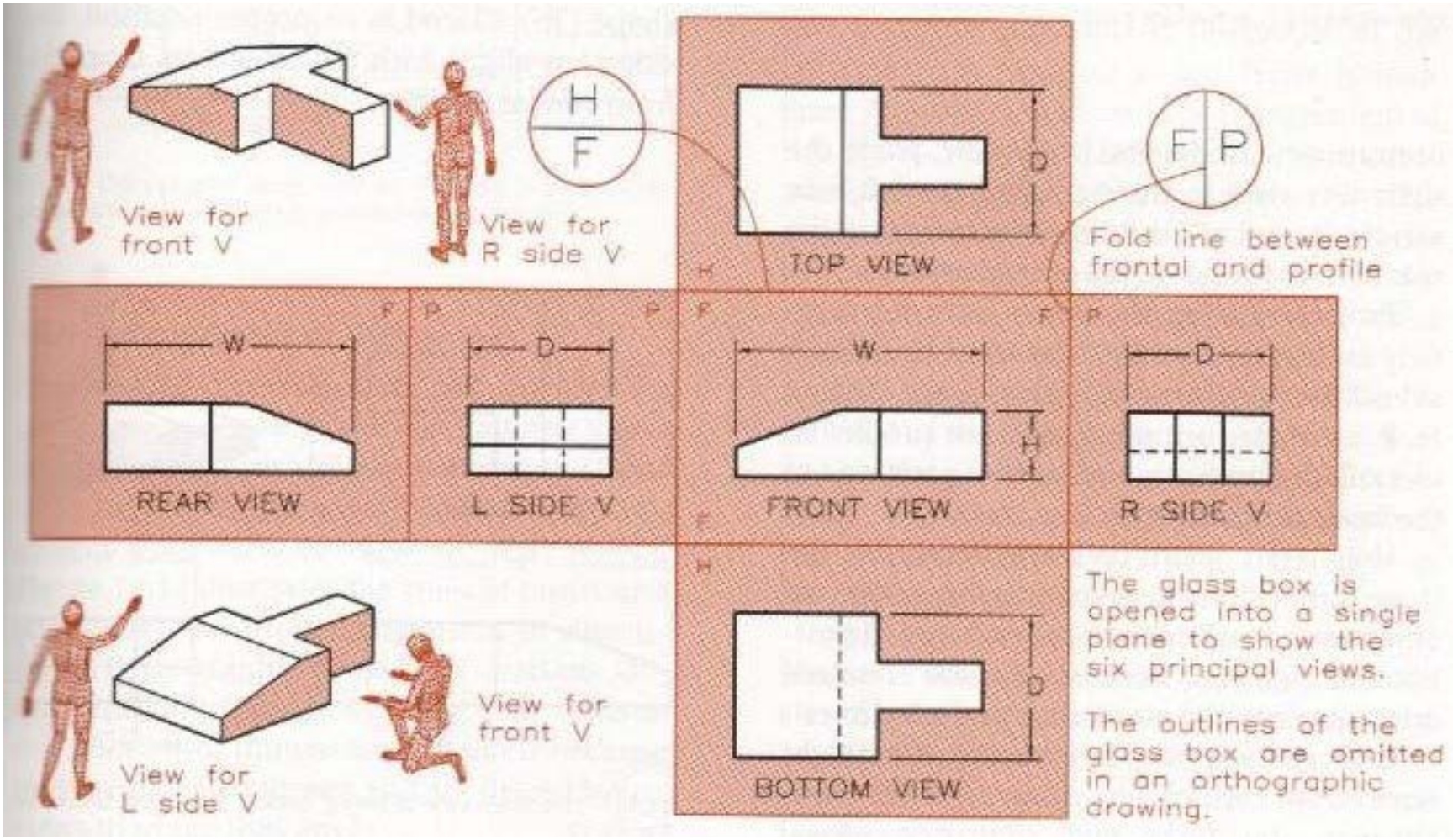




Orthographic Projection

- Six principal views can be drawn in orthographic projection
- Imagine a glass box with the views projected onto its six planes





Orthographic Projection

Opening the box into a single plane (the front plane) gives the six views

Orthographic Projection

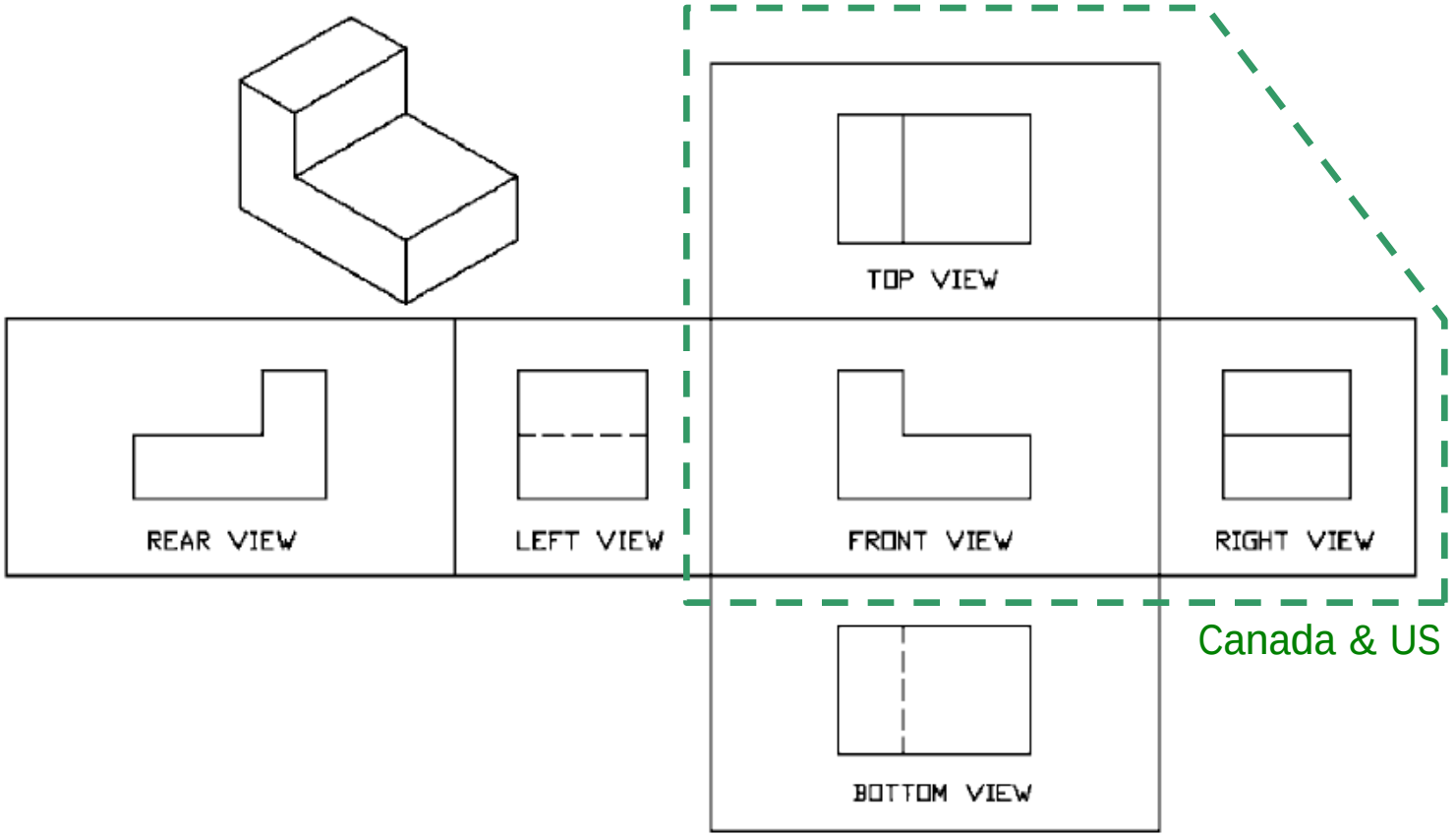
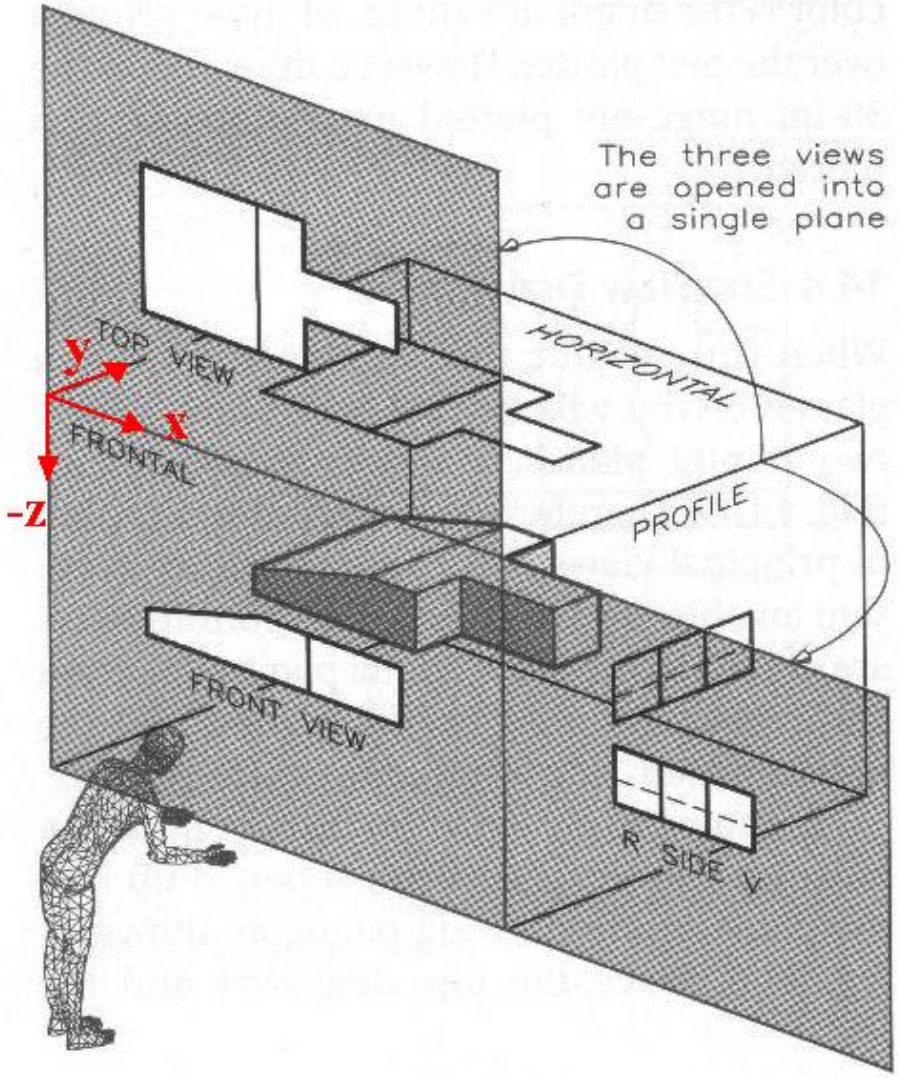
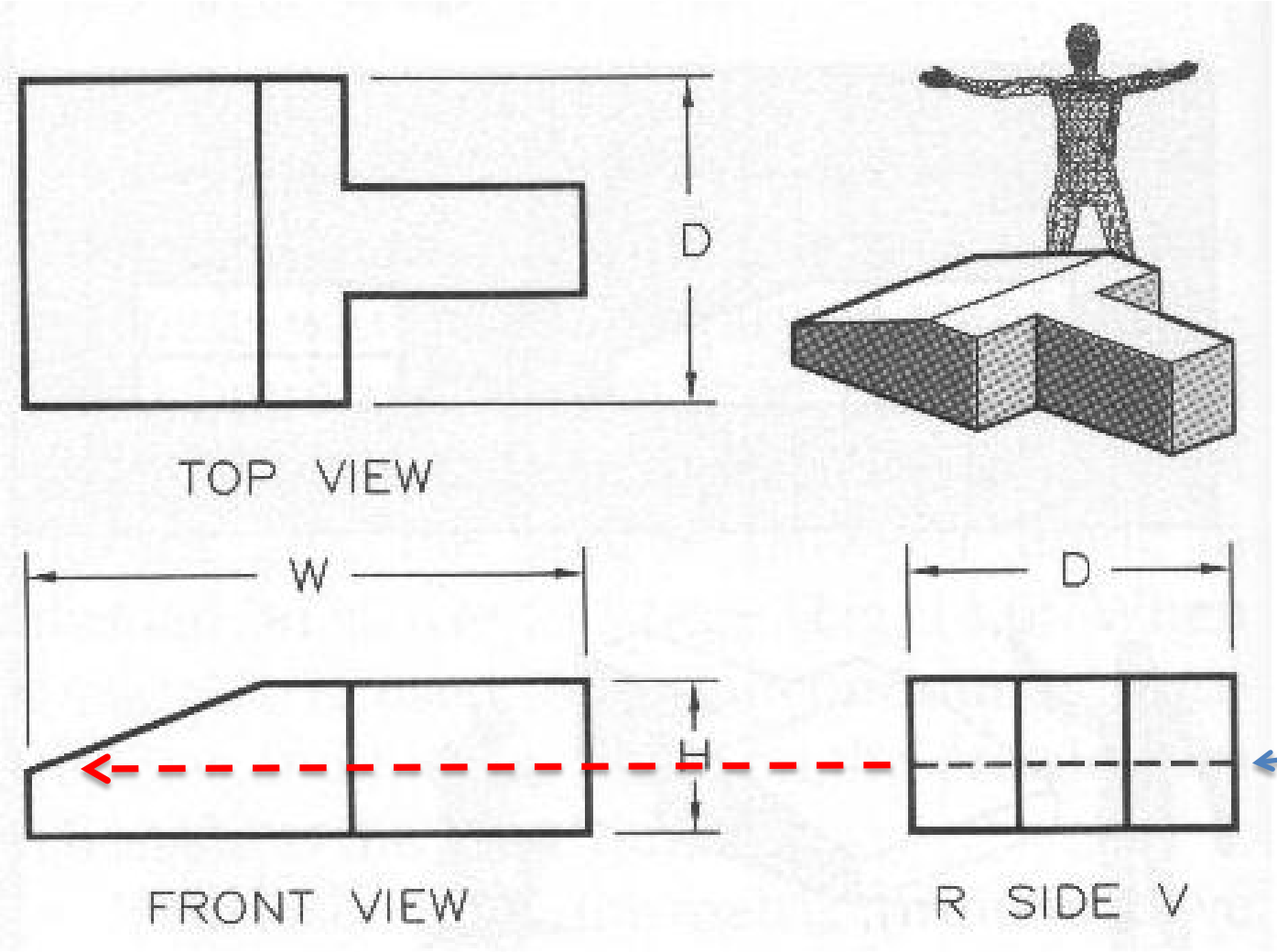


Figure 12.20 Six principal views.

Three-View Drawings

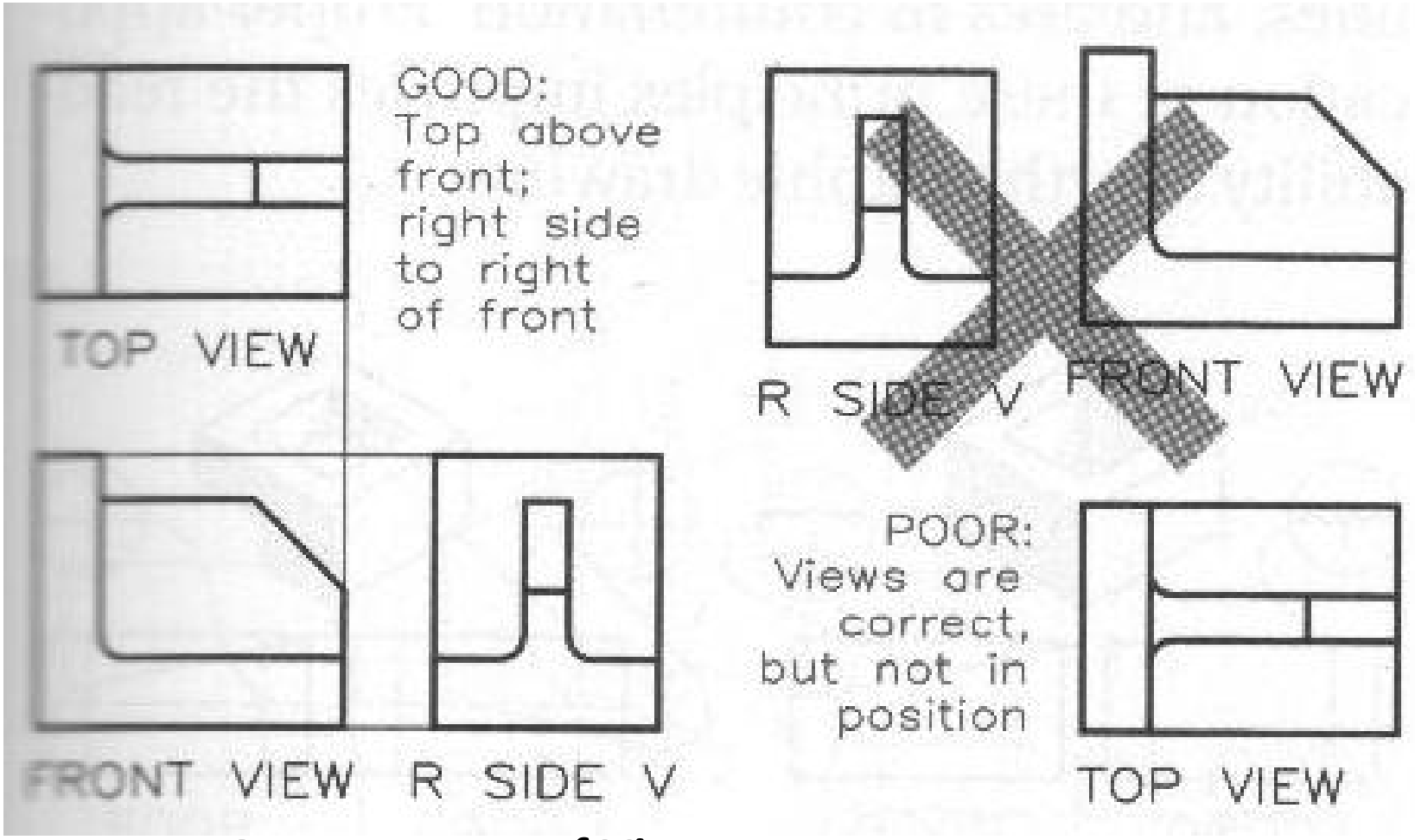
- We use third-angle projection
- Three-view drawings typically, though not always, consist of top, front, and right-side views
- Imagine the object is placed in the box and orthographically projected onto the three planes
- The box is then opened into the frontal plane





Three-View Drawings

Width, Height, and Depth dimensions can be represented, giving enough information to construct the object

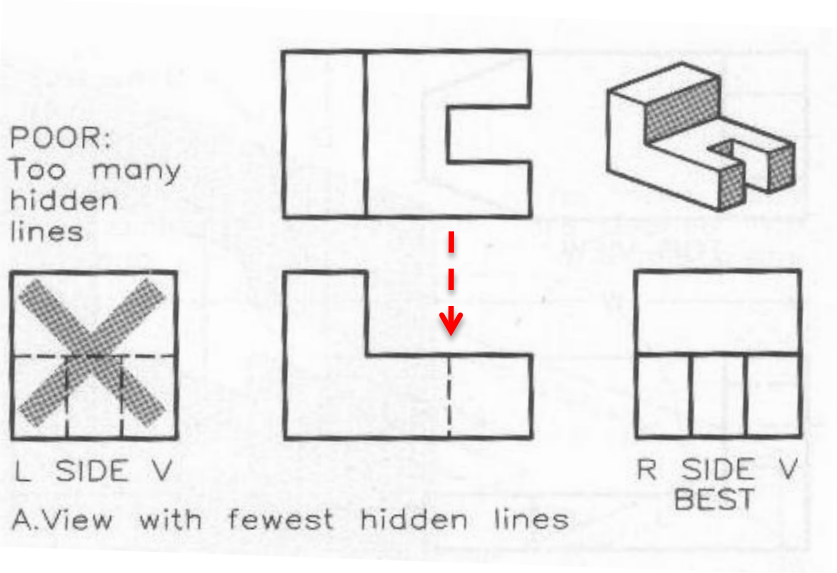


Arrangement of Views

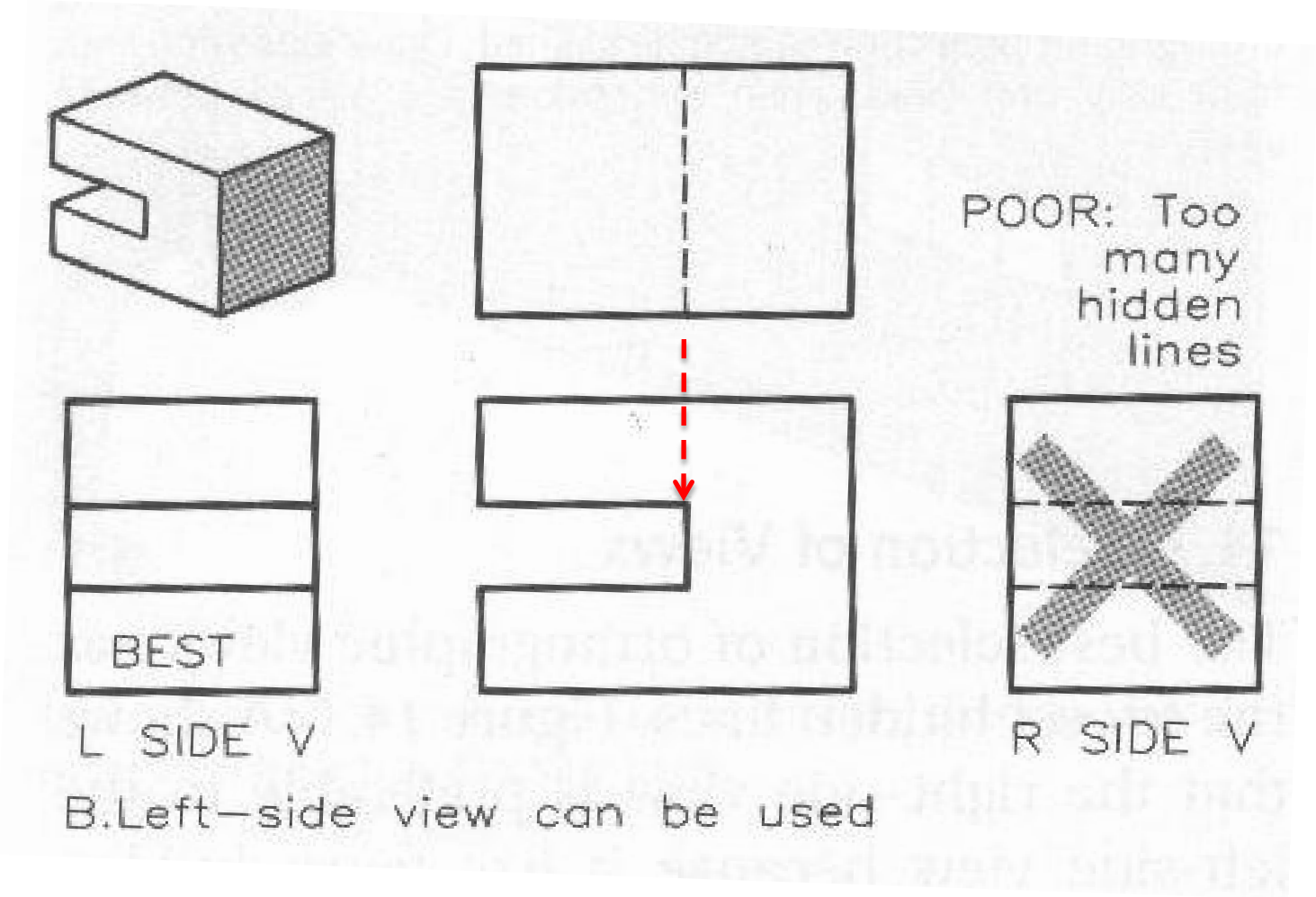
- The three views must be arranged according to the projection convention (first-angle or third-angle)
- Top and side views are projected from and aligned with the front view

Selection of Views

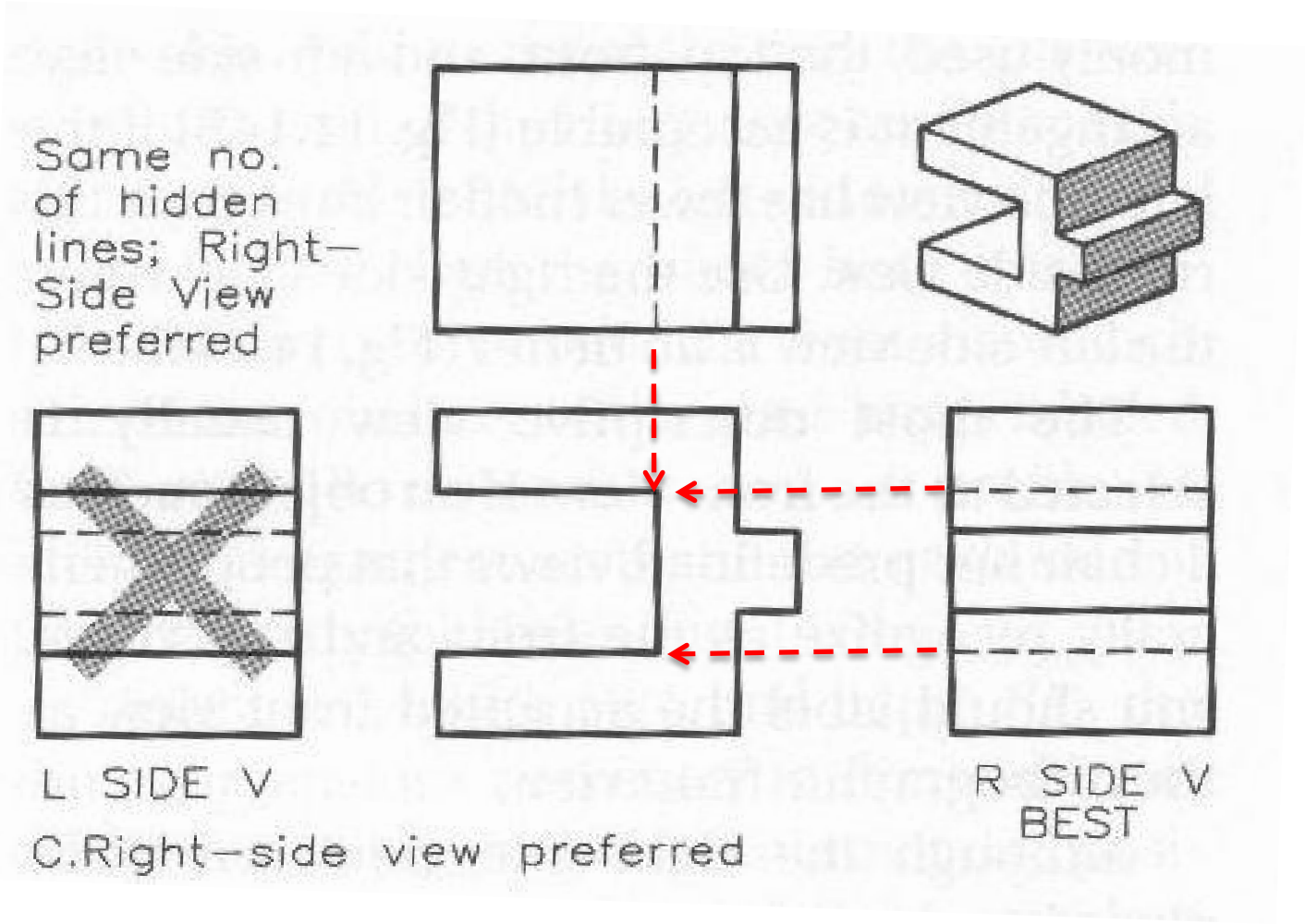
- The most descriptive view is usually selected to be the front view
- The remaining views are selected such that they contain the fewest hidden lines
- If a tie occurs (say between the left and right-side views) use the conventional view (top or right-side)



Selection of Views



Selection of Views



Assignment

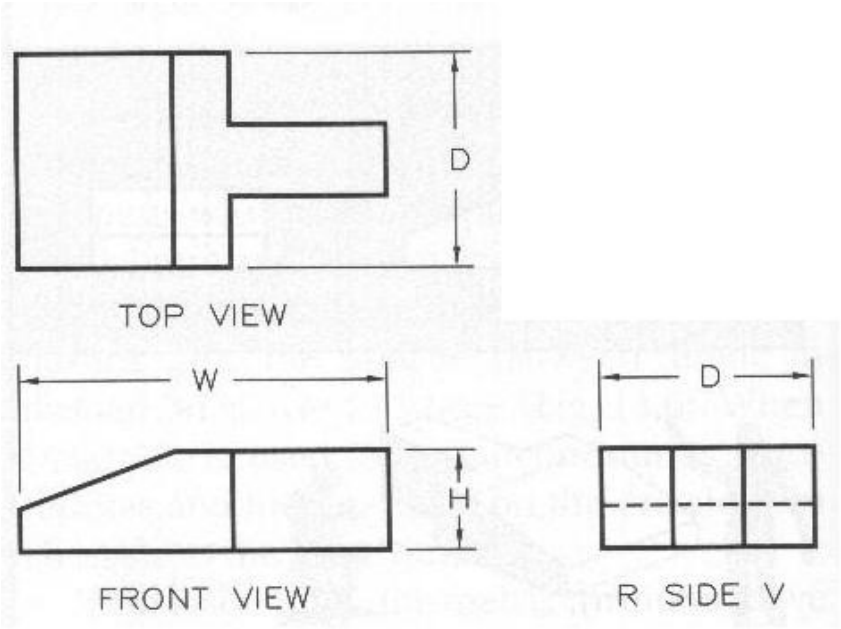
- Read Chapters 12 & 14

ECOR 1010
Lecture 6

Engineering Graphics - 2

Standard Drawing Layout

- The standard arrangement for a technical drawing is a three-view orthographic projection:
  - Top view is located above front view
  - Right view is located to the right of frontview
- The views must be aligned



Orthographic Projection - Lines

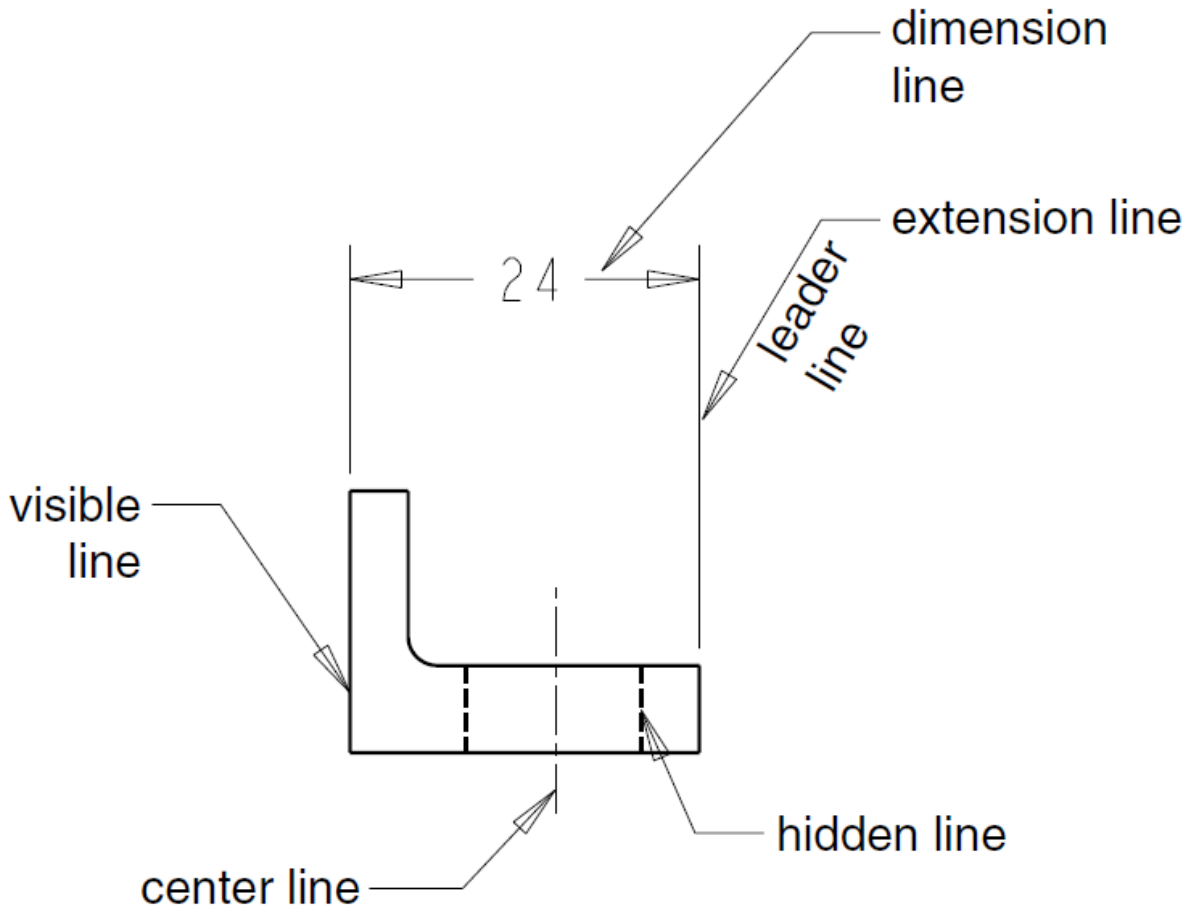
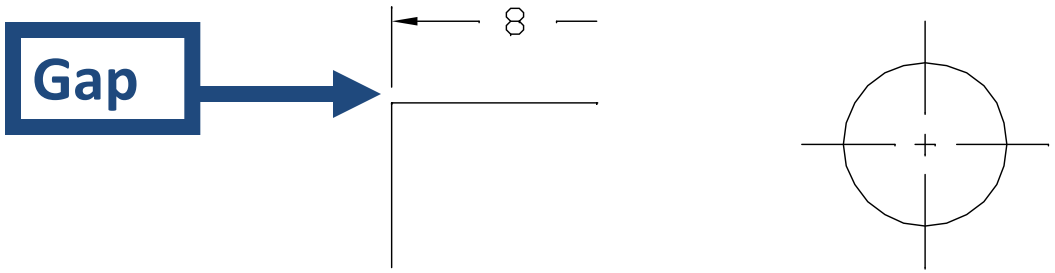


Figure 14.3 Types of lines used in drawings.

Extension and Centre Lines

- Conventions:
  - Leave a gap between the end of an extension line and the object to which it refers (a)
  - The short dashes of crossing perpendicular centre lines form a small cross (b)



(a)

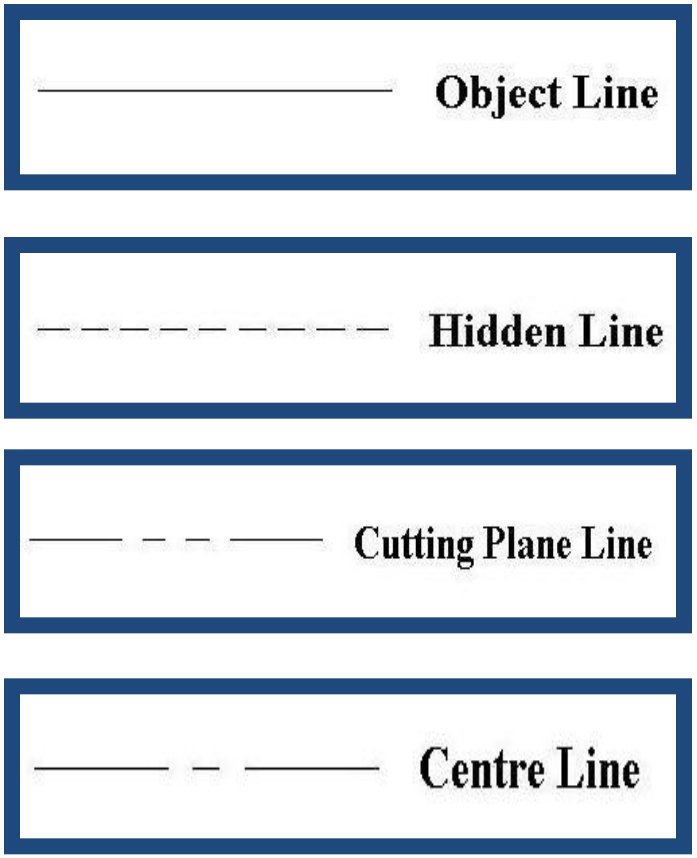
(b)

Orthographic Projection - Lines

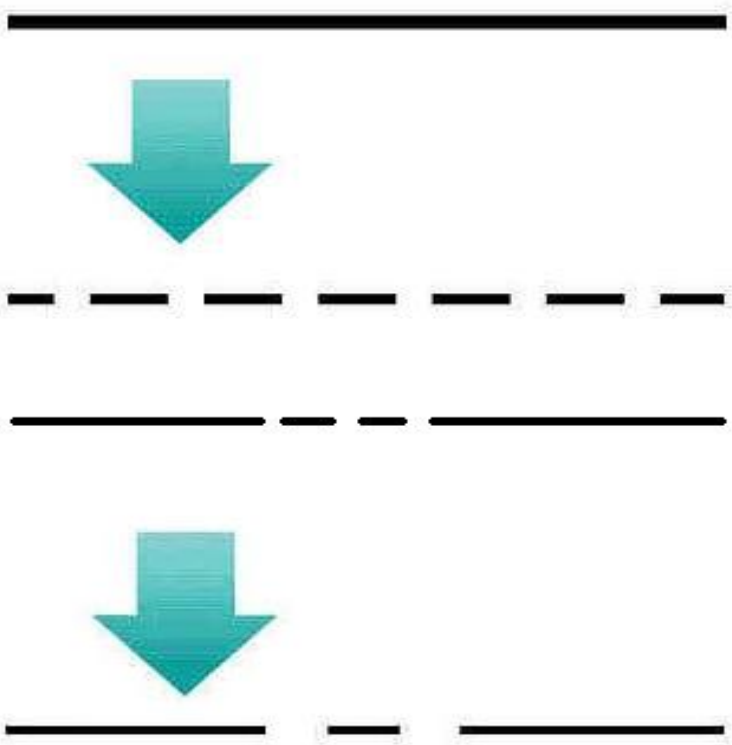
- When two or more lines coincide, there is a convention called ‘precedence of lines’ to establish which is visible
  - Visible object lines
  - Hidden lines and cutting plane lines
  - Centre lines
  - Extension & leader lines

Line Types

- **Object Lines:** indicate all visible edges of an object; must stand out and be apparent to the eye
- **Hidden Lines:** shows object lines that are hidden from view
- **Cutting Plane Lines:** indicates edge view of an imaginary cutting plane
  - Define section views
- **Centre Lines:** indicates centres of holes and symmetrical features of an object



Line Type Precedence



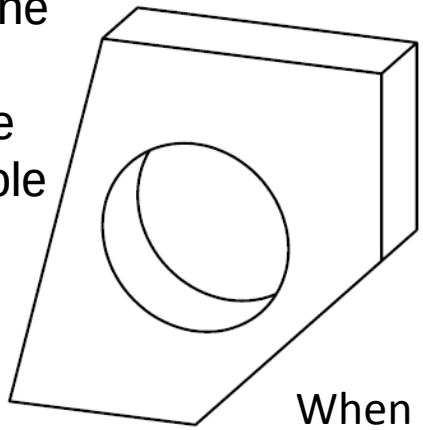
VISIBLE LINE takes precedence over all other lines

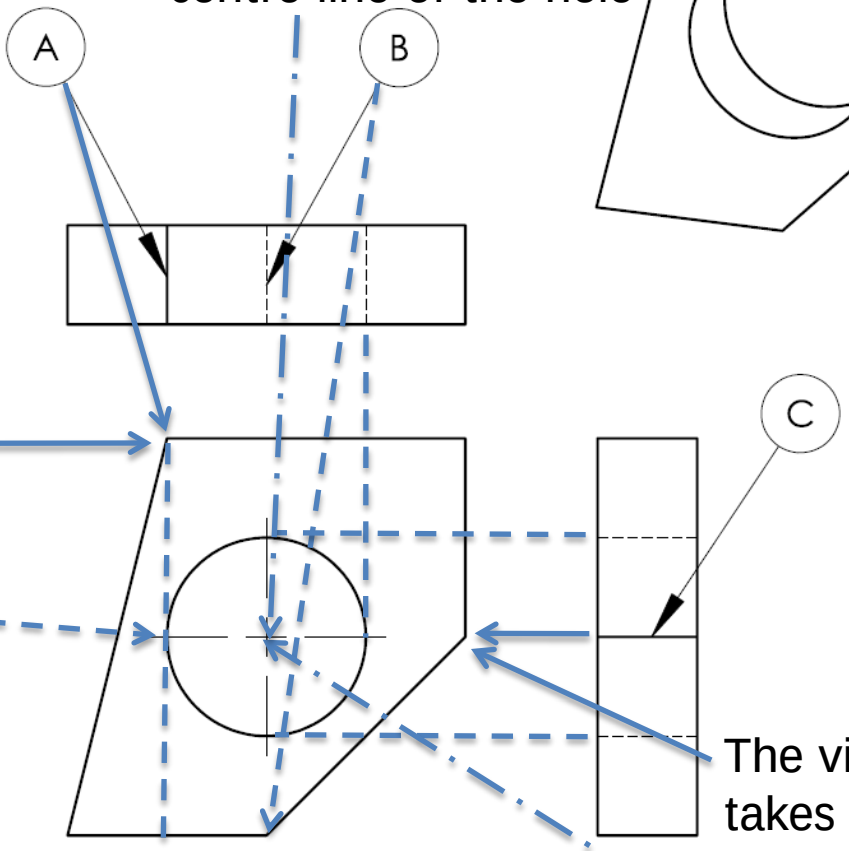
HIDDEN LINE
and
CUTTING PLANE LINE
take precedence over center lines

CENTER LINE does not have precedence

Orthographic Projection - Lines

The hidden line of the bottom edge takes precedence over the centre line of the hole





The visible line takes precedence over the hidden edge of the hole

When two or more lines coincide, there is a convention called 'precedence of lines' to establish which is visible

- Visible lines
- Hidden lines and cutting plane lines
- Centre lines
- Extension & leader lines

The visible line takes precedence over the centre line of the hole

An example showing the precedence of lines

Dimensions

- Two fundamental rules for dimensioning:
  - Dimensions must describe the complete geometry of the part
  - Redundant dimensions should be avoided
- More specific rules apply to the type of geometry and the placement, and style of the dimension

Dimensions

- Dimension from visible lines, not hidden features
- Repeated regular identical features may be dimensioned once along with a small note indicating quantity, etc ...
- The designer should locate dimensions in a way to indicate how tolerances accumulate

Dimensions – Example

- The repeated geometry of the holes is indicated by '2x'
- Figure (a) is incorrect.
- Figure (b) shows that the distance between the two holes is important
- Figure (c) shows that the distance from the centre of the right hole to the left edge is important

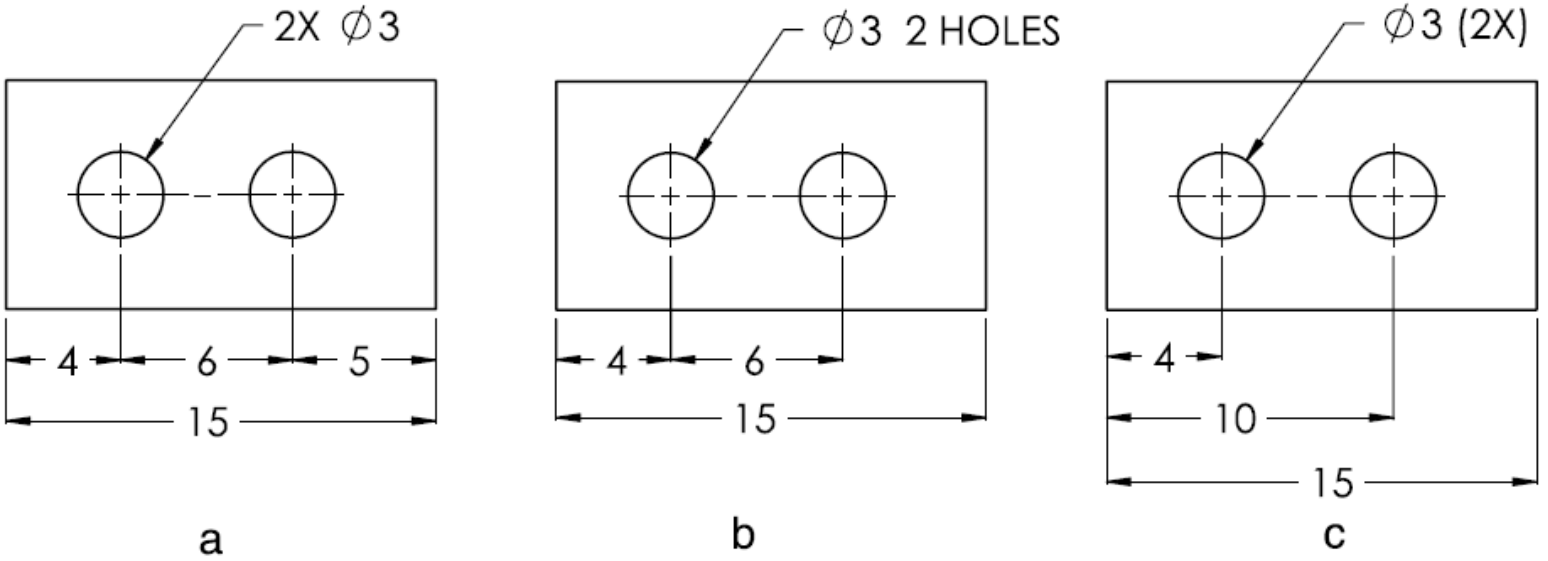


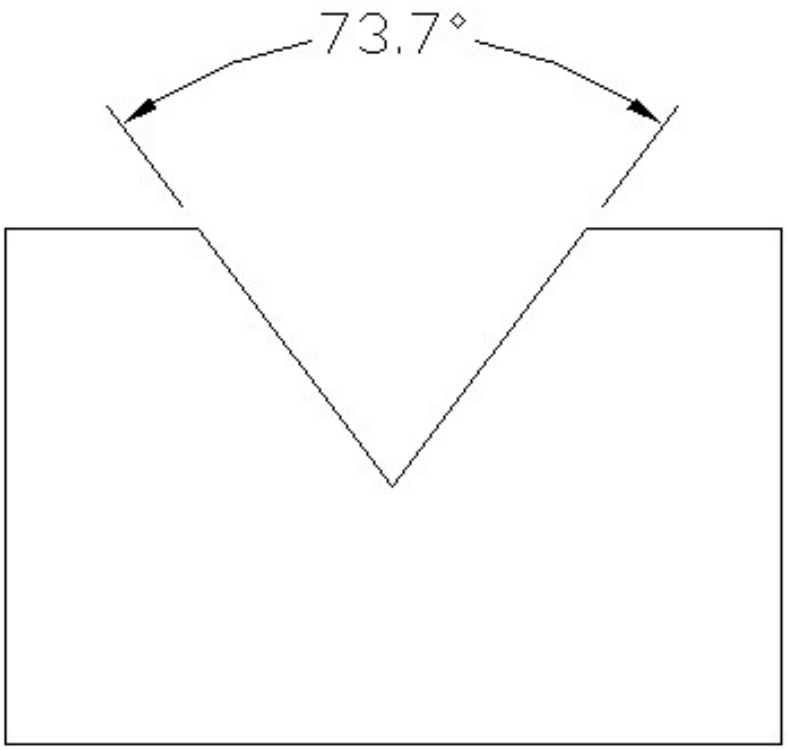
Figure 14.5 (a) An overdimensioned drawing; (b) A dimensioning scheme that emphasizes the 6-mm distance between the holes; (c) A dimensioning scheme that emphasizes the distance from the left edge to each hole.

Dimensions

- Circles and arcs (see previous example):
  - Radii are dimensioned using a leader line with an arrow at the end of the line
    - A capital “R” indicates radius
    - Dimension rounds and fillets with their radii
  - Similarly, a diameter has a leader line with an arrow
    - The symbol ∅ indicates diameter
    - Never dimension holes or cylinders with radii … use diameter
- Angles:
  - Fractional degree measurements can be represented with decimals or minutes and seconds
  - Dimension lines are drawn as arcs

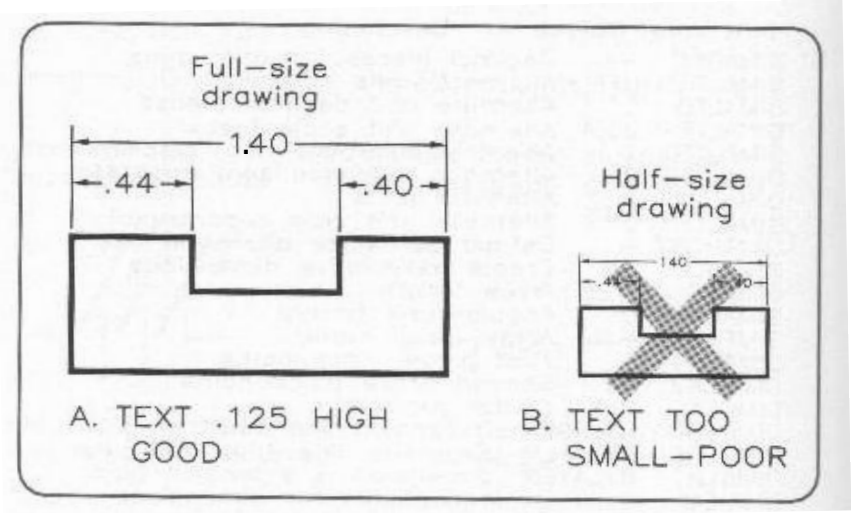
Dimensions

- Angle dimension example:



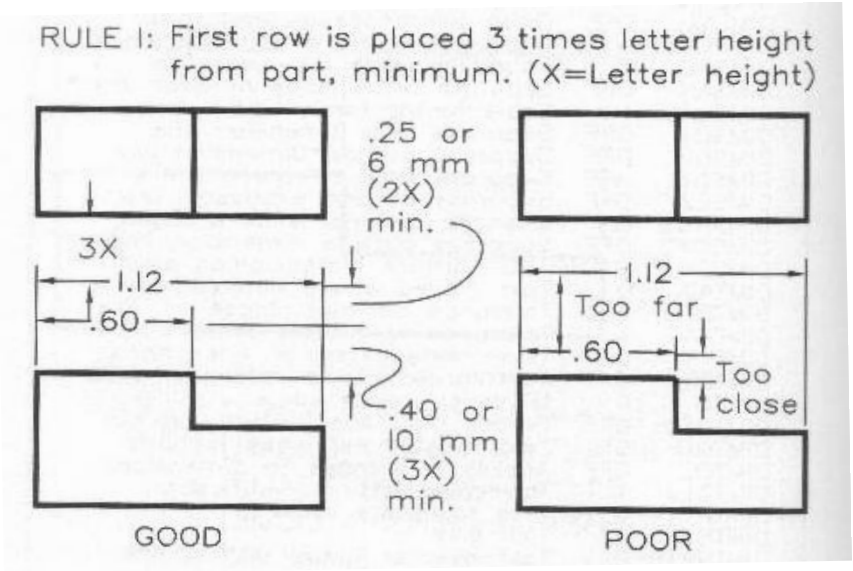
Dimensioning: Rule Zero

- When dimensioning a drawing, set the dimensioning variables so the text is readable when the drawing is printed in its final size
  - In IntelliCAD dimscale is the most useful command for scaling the dimension variables (text size, arrow head size, offsets, etc.)



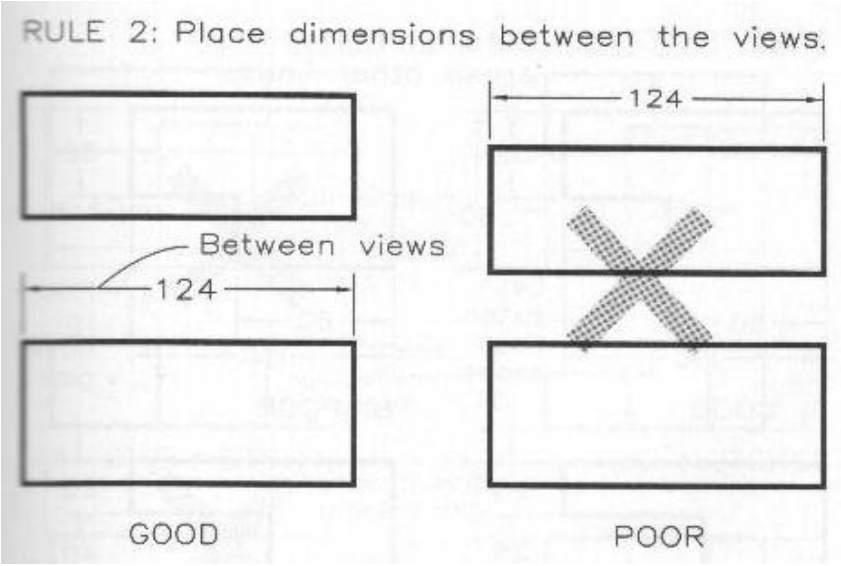
Dimensioning: Rule 1

- The first dimensions should be three times the letter height from the object
- Successive dimensions should be two times the letter height apart



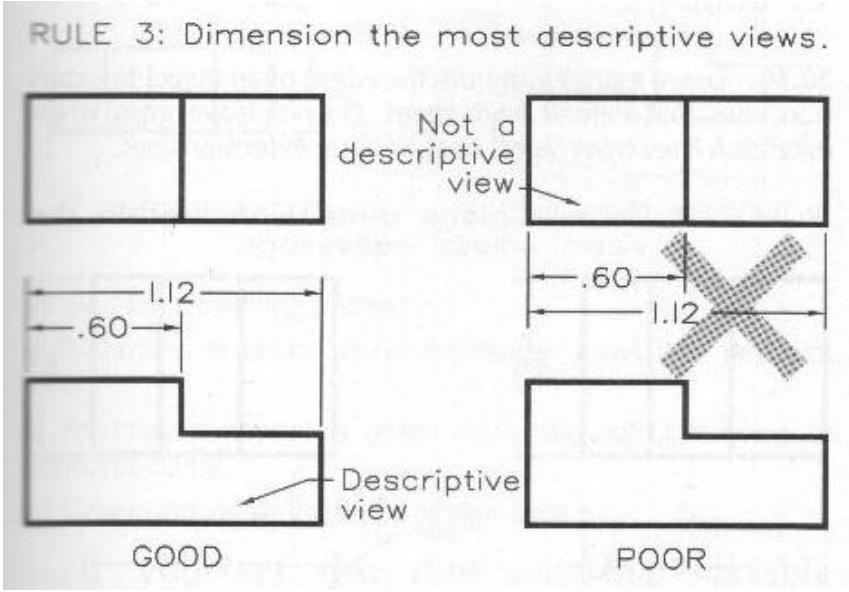
Dimensioning: Rule 2

- Place dimensions between the views sharing the same dimensions



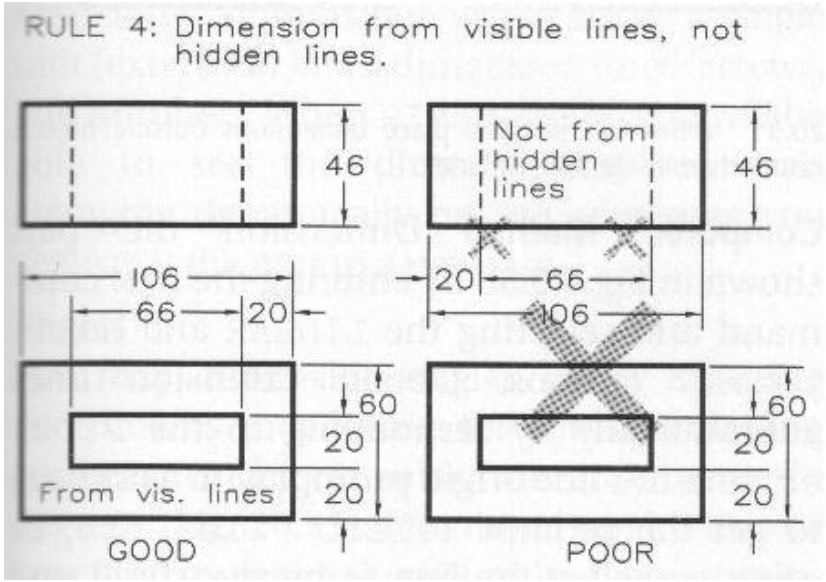
Dimensioning: Rule 3

- Dimension the most descriptive view



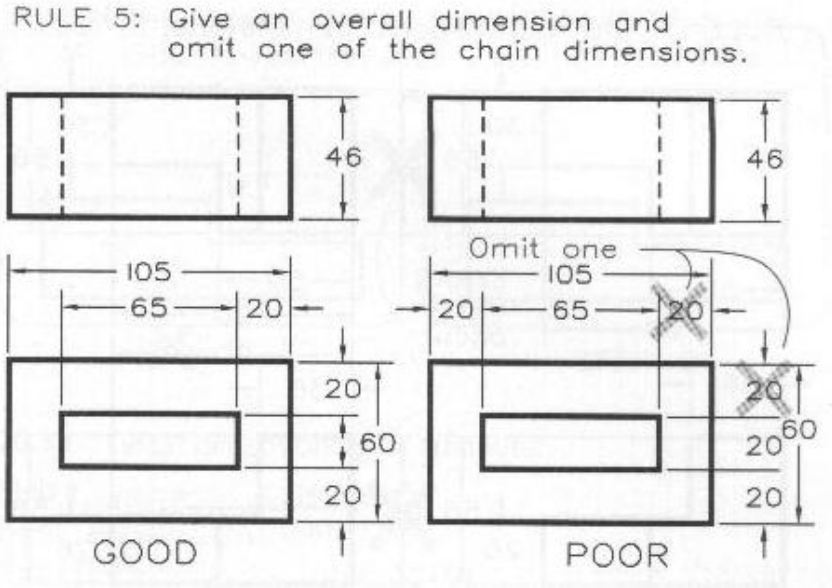
Dimensioning: Rule 4

- Dimension from visible, not hidden features



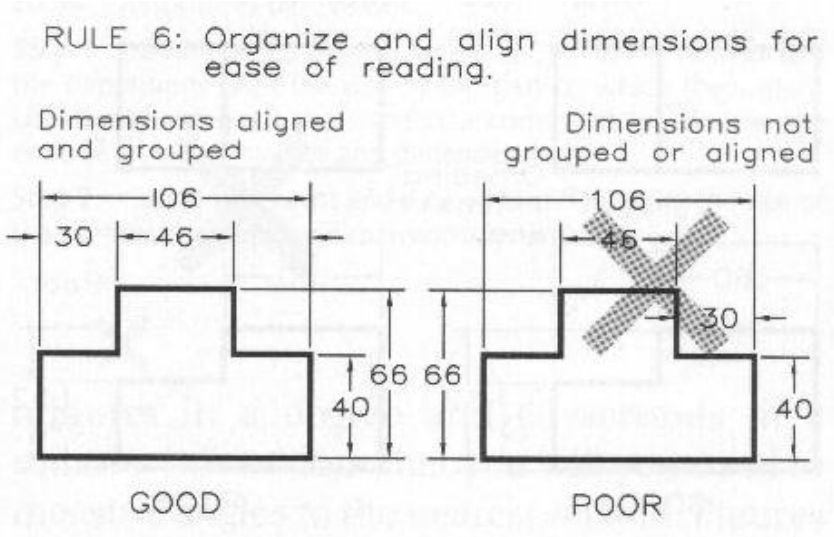
Dimensioning: Rule 5

- Give an overall dimension, omitting the last in a chain of dimensions



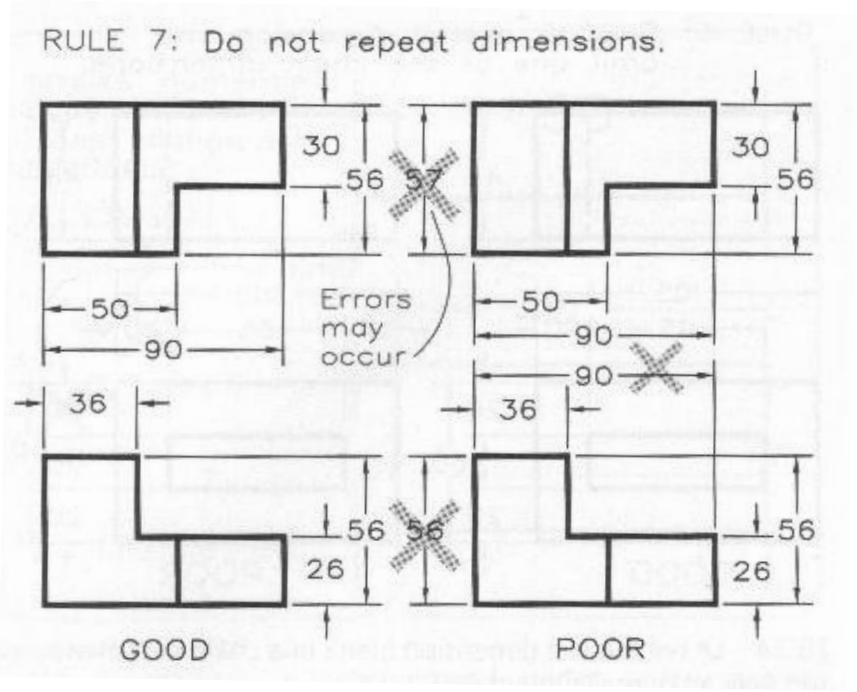
Dimensioning: Rule 6

- Organize the dimensions to reduce clutter in the drawing



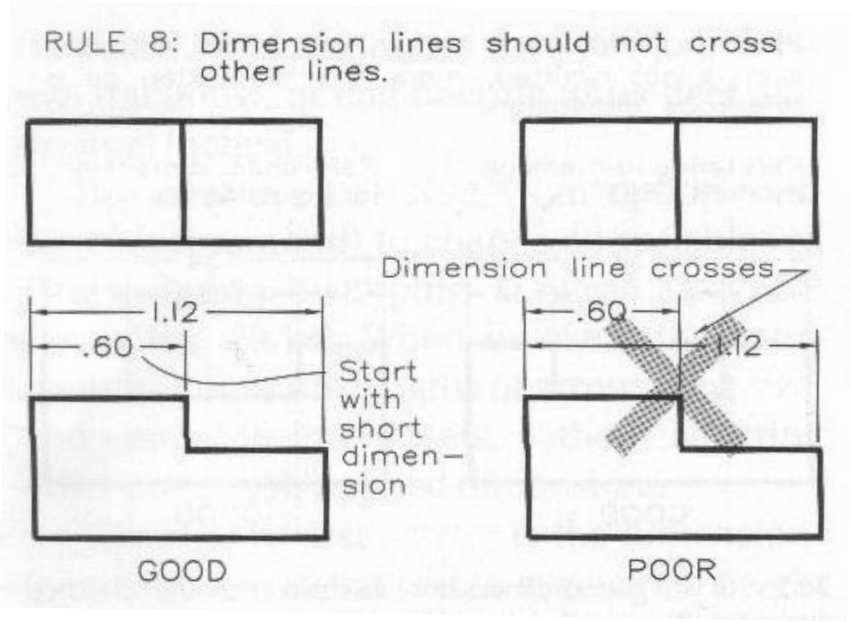
Dimensioning: Rule 7

- To avoid errors and confusion, do not duplicate dimensions



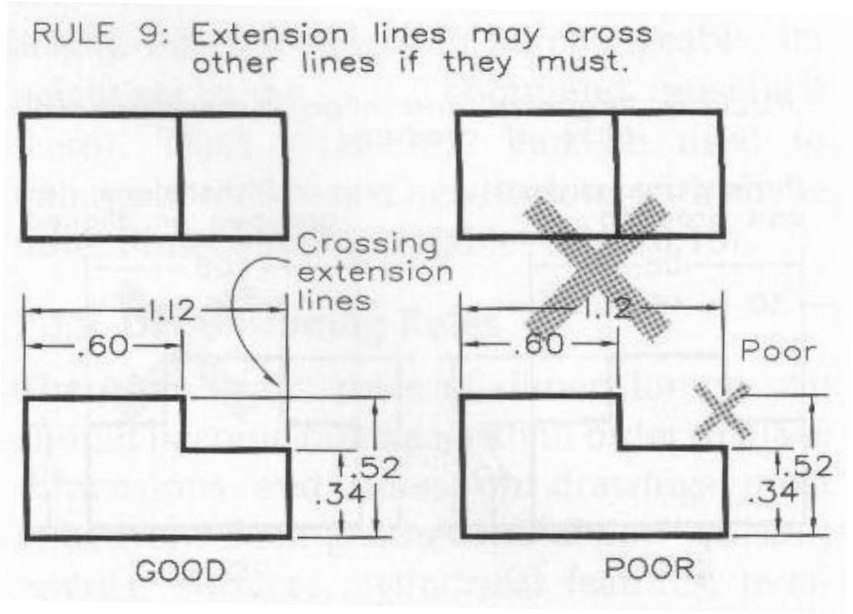
Dimensioning: Rule 8

- Dimension lines never cross any other lines, unless absolutely necessary



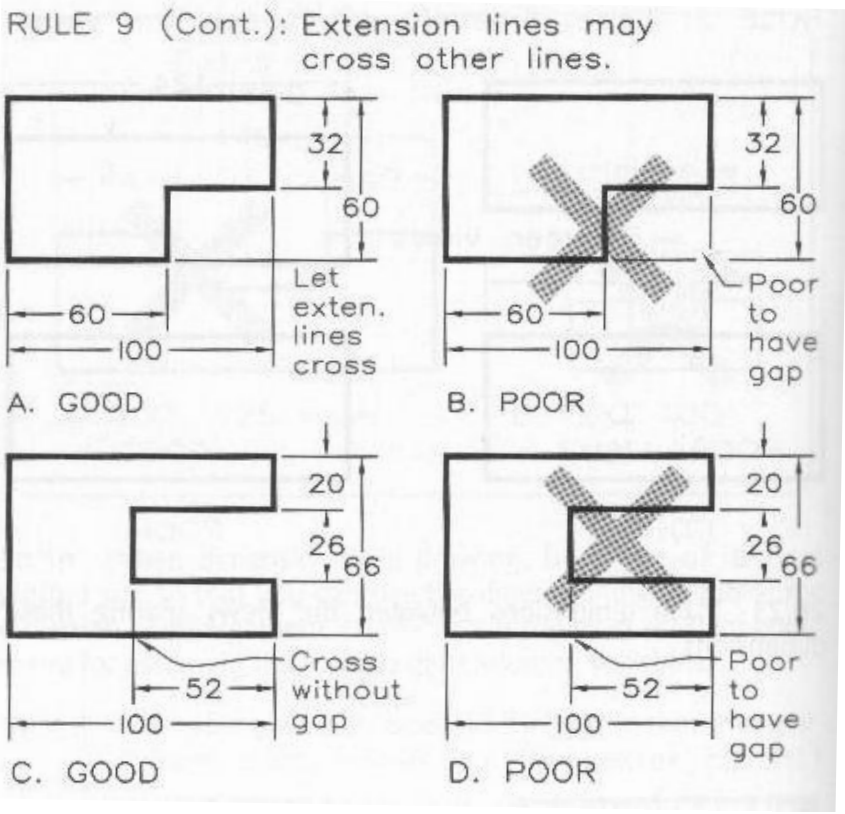
Dimensioning: Rule 9

- Extension lines may cross other extension lines, or object lines, if necessary
- Leave a small gap from the object to the lines that extend from them



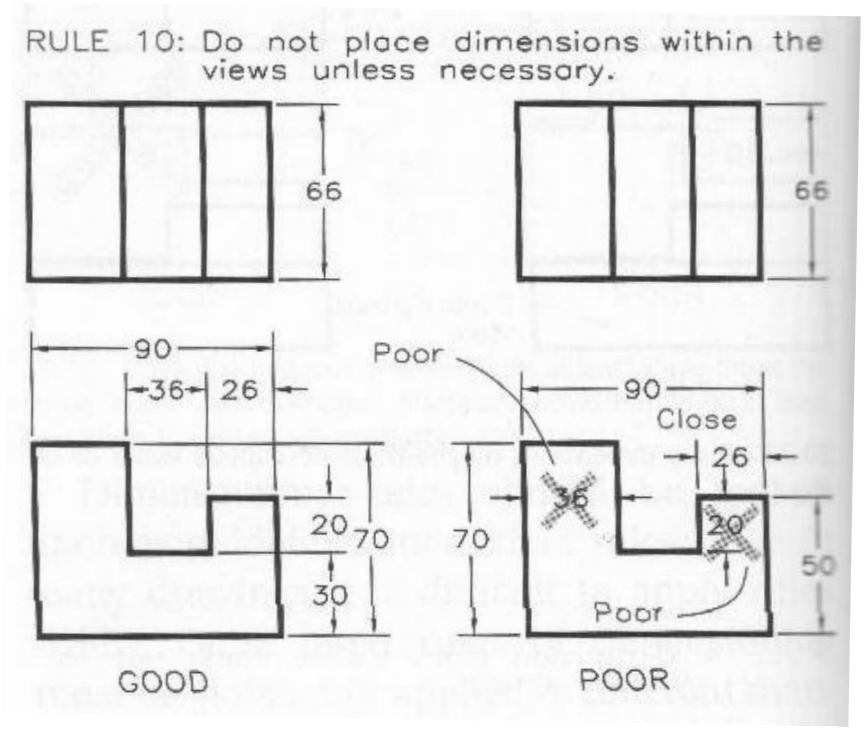
Dimensioning: Rule 9 (Cont)

- Do not leave gaps where extension lines cross object lines or other extension lines



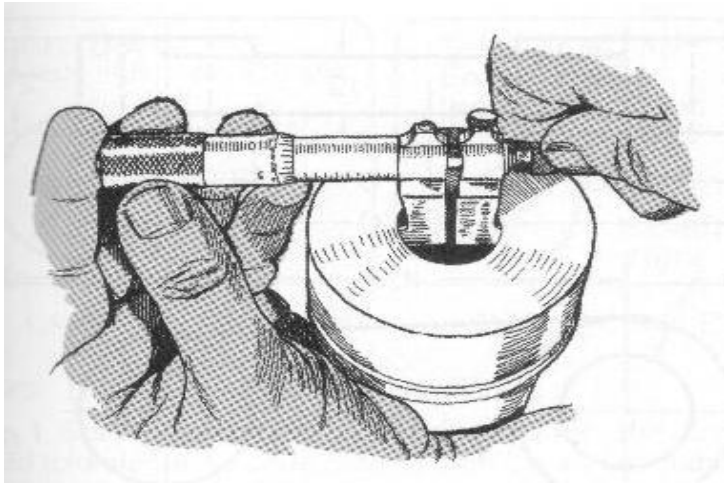
Dimensioning: Rule 10

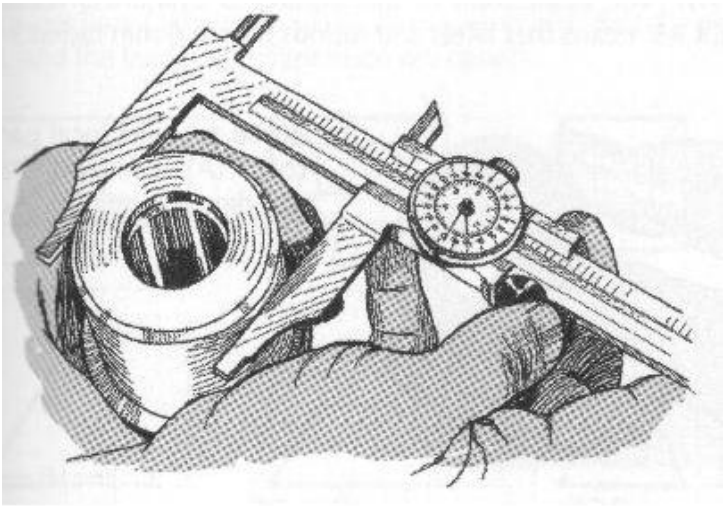
- Where possible place dimensions outside objects

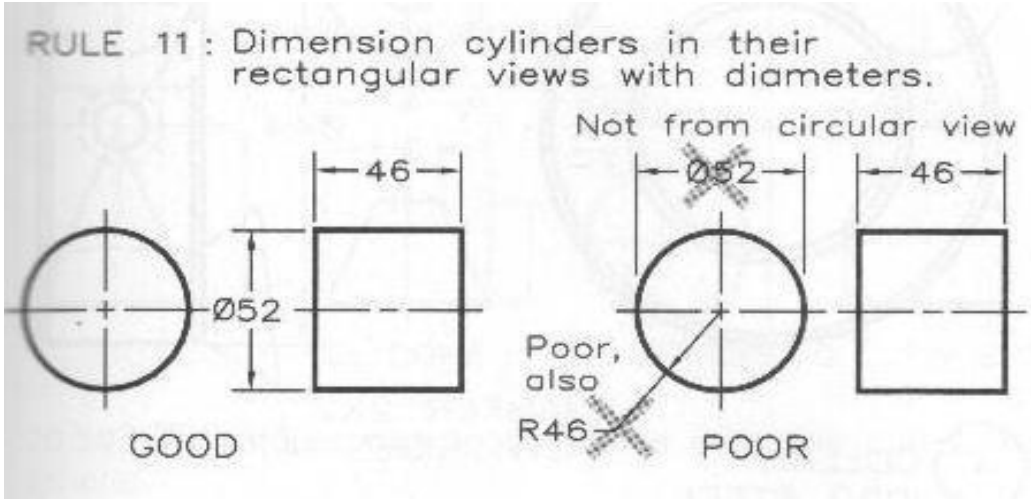


Dimensioning: Rule 11

- Dimension the diameter of cylinders in rectangular view
  - External calipers measure the diameter of a cylinder
  - Internal calipers measure the diameter of holes
- Radii cannot be measured

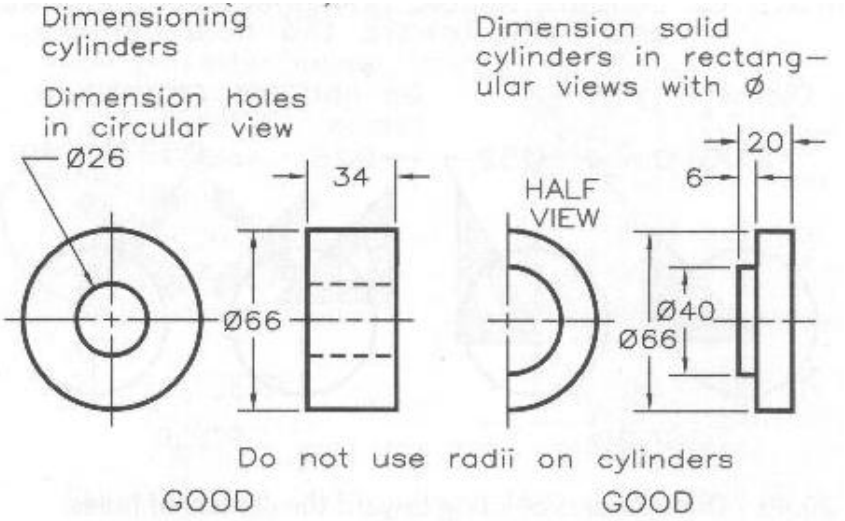






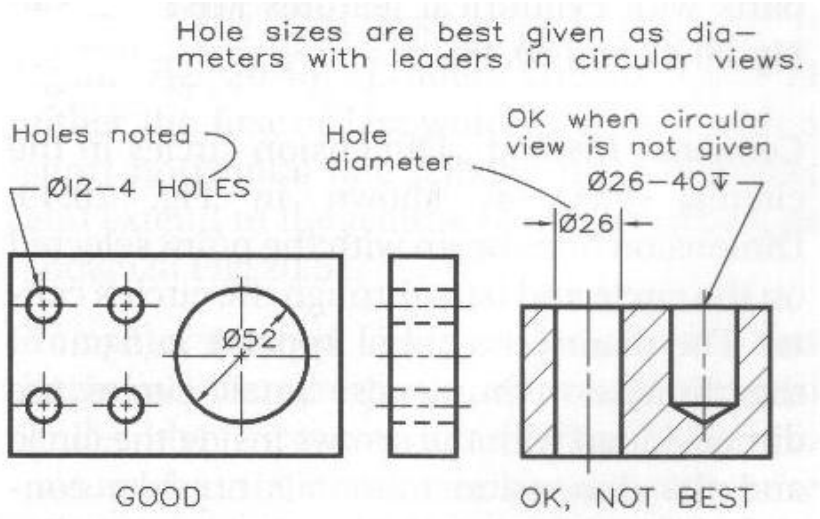
Dimensioning: Rule 12

- Dimension circular holes in the view where they look like holes

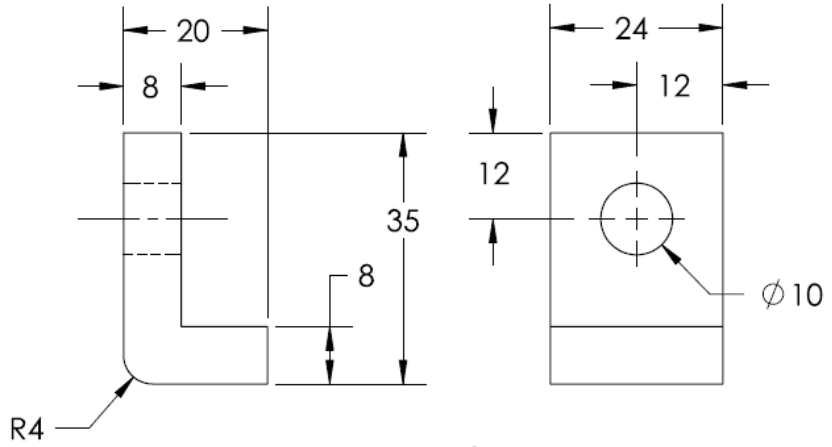


Dimensioning: Rule 12 (Cont)

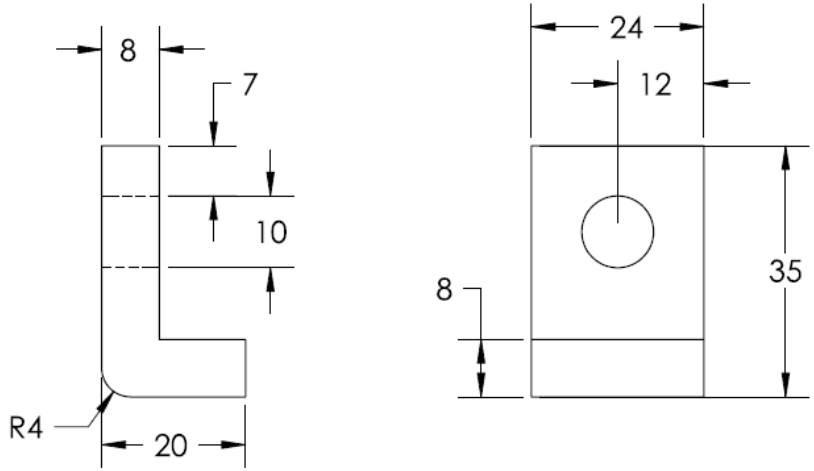
- Dimension circular holes in the view where they look like holes



Dimensioning - Example



correct



poorly dimensioned

Figure 14.7 Properly and improperly dimensioned drawings.

Orthographic Projection

- Advantages
  - Able to contain a high degree of detail
  - Angle and length measurements can be made on all views (exceptions do exist)
- Disadvantages
  - Effort is needed to interpret the object
  - Many conventions must be followed – not as easy as the other three

Drawing Layout Conventions

- Layout possibilities other than three-view exist for orthographic drawings
- Sometimes, only two views are necessary
- The same rules still apply to these projections
    - For example, the views must be aligned
- The designer must choose the best layout to convey the information in the most effective way possible

Orthographic – Section Views

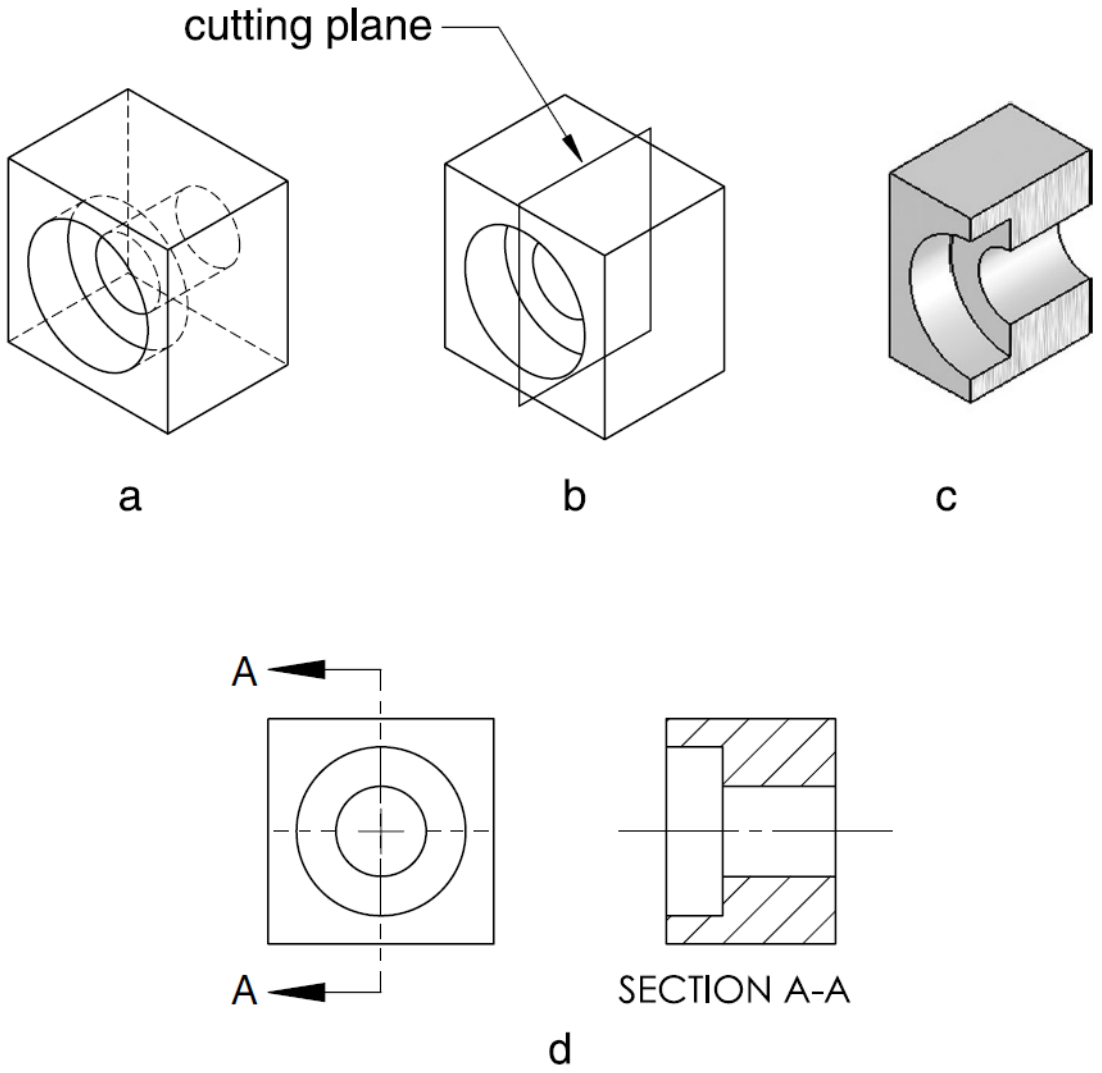
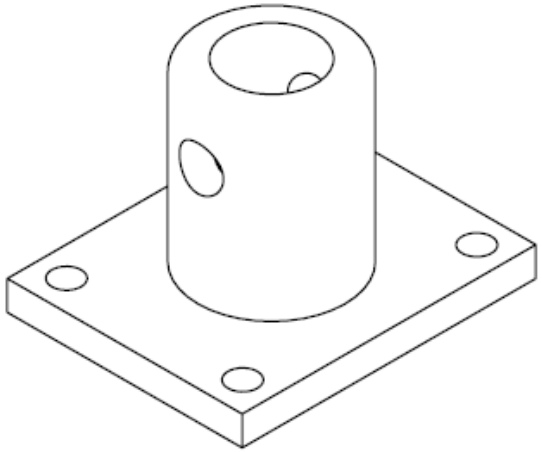
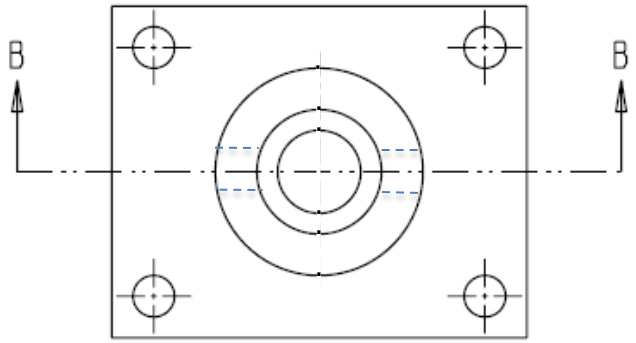
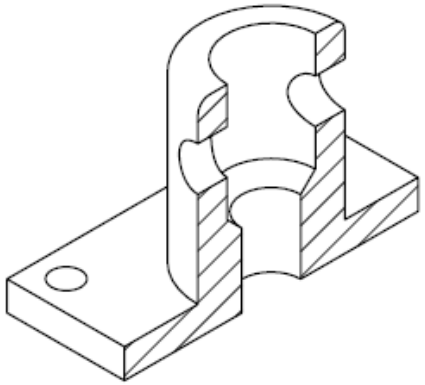


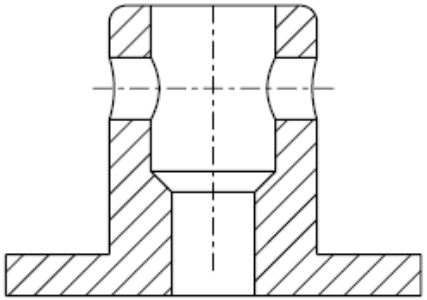
Figure 14.10 Creating a section view.

Orthographic – Section Views





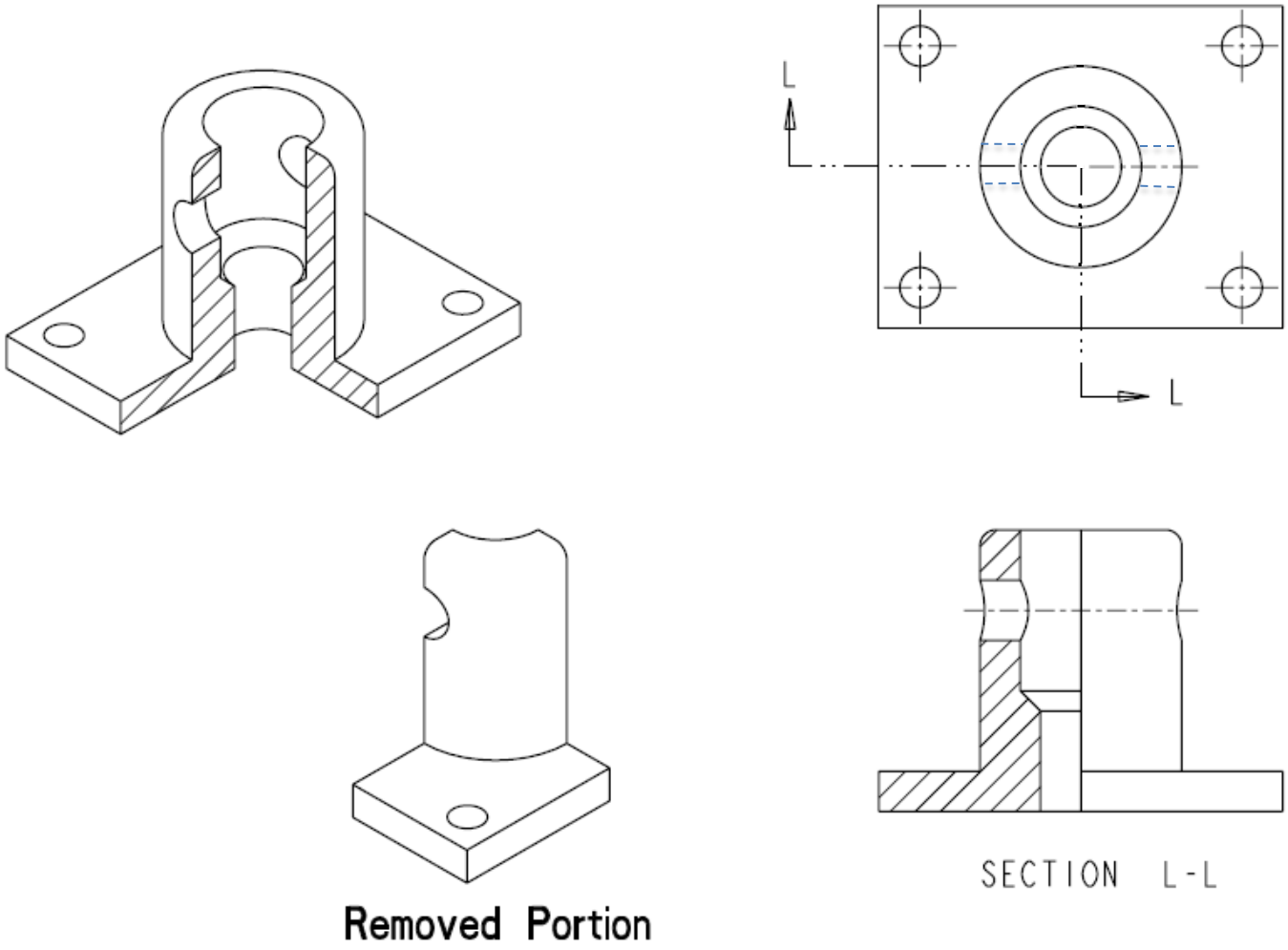




SECTION B-B

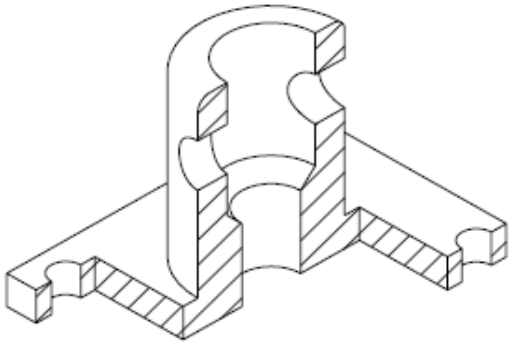
Corrected ***Figure 14.11*** The full section is the orthographic view at the lower right.

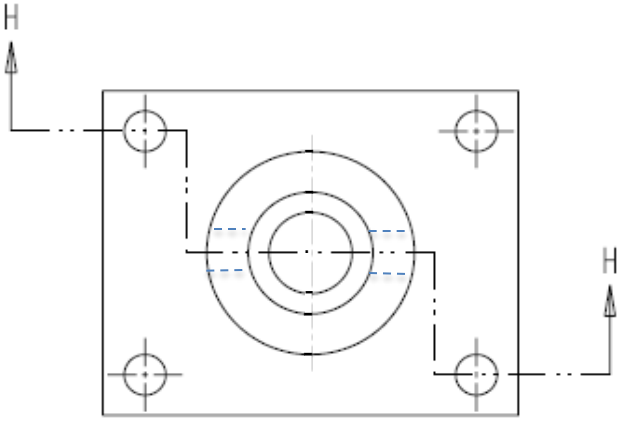
Orthographic – Section Views

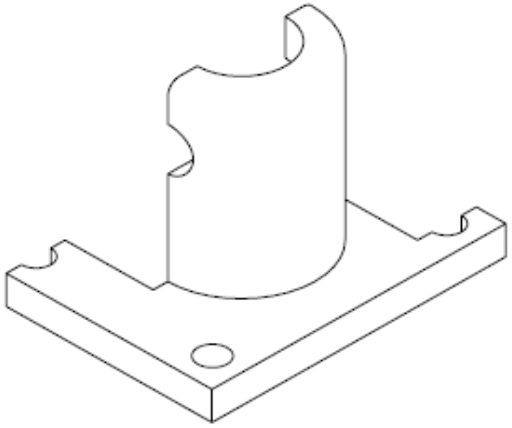


Corrected ***Figure 14.12*** The half section is the orthographic view at the lower right.

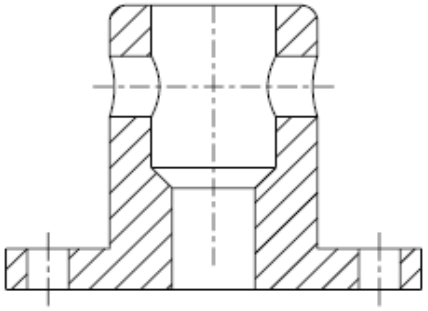
Orthographic – Section Views







Removed Portion



SECTION H-H

Corrected ***Figure 14.14*** The offset section is the orthographic view at the lower right. Note that the horizontal holes in the cylindrical upper portion of the part have curved edges in the section view due to the shape of the part, whereas the vertical holes in the flat flange at the bottom of the part have straight edges.

Orthographic – Section Views

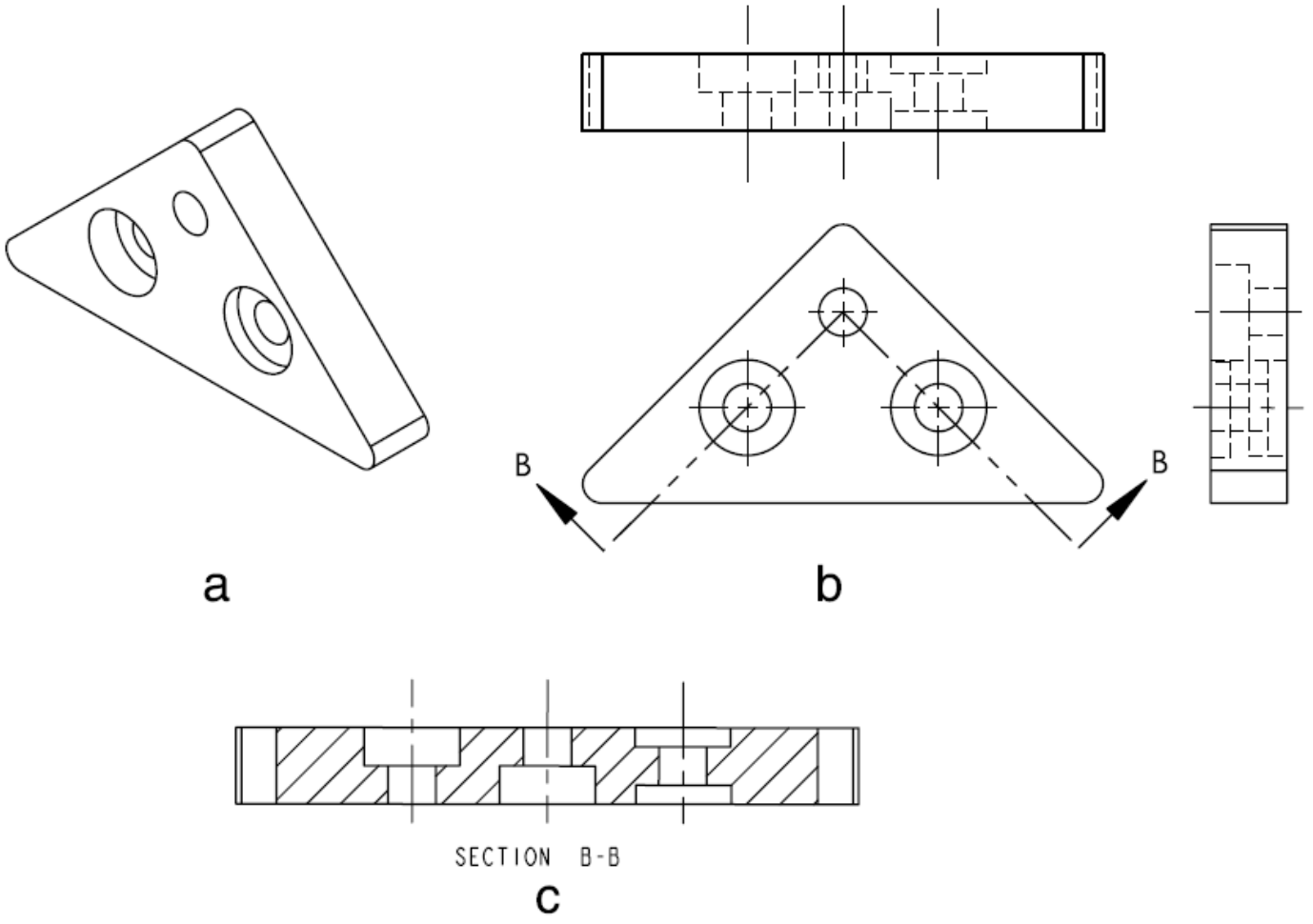
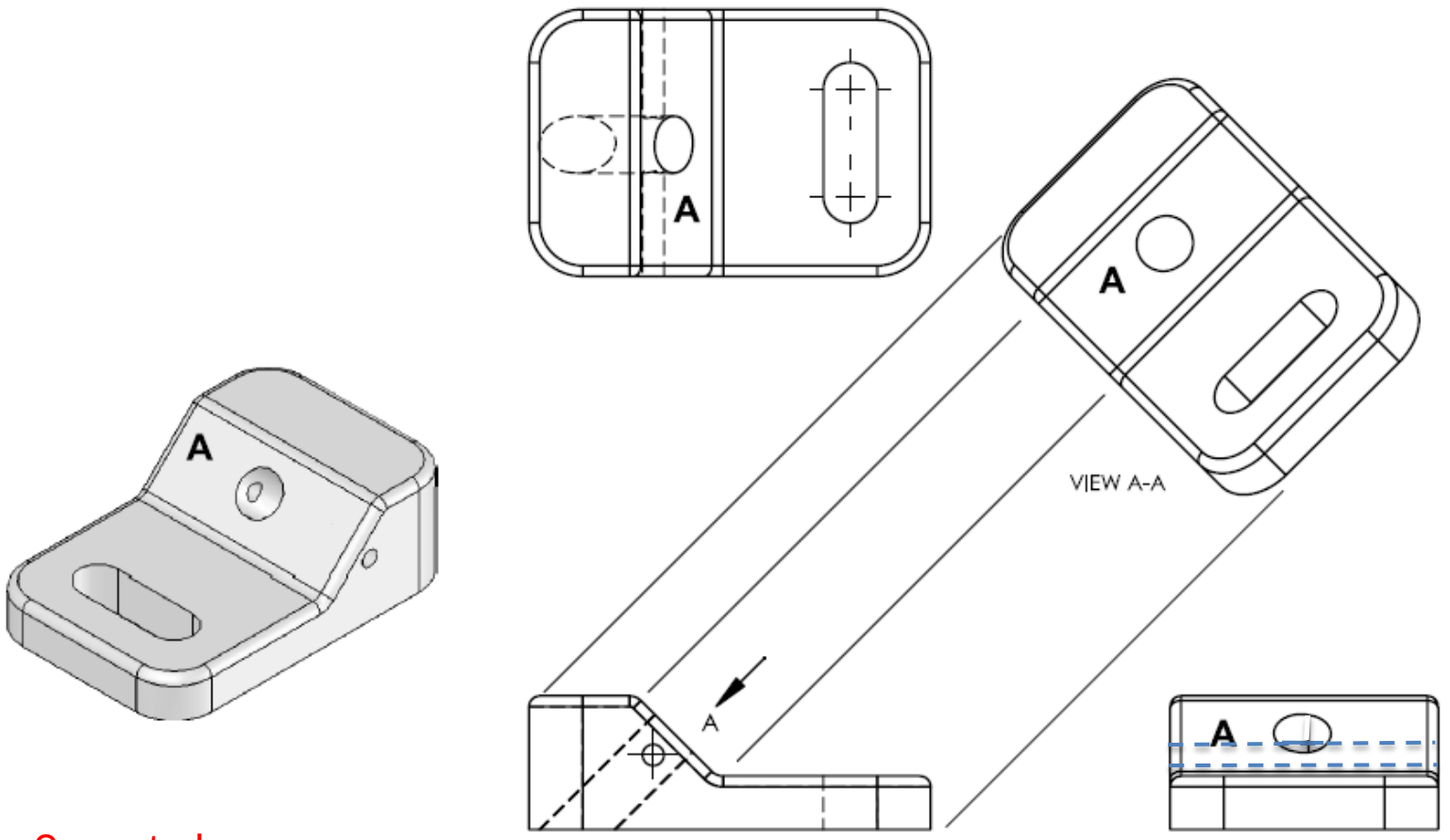


Figure 14.15 The aligned section is shown in (c).

Orthographic – Auxilary Views



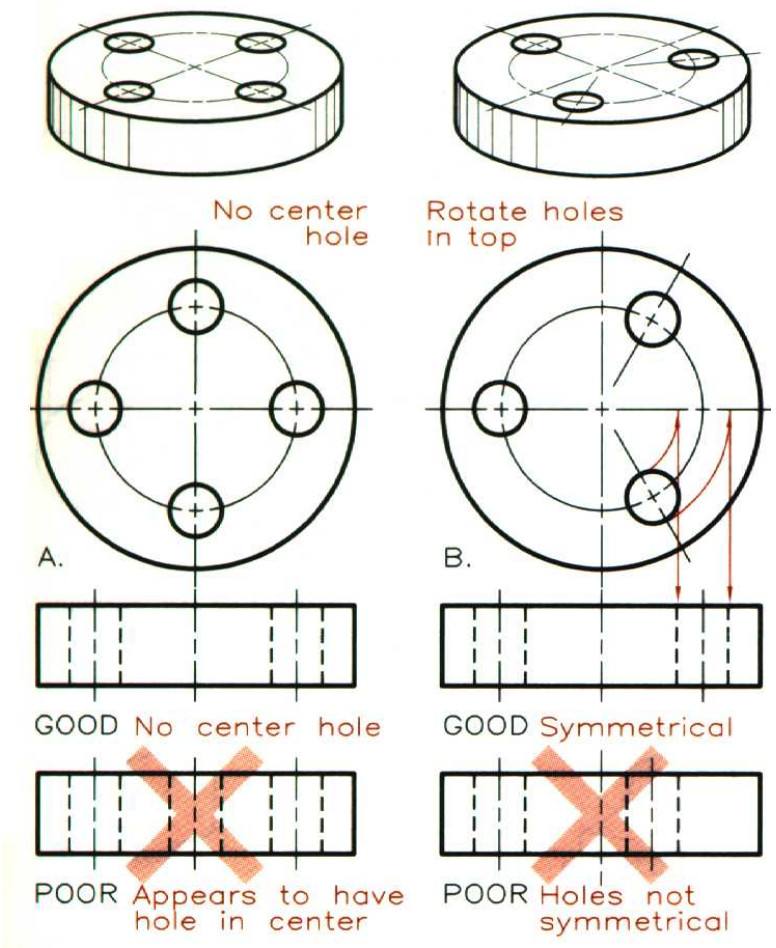
Corrected

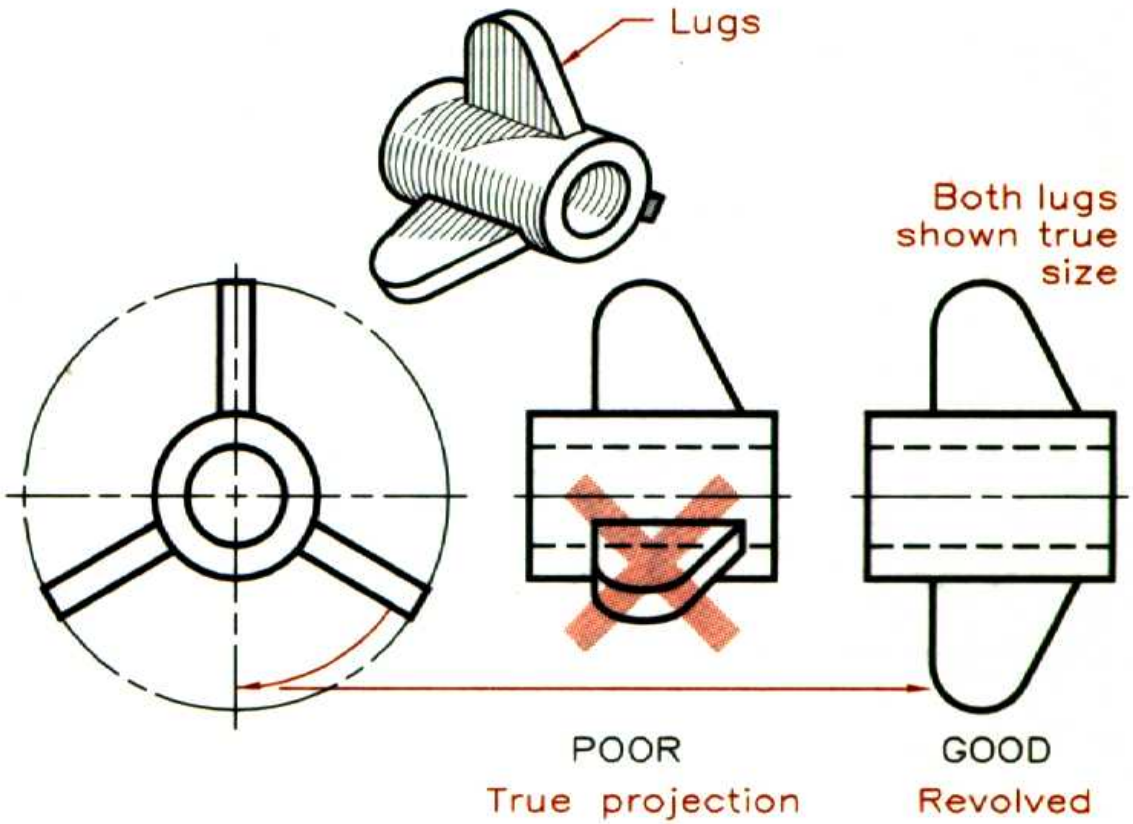
Figure 14.18 Auxiliary view of plane A. The labels A on the isometric projection and on the auxiliary and right views are not included on standard drawings.

Drawing Layout Conventions

- Sometimes, the rules of projection must be violated in order to improve clarity
- EXAMPLE: Symmetrically spaced holes on a circular plate:
  - In the front view, the holes are represented by hidden lines placed at the maximum radial distance from the centre of the plate
  - In the top view, the holes are placed where they physically exist

Drawing Layout Conventions





Drawing Layout Conventions

Applies to other symmetric features such as webs, ribs, and lugs

Orthographic – Threads

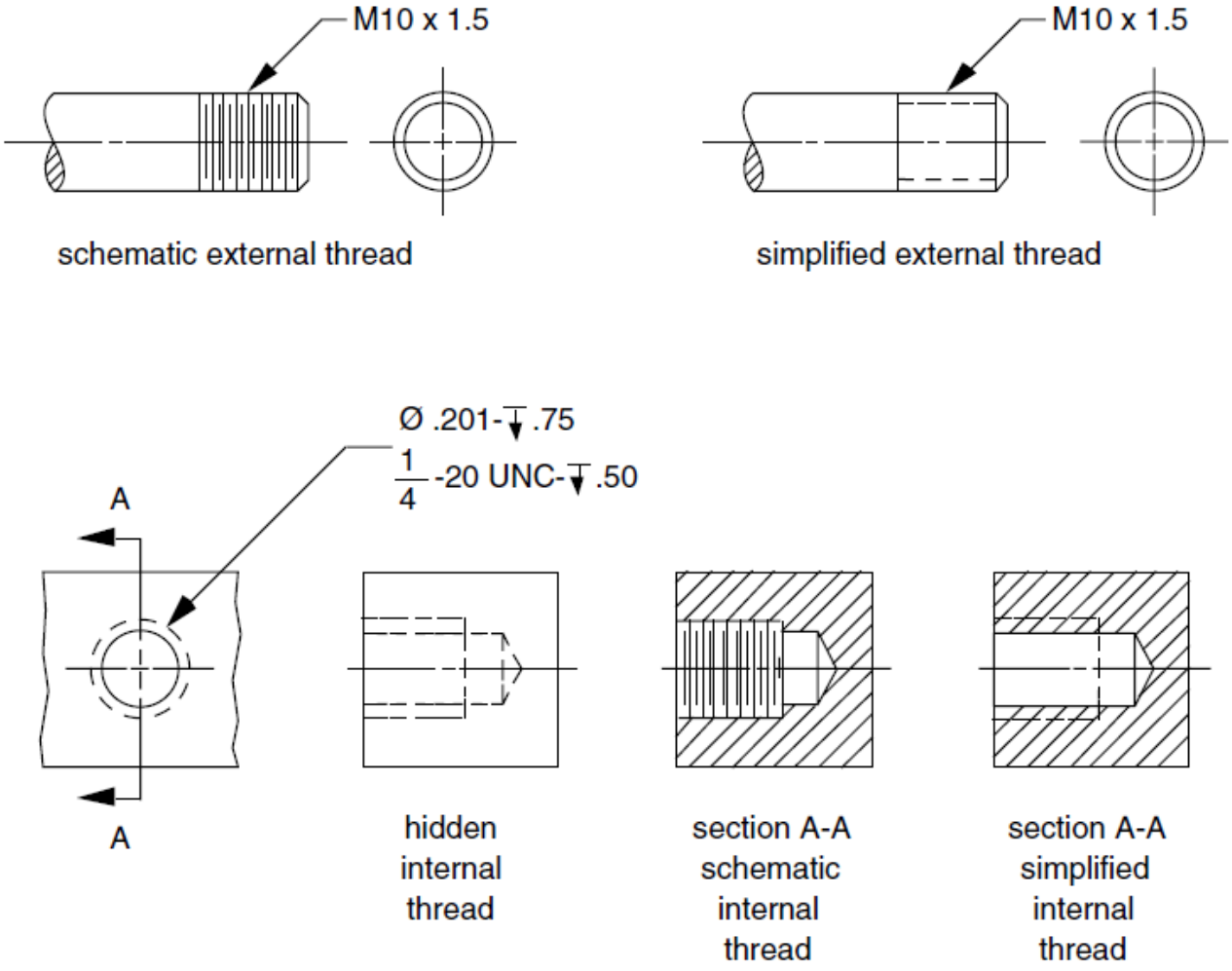
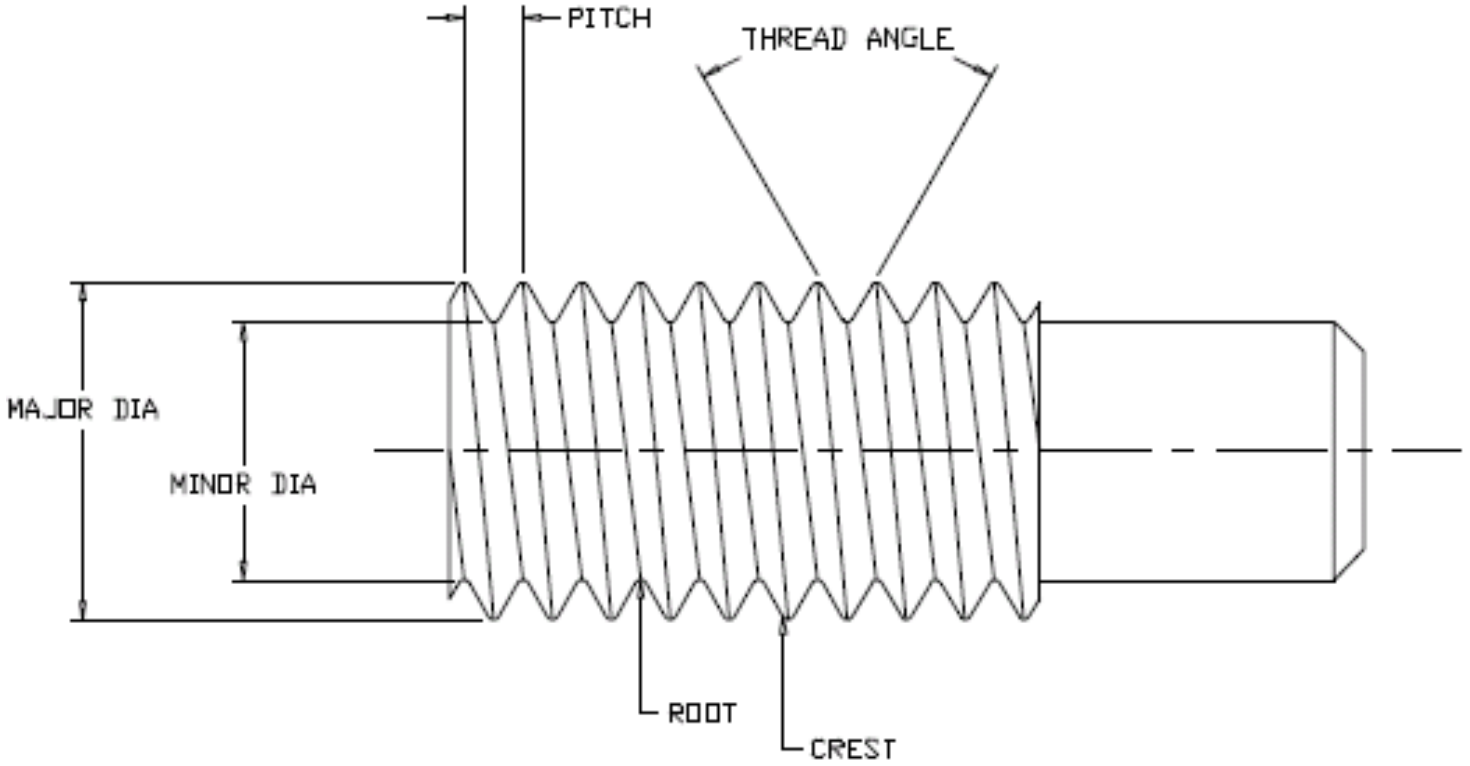
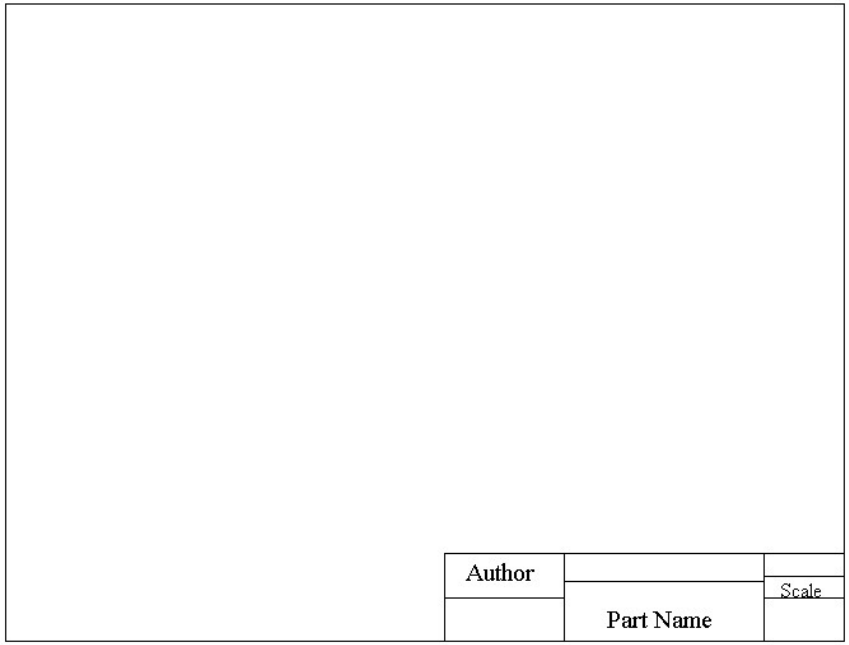


Figure 14.21 Conventions to show screw threads.


PITCH
THREAD ANGLE
MAJOR DIA
MINOR DIA
ROOT
CREST

Orthographic – Title Block

- Contains important information about the drawing such as the part name and number, the person who made it and the scale used
  - Usually located in the lower right corner of the drawing
  - All working drawings have a title block!



Orthographic – Title Block

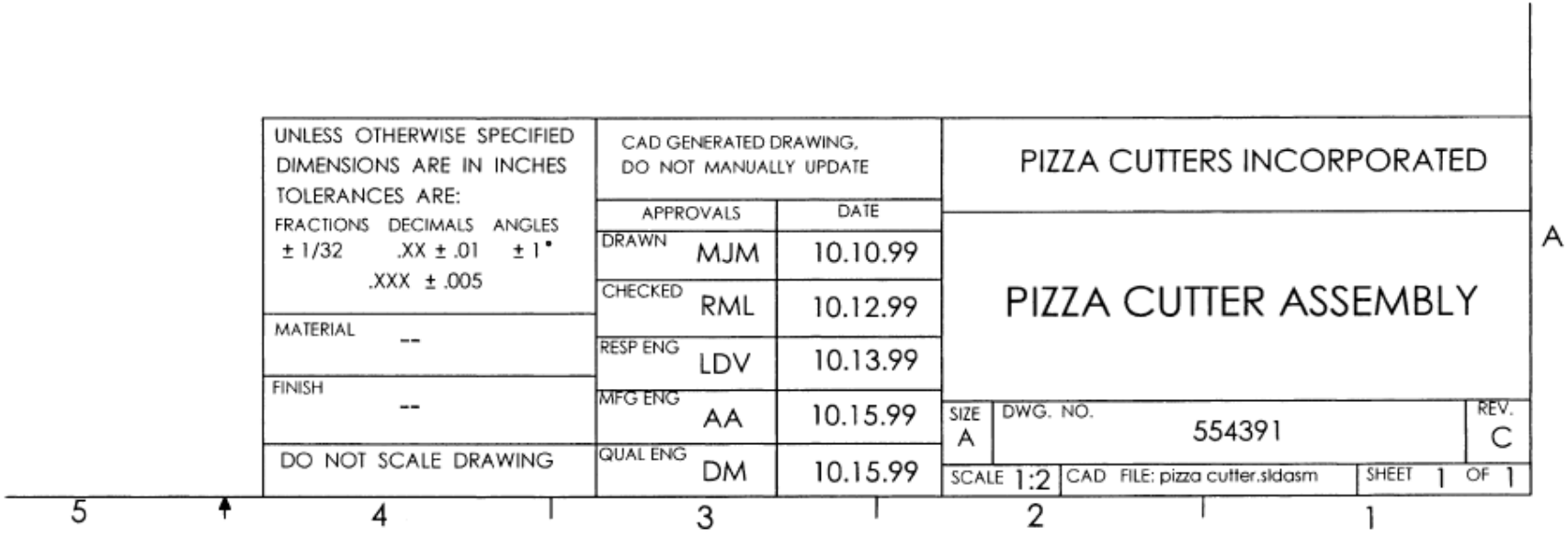
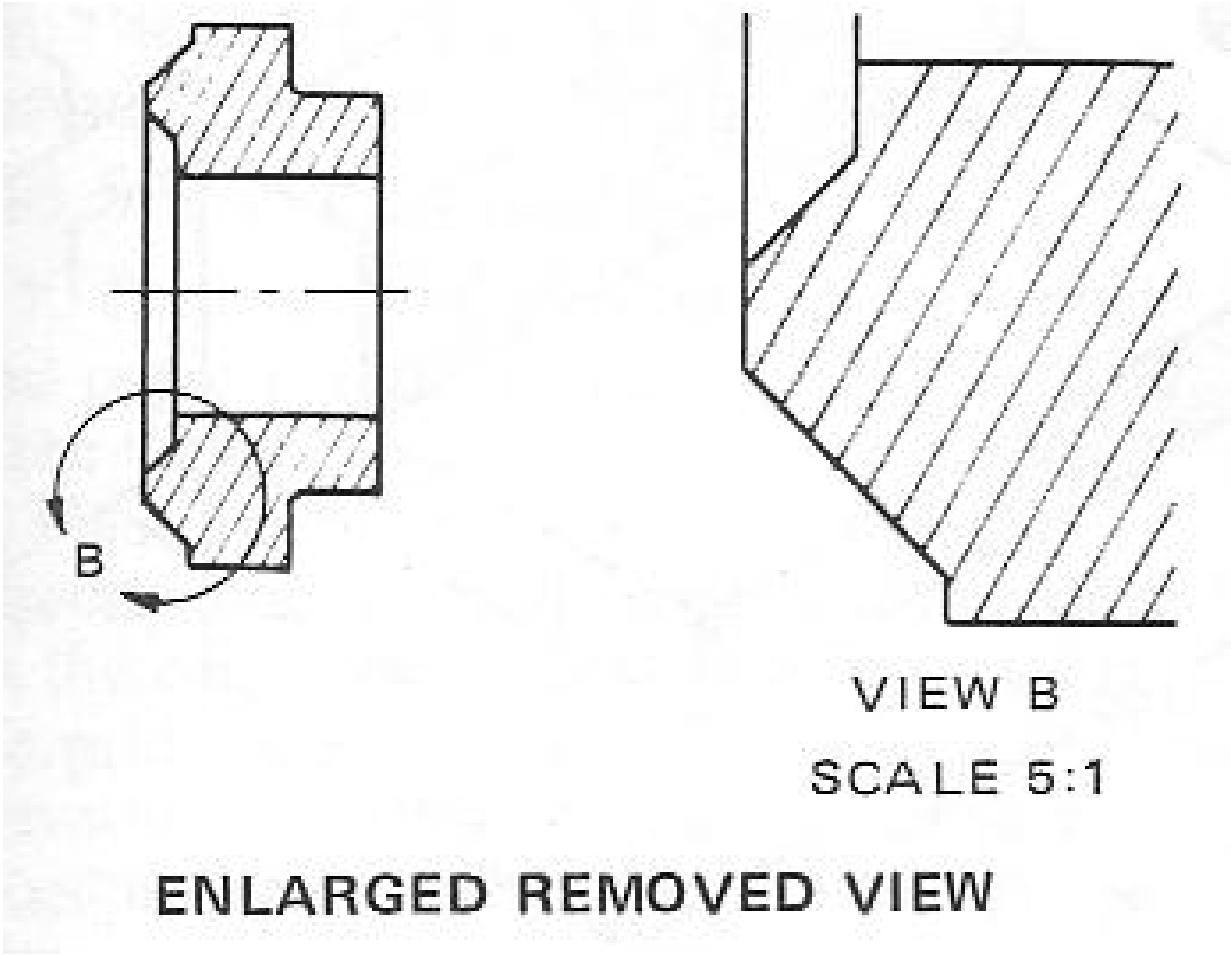
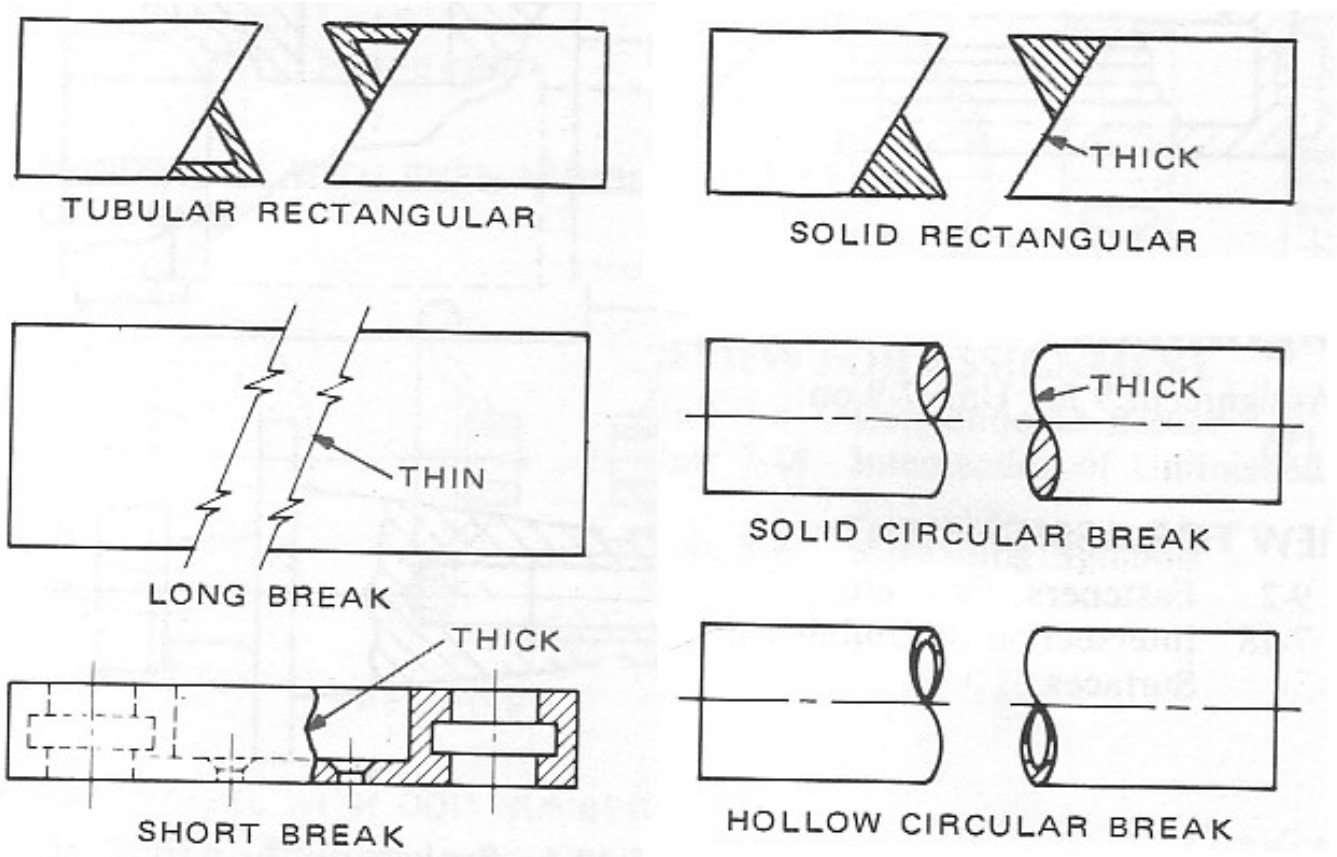


Figure 14.2 A typical title block.

Special Drawing Conventions



Special Drawing Conventions



Conventional breaks.

Orthographic – Example - 2

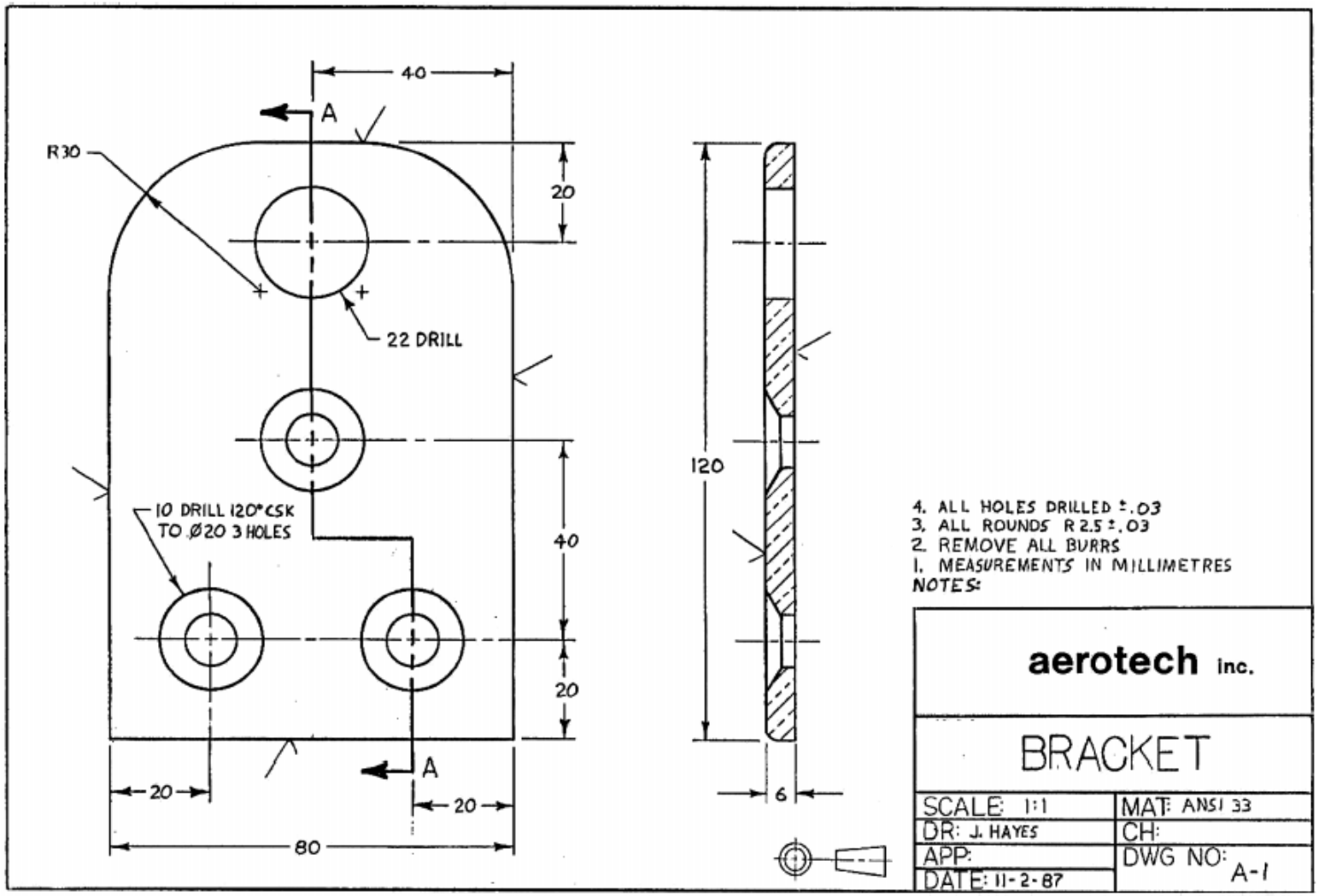


Figure 12.21 Working drawing for a bearing bracket.

Orthographic – Example - 3

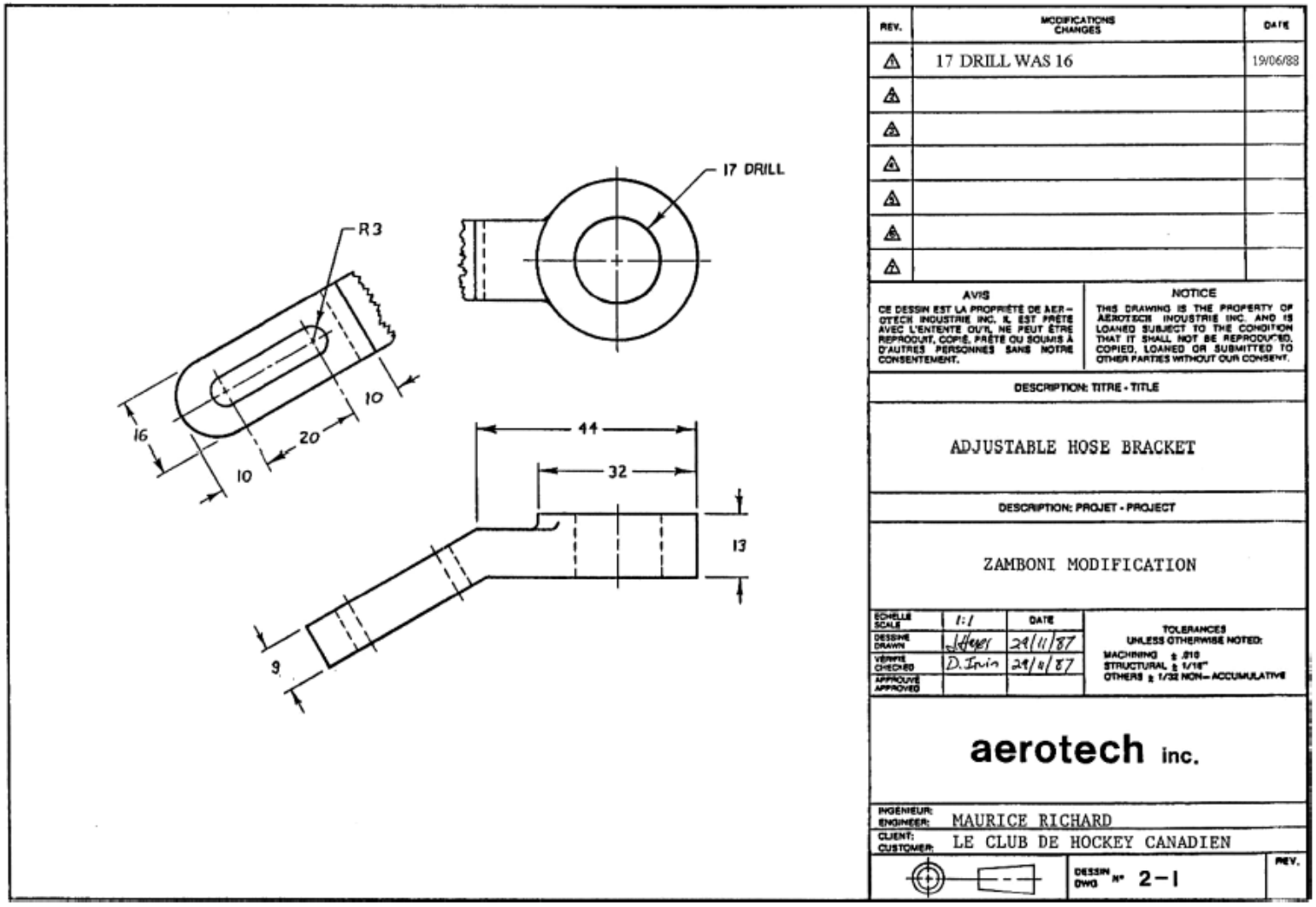
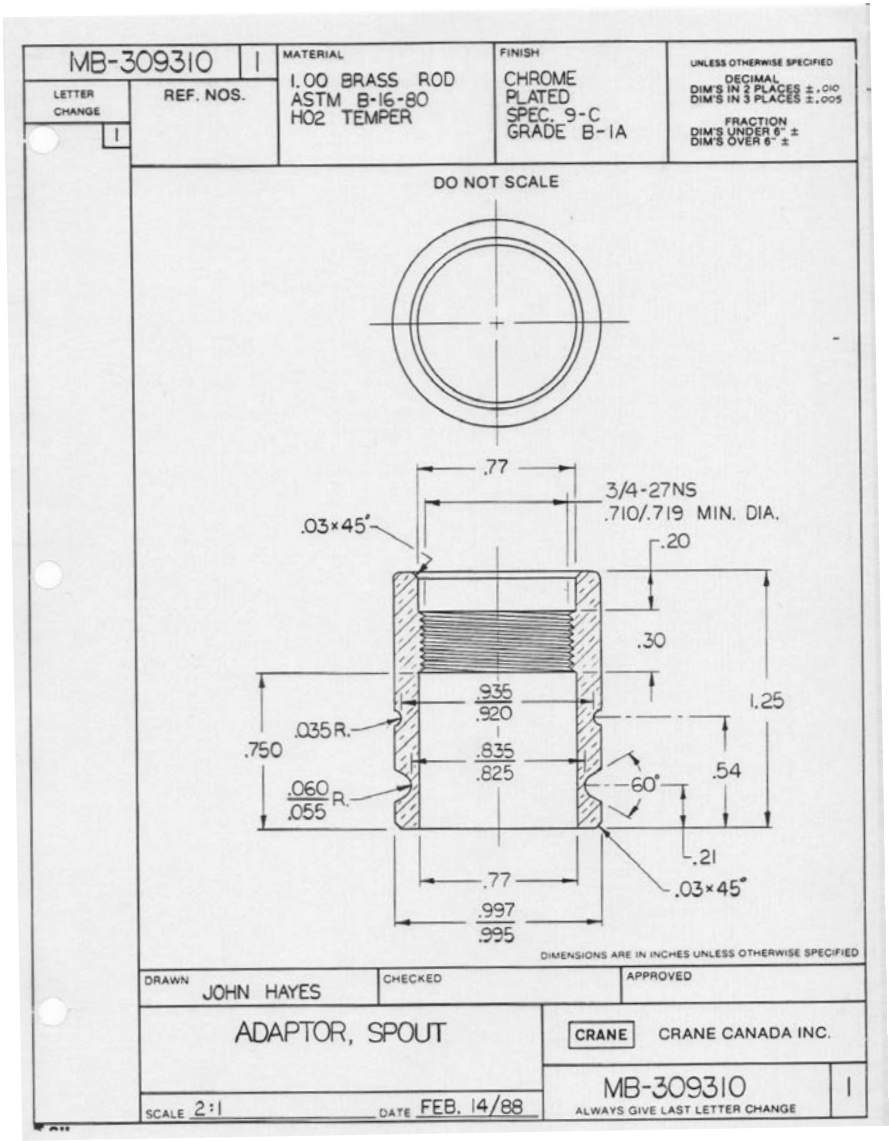
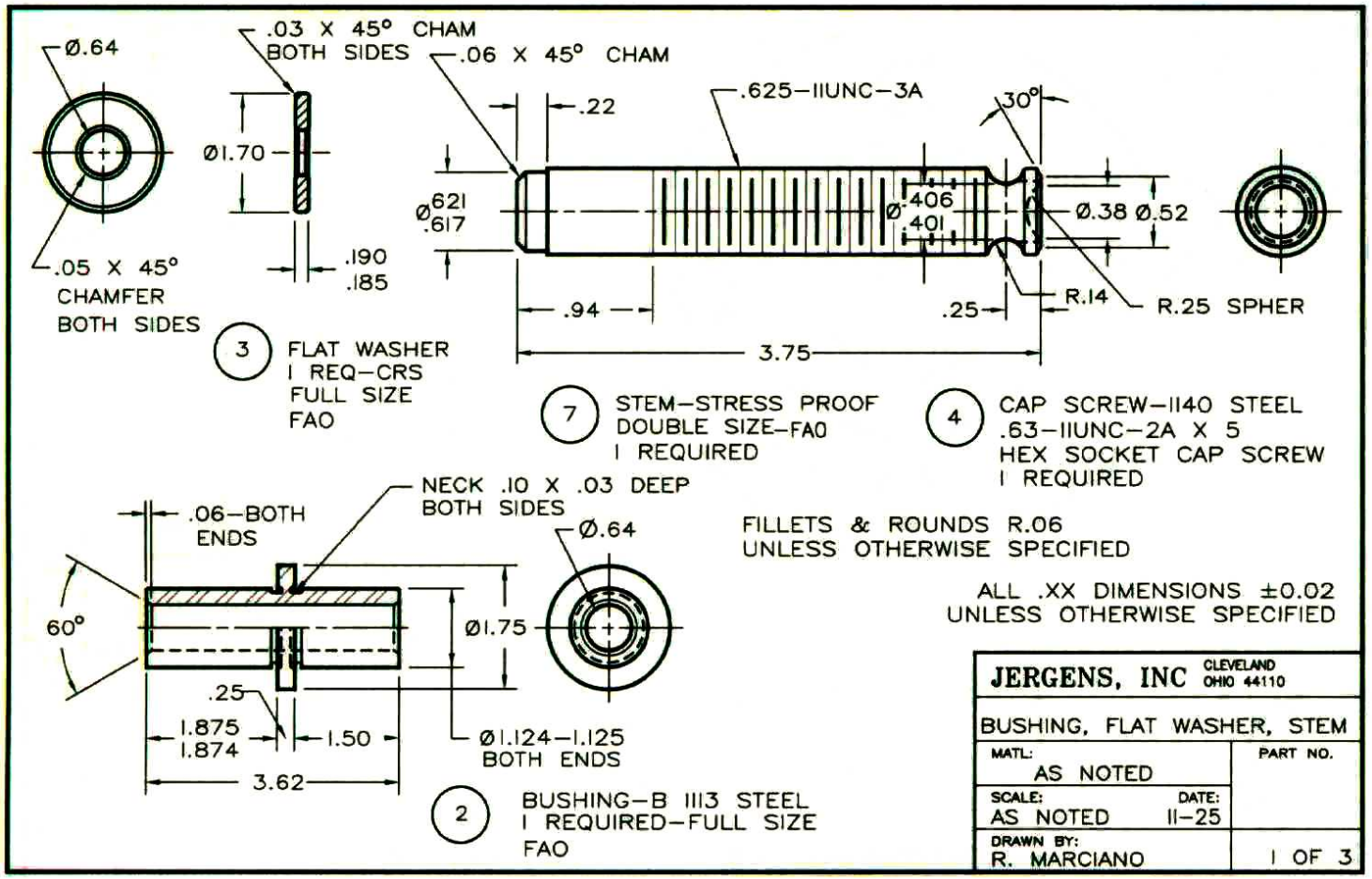


Figure 12.22 Working drawing with an auxiliary view and a revision block.

Orthographic – Example - 4



Orthographic – Example - 5



Reading Assignment

- Have you read Chapters 12 & 14 ?
- Read Chapter 13

ECOR 1010
Lecture 7

Engineering Graphics - 3

Engineering Graphics

- Engineering graphics has evolved into six major areas, which overlap:
  - Descriptive Geometry (Engineering Drawing, as shown previously)
  - **Graphical Mathematics**
  - **Nomography**
  - **Empirical Equations**
  - Technical Illustration
    - in manuals, etc. used to communicate an idea, not necessarily technically exact.
  - **Engineering Computer Graphics: CAD**

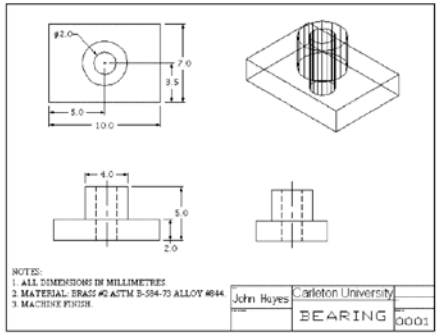
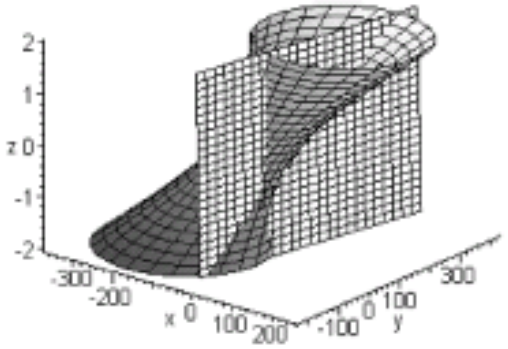


Figure 12.17 A Three-view working (detail) drawing.

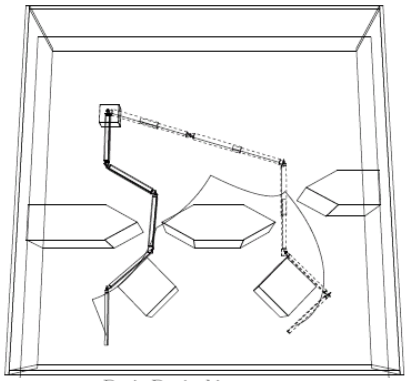
An important example of effective graphical communication.

Graphical Mathematics

We may wish to find the intersection of all the possible positions a robot arm can have and a space in which it will operate.



Intersection between a plane and an hyperboloid.



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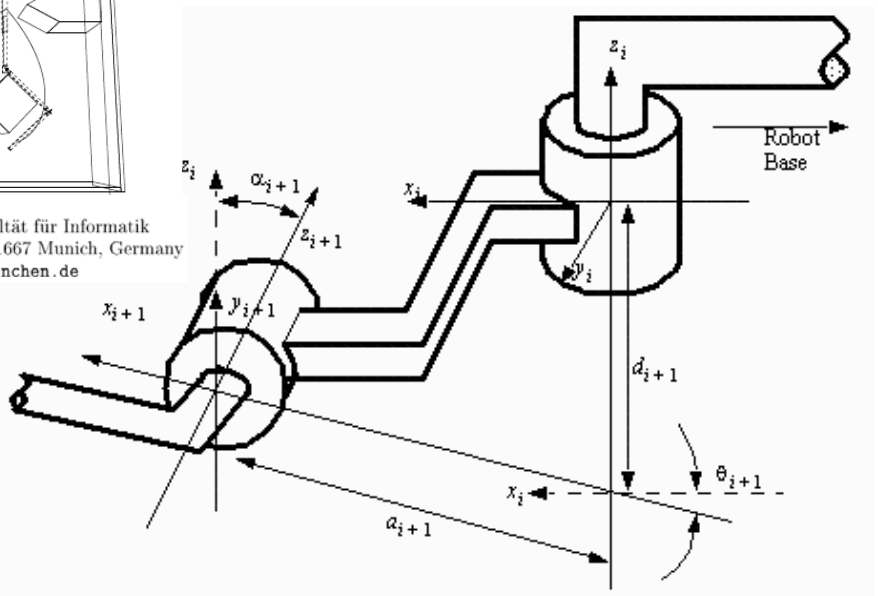
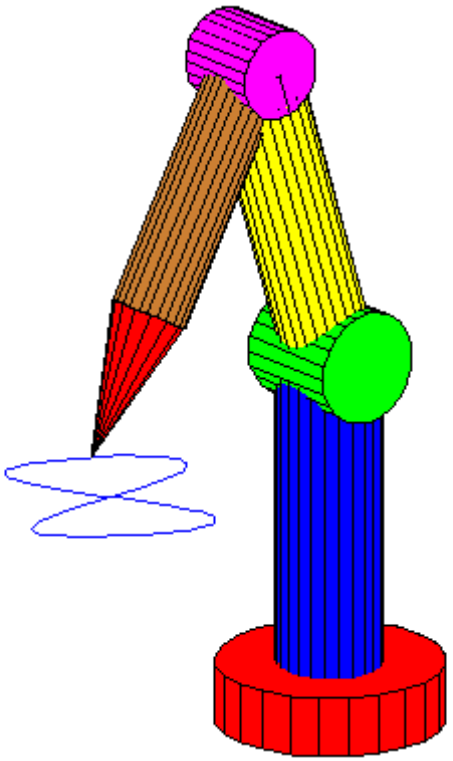


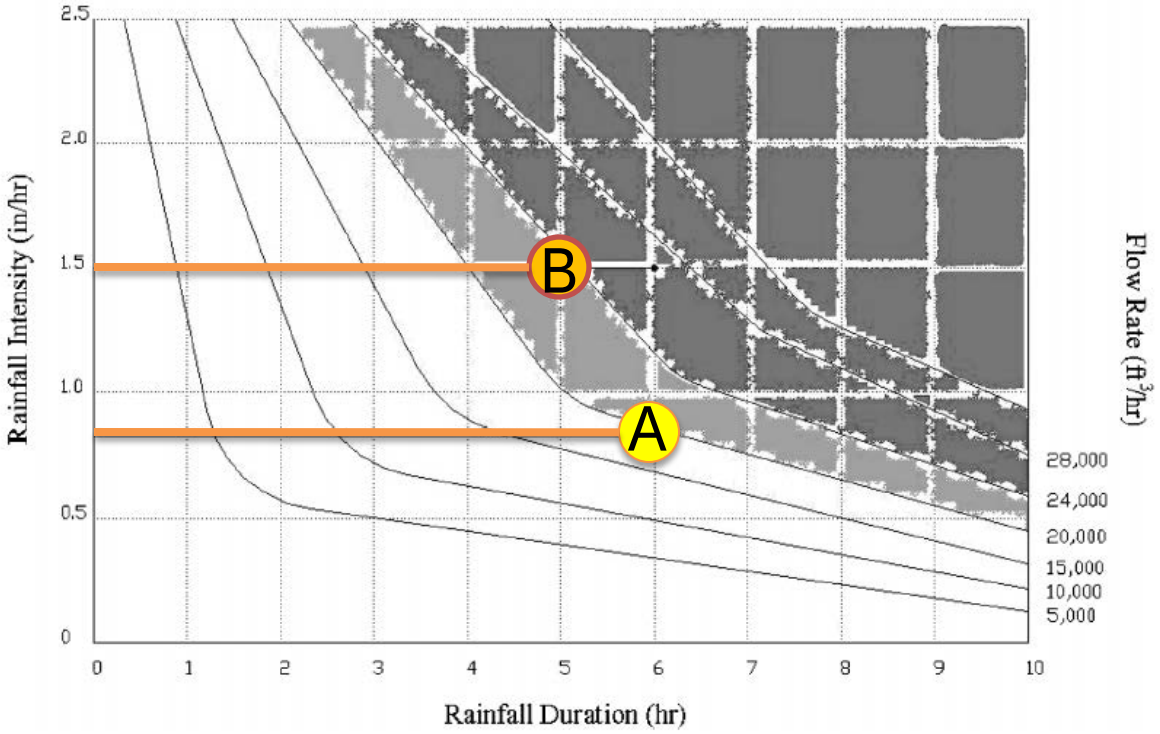


www.maplesoft.com/applications/view.aspx?SID=6850&view=html

Nomographs

- A nomograph, also called an alignment chart, is a calculating chart with scales that contain values of three or more mathematical variables
- Widely used in engineering, industry, and the natural and physical sciences

Nomograph example:
Expected Flows in a river (Will it flood?):



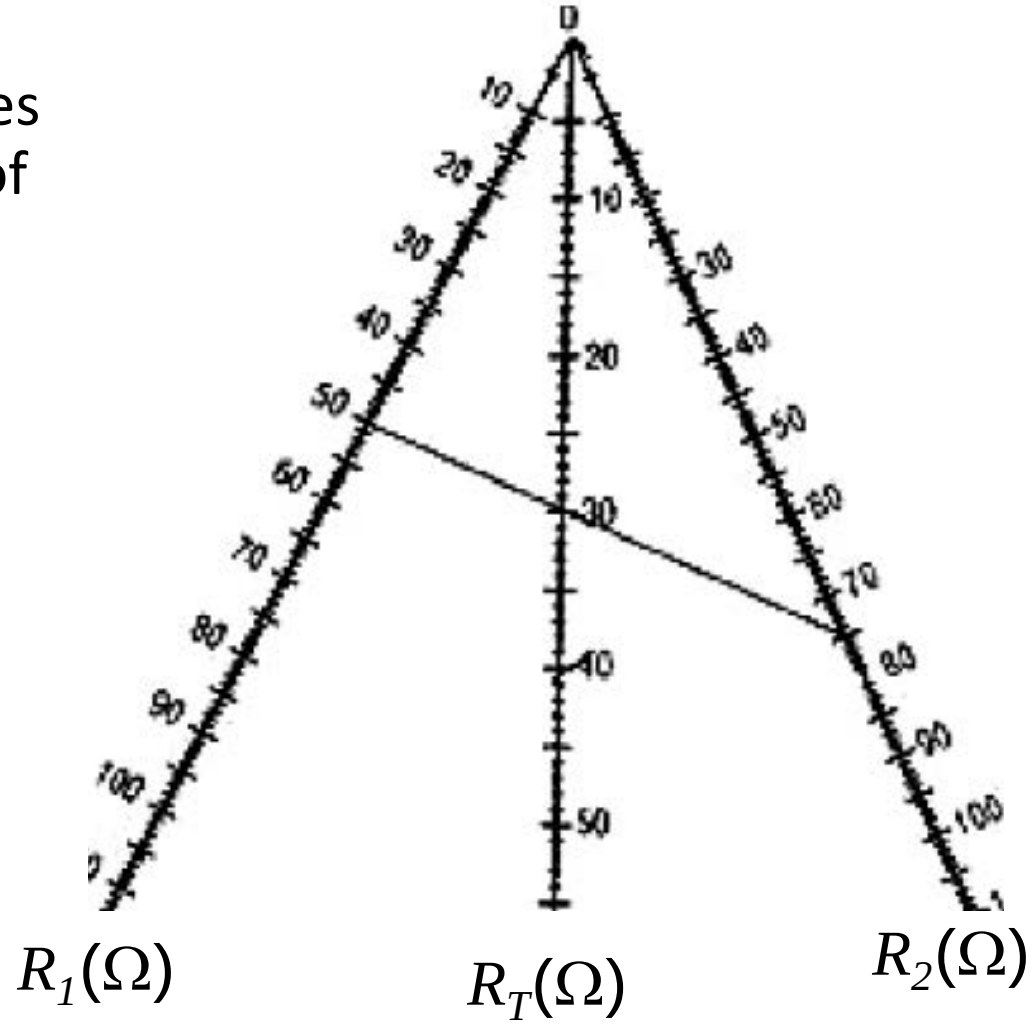
A. It rains 5 inches in 6 hours, the average intensity is 0.83 in/h; the point on the chart falls closest to the curve for 22,000 cu ft/s: yellow "Flood Caution" zone

B. It rains for 4 hours at an intensity of 1.5 in/h (for a total of 6.0 in). It is expected the rain will continue for another hour at the same rate, a flow level of ~23,500 ft^3/s can be expected: flooding is highly likely!

Parallel Resistor Nomograph

- This nomograph determines the equivalent resistance of two parallel resistors
- e.g., the equivalent resistance of a 50 Ω and a 75 Ω resistor in parallel is 30 Ω

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$



Empirical Equations

- Modeling relations between empirical data with mathematical equations
- Example: find an empirical equation to describe how different parts of a robot heat up from ambient conditions during the course of performing a continuous cyclic task

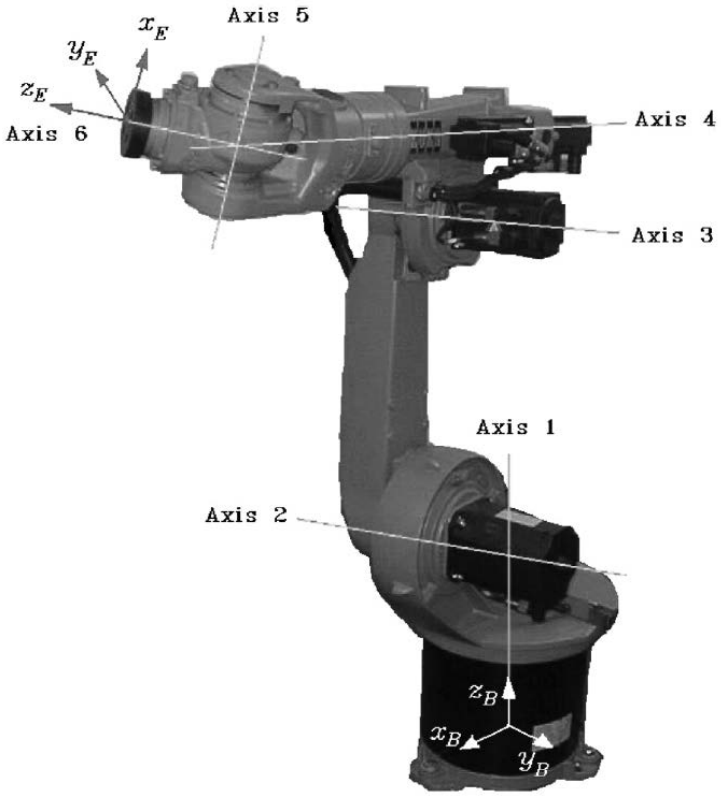
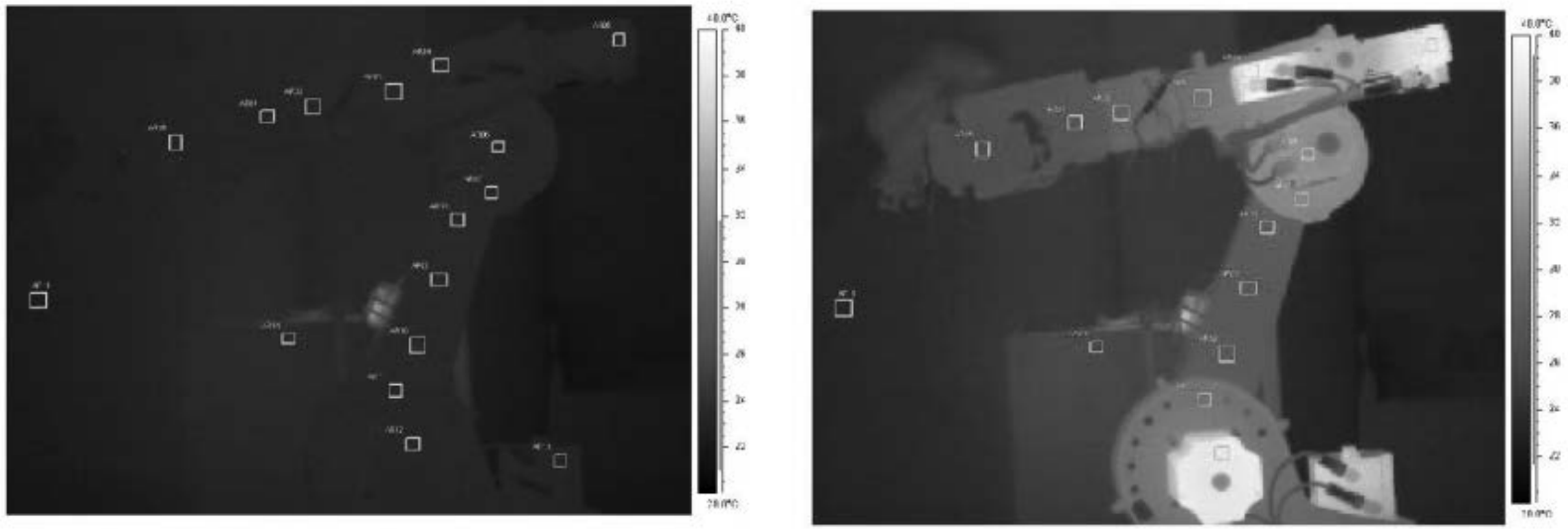


Figure 12.33 A KUKA KR-15/2 industrial robot.

Empirical Equations

- Infra-Red Thermogram (start)
- Infra-Red Thermogram (end)



(a) (b)

Figure 12.34 Infrared camera thermographs of robot: (a) cold start; (b) after 15 hours continuous operation.

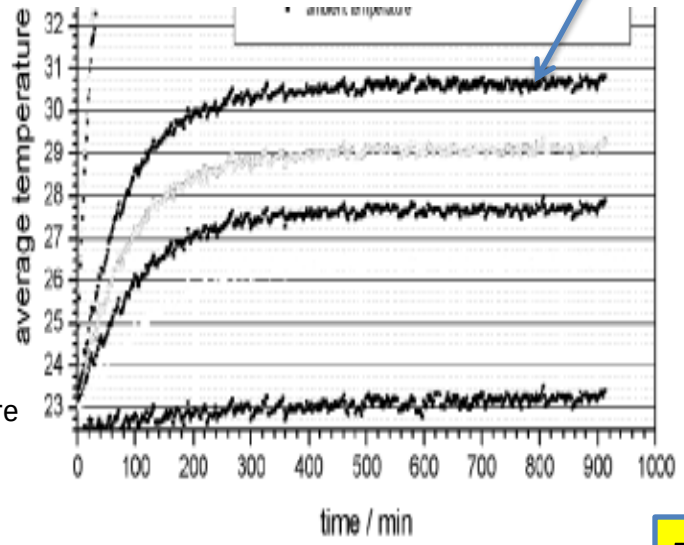
Empirical Equations

Average temperature at measurement spots on lower arm

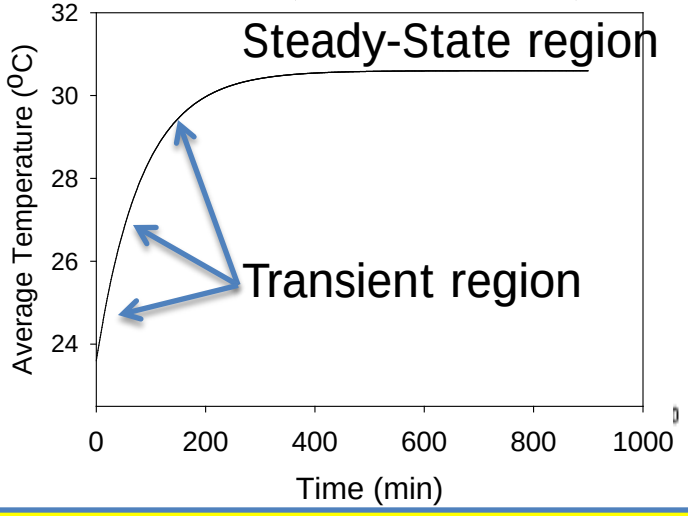
These data are modeled empirically with:

$$T = T_{ss} - (T_{ss} - T_o)\, e^{-(t/\tau)}$$

$$= 30.6 - (30.6 - 23.6)\, e^{-(t/83)}$$



(a)



This can be just an equation that fits the data, with no physics behind it, if the goal is an equation for interpolation …

Figure 12.35 Empirical data plots: (a) heat-up curves of areas on the end effector; (b) heat-up curve of a single area.

Where do these equations come from?

- Three places:
  1. Any equation that reproduces the data in an ‘acceptable’ way can be used, IF the goal is to have an equation for interpolation.
     - This is called “curve fitting”.
  2. A theoretically-based equation that is derived from some physical insight.
     - this can be used for interpolation and extrapolation, within limits.
  3. Or, a combination of the above

Where did we get:

$$T = T_{ss} - (T_{ss} - T_o)\, e^{-(t/\tau)}$$

$$= 30.6 - (30.6 - 23.6)\, e^{-(t/83)}$$

Assume that the rate the temperature changes with time is proportional to how far the piece is from its final steady-state temperature:

$$\frac{dT}{dt} \propto T_{SS} - T$$

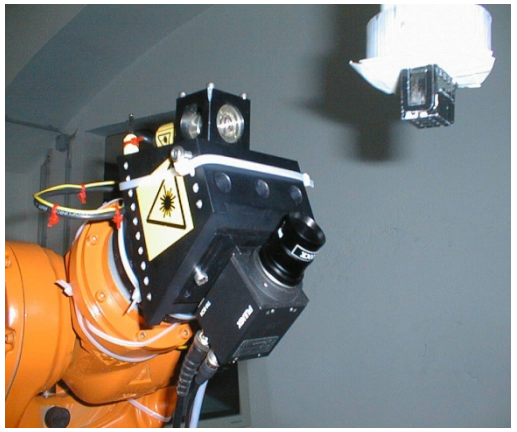
The proportionality constant we will call: $1/\tau$, where τ is some 'time constant' that depends on the material properties. Hence,

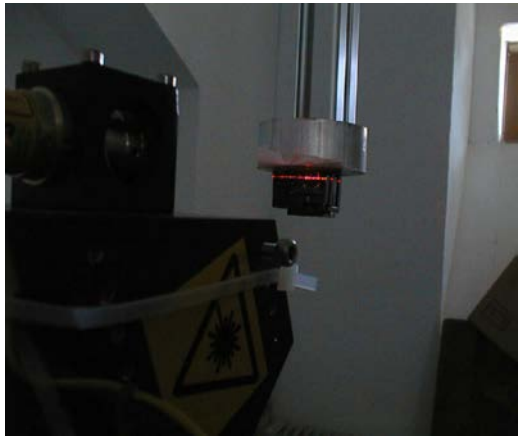
$$\frac{dT}{dt} = \frac{1}{\tau}(T_{SS} - T)$$

We can now integrate this expression over the limits of the test, and determine the parameters for this model equation "empirically" by finding the values that make the equation 'fit' the data. We will learn how this is done when we study regression later.

Empirical Equations

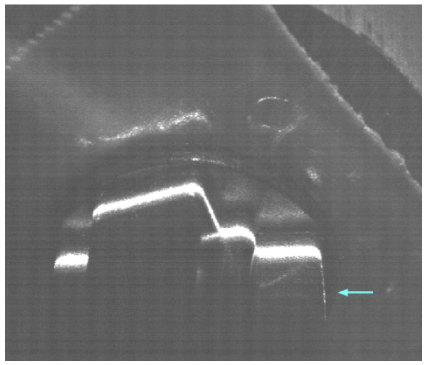
- Integrated optical/robotic measurement system
- Application to rapid prototyping



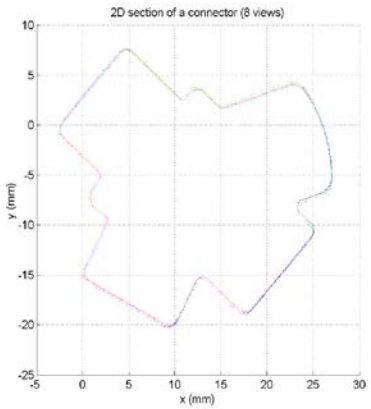


Empirical Equations

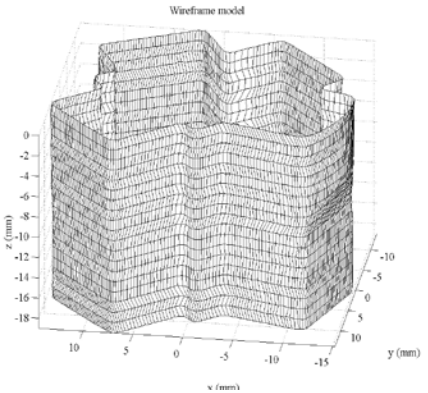
Raw image



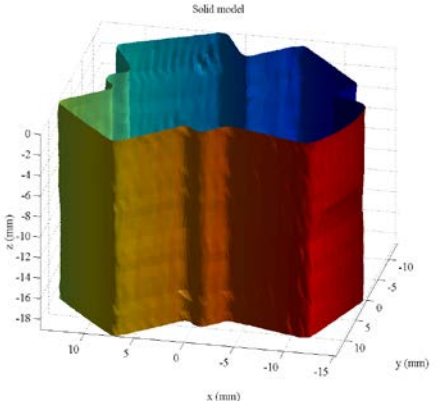
Reconstructed section



Wireframe



Rendered solid model



Introduction to CAD

Evolution of Drafting

A drafting room in the 1950s

Your drafting room in 2011

Computer Aided Drafting (CAD)

- Replaced the drafting table
- Creating electronic drawings
- Can be used to create pictorial perspective, isometric, oblique, and orthographic drawings as well as electrical, pneumatic, hydraulic, and control system schematics
- Examples include **IntelliCAD** and **AutoCAD**

Why do we need CAD?

- CAD is an effective way to communicate your ideas and designs
  - Used to produce working drawings
- Manufacturing is becoming more integrated, more global
- Systems are becoming more complex
- Working drawings are needed in all disciplines
  - Electrical, civil, mechanical, aerospace, manufacturing, architecture

Why do we need CAD?

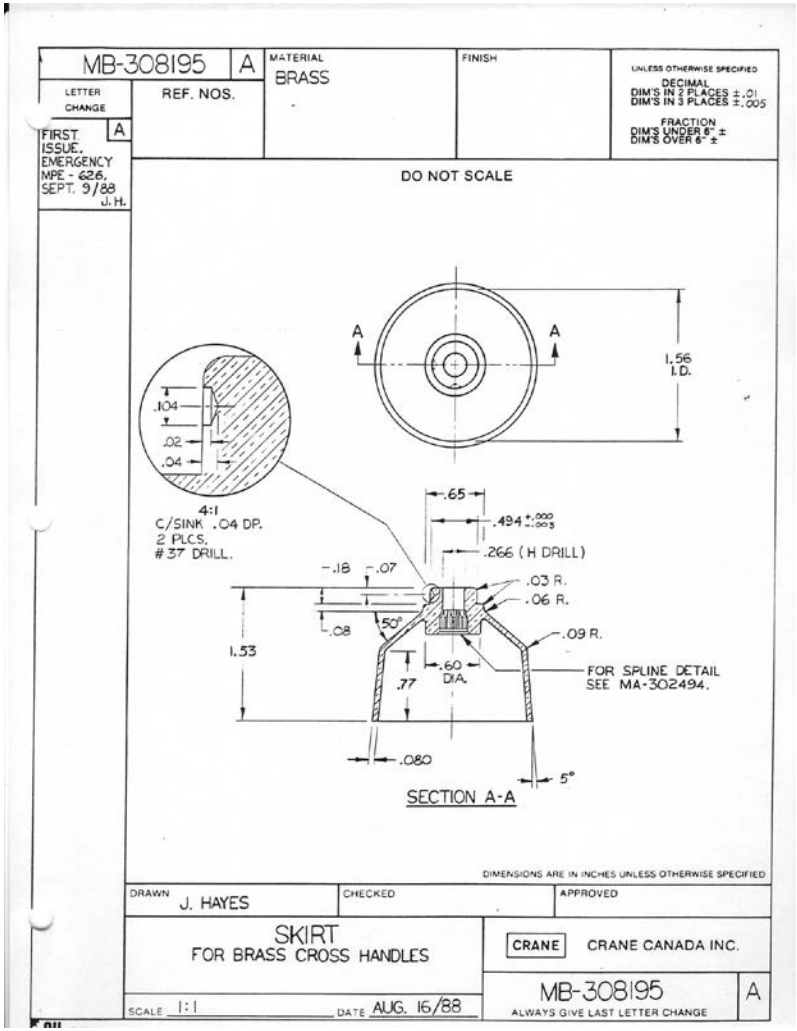
- 1960s – Lockheed SR-71
  - Supersonic reconnaissance aircraft
  - 30,000 hand-drafted working drawings!
    - Design changes required a lot of time
    - Filing and record keeping were challenging

Why do we need CAD?

- 2007 – Airbus A380
  - Modern, 500+ passenger commercial aircraft
  - Designed and manufactured in several countries
    - Approximately 500 suppliers
  - 1 global database
    - Database with solid models and CAD drawings
    - Automatically updated

Computer Aided Drafting

- CAD is crucial in the detailed design stage
- Computer aided drafting enables modifications to be made with ease
- Compare this with hand drafting



A Word On CAD

- CAD programs are very useful tools because most of them automatically follow the conventions discussed
- However, the designer is still responsible for ensuring the integrity of the drawing
  - CAD programs make mistakes, and sometimes the default options are not the most efficient way to convey the information

CAD Advantages

- Increased accuracy
- Increased speed
- Easy revision
- Better design analysis
- Better presentation
- Libraries of drawing aids
- Improved filing

When do we use CAD?

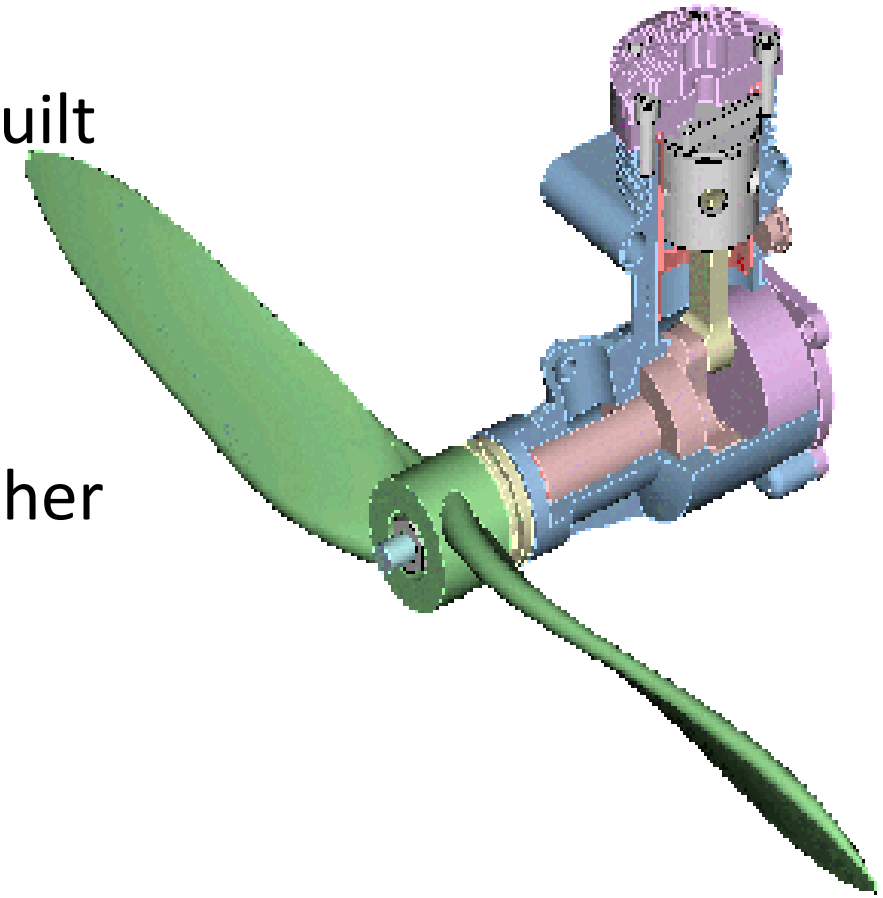
- When you want to clearly communicate a conceptual design
- When you want to machine a part
- When someone else is manufacturing or machining parts for you
  - Want to get exactly what you had in mind
  - Technologists and machinists need to be able to understand and interpret the design

Engineering Computer Graphics

- The major areas of computer graphics are:
  - CAD: Computer-Aided Design
    - Used to solve design problems, analyze design data, store and disseminate design information
  - CADD: Computer-Aided Design Drafting
    - Using computers to generate engineering drawings and technical documents
  - CAD/CAM: Computer-Aided Design/ Computer-Aided Manufacturing
    - A computer based system used to design a product, devise the production steps, electronically transfer the data to control the manufacturing equipment
  - CIM: Computer-Integrated Manufacturing
    - A computer based system that coordinates and operates all stages of manufacturing from design to finished product

Solid Modeling (Visualization)

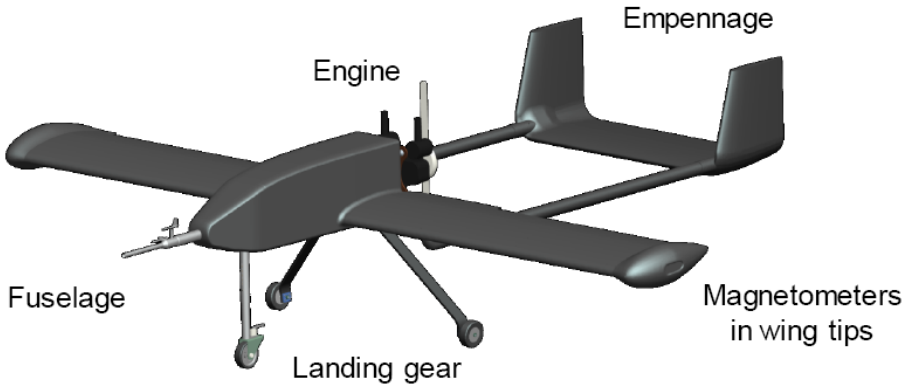
- Using a solid modeler, an entire prototype can be built and tested in a virtual environment before machining a single part
- Shows how parts fit together



Solid Modeling

- The software creates 3D virtual objects
- The virtual objects appear as axonometric projections
- The models can be virtually manipulated, just like a physical object
- Example products include **Pro/ENGINEER** and **Solid Edge**

Carleton GeoSurv II UAV Project



CAD in ECOR 1010

- CAD is one of the many tools that you're learning this semester
  - Lab 2, lab 3, and the design project
- Won't become an expert in 4 months, so don't worry
  - You'll learn what the tools are and where to find them
  - Will develop a base that you can build on in future years
  - Will have many opportunities to use these skills at Carleton and in your careers as engineers

CAD Software: IntelliCAD

- IntelliCAD can be used for report sketches, but it is really meant for technical drawing
- You should already be familiar with IntelliCAD (Lab 2)
  - The layout of the IntelliCAD environment
  - Basic drawing – lines, circles, etc.
  - Grid and snap features
  - Importing blocks
  - Creating text

IntelliCAD and Pro/E Help

- On your own, go through the IntelliCAD primer slides (associated with Lecture 8)
  - on WebCT
- Read Chapter 15 and Pro/ENGINEER Tutorial in Support Material Folder in WebCT

Design and CAD

- As a result of CAD, the design process has become much faster
- Although revolutionary, CAD has not taken over every aspect of drawing
- Freehand sketching is still important

Freehand Sketching

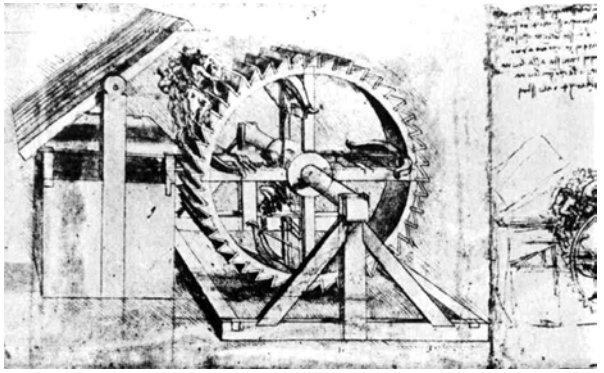
- Freehand sketch: drawing created without the use of a straightedge or other aids
- Used in the early stages of design
  - Ideas sketched on a napkin or notepad
- Outperforms CAD when a fast sketch is needed
- Not intended to be used as a technical drawing for manufacturing a part

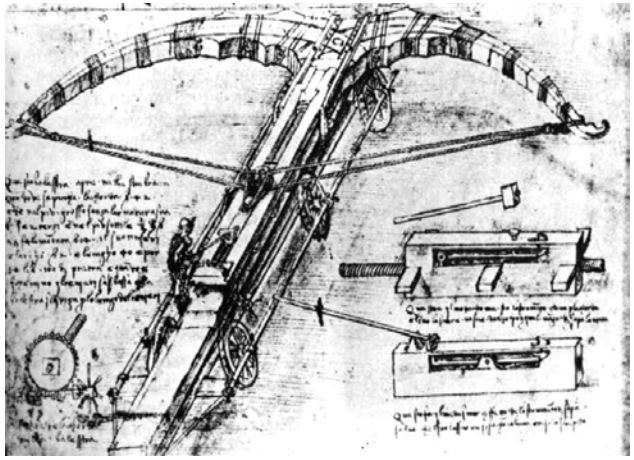
Visualization

- Being able to visualize in 3D is key
- Thought experiment:
  - Close your eyes and picture any object floating in mid-air … Now rotate the object in your mind … Imagine looking at it from every angle and direction
- This ability is crucial when creating graphical representations of real objects

Sketching

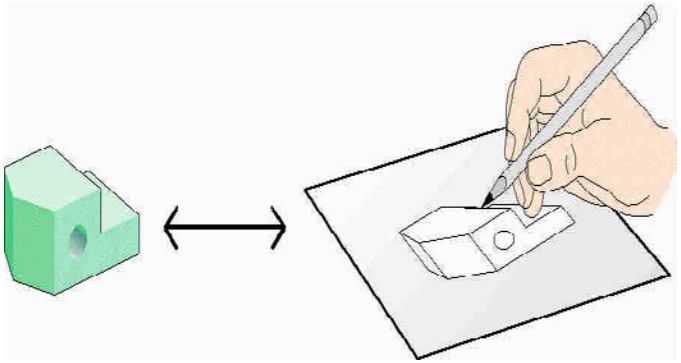
- Sketching is *freehand* drawing without the use of instruments such as a straightedge, compass, or drawing templates
- Sketching is a key means of engineering communication
- Sketches are used to develop ideas and make decisions about how to solve a problem
- Many new projects and products begin as sketches made on the back of an envelope, or on a napkin in a restaurant, hockey game, airplane ...

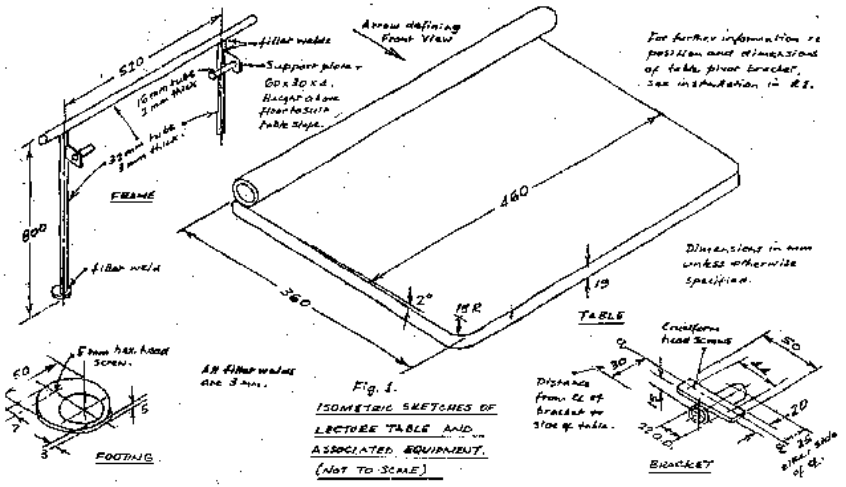




Sketching

- Sketching is used when “on-site” problems are encountered
- These are “back-of-the-envelope” solutions
- The ability to communicate by any means is a great asset
- Sketching is the best way to communicate engineering ideas
- Sketching skills must be used on-the-job to explain ideas, delegate work assignments, or to get help

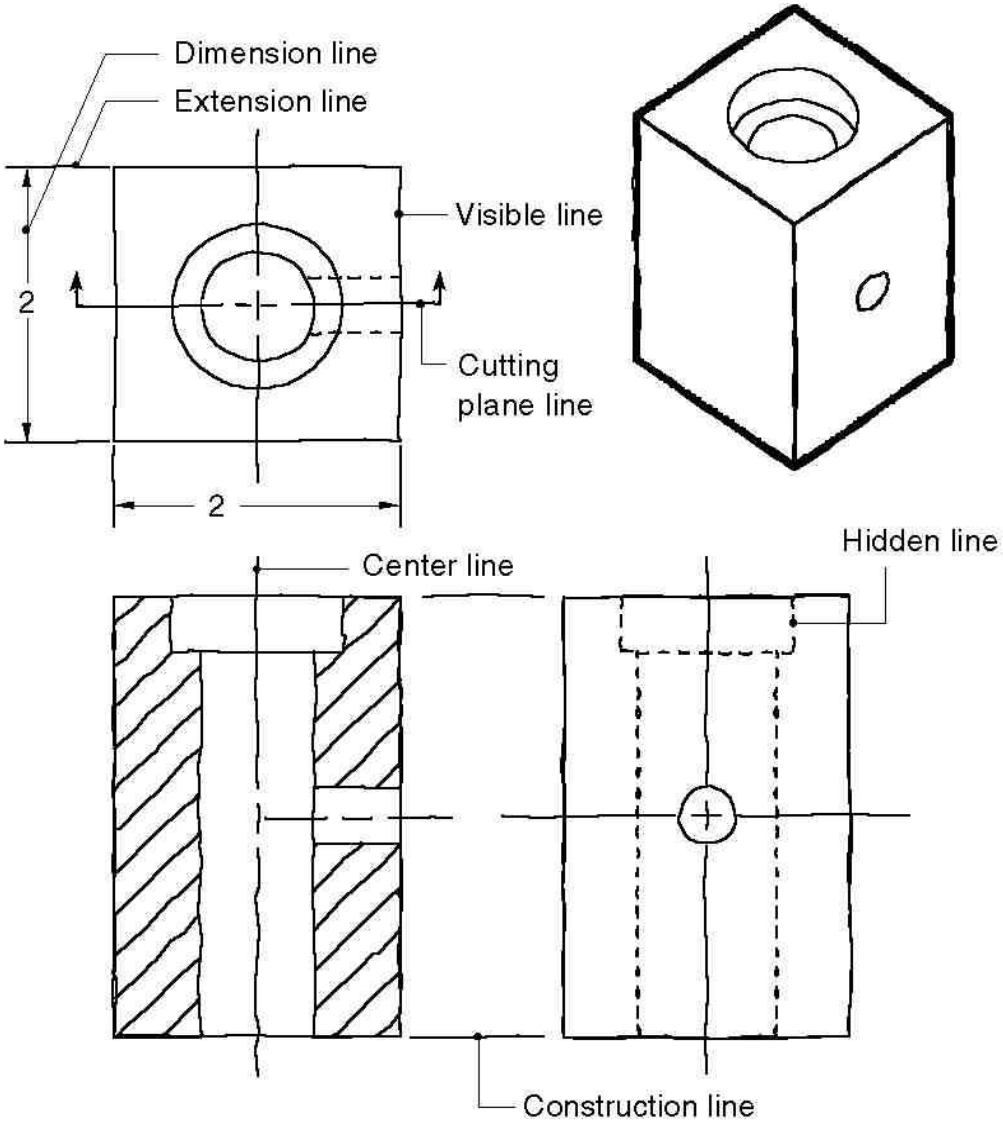




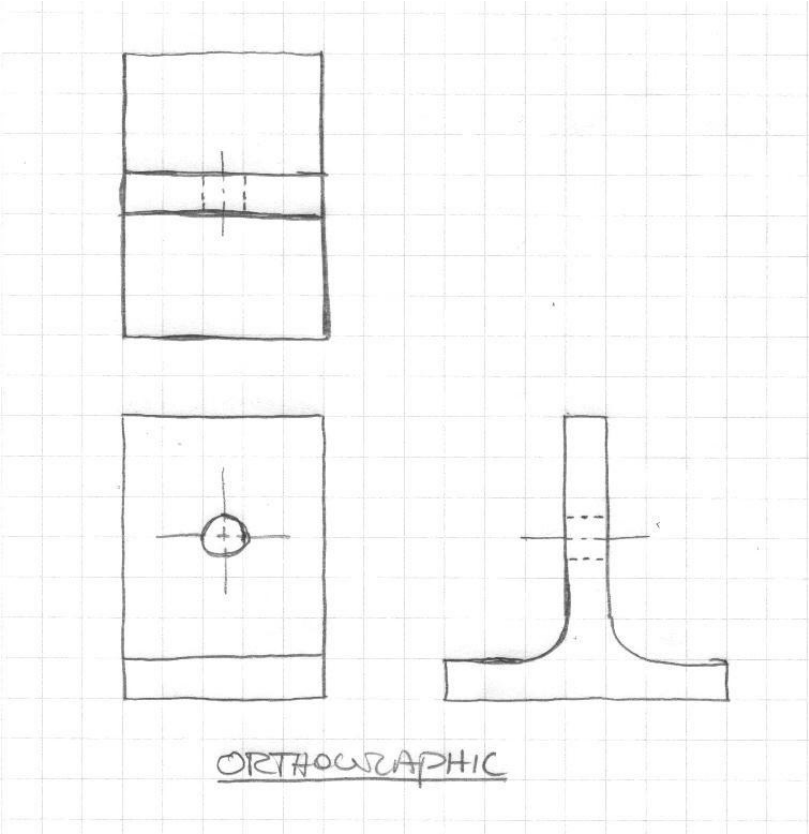
Hand Sketching Tips

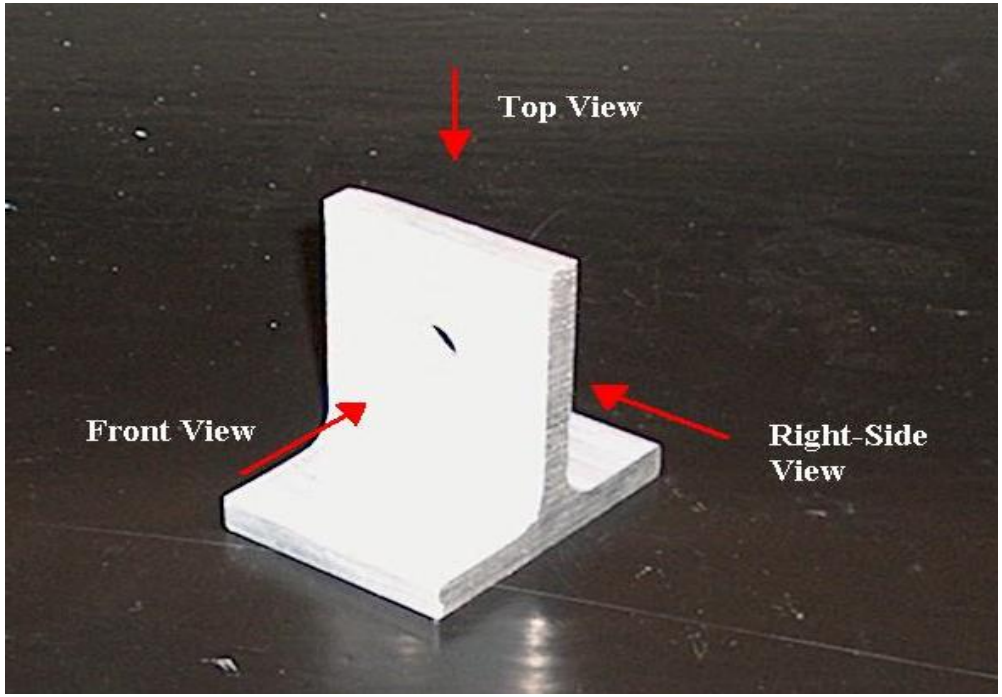
- Use one stroke when drawing a line – don't lift pencil off paper
- For long lines, keep your eyes focused on where the line is going to end
- Use construction lines – very faint lines that outline an object
- For circles, use a square construction square and then draw the inscribing circle

Sketching Example

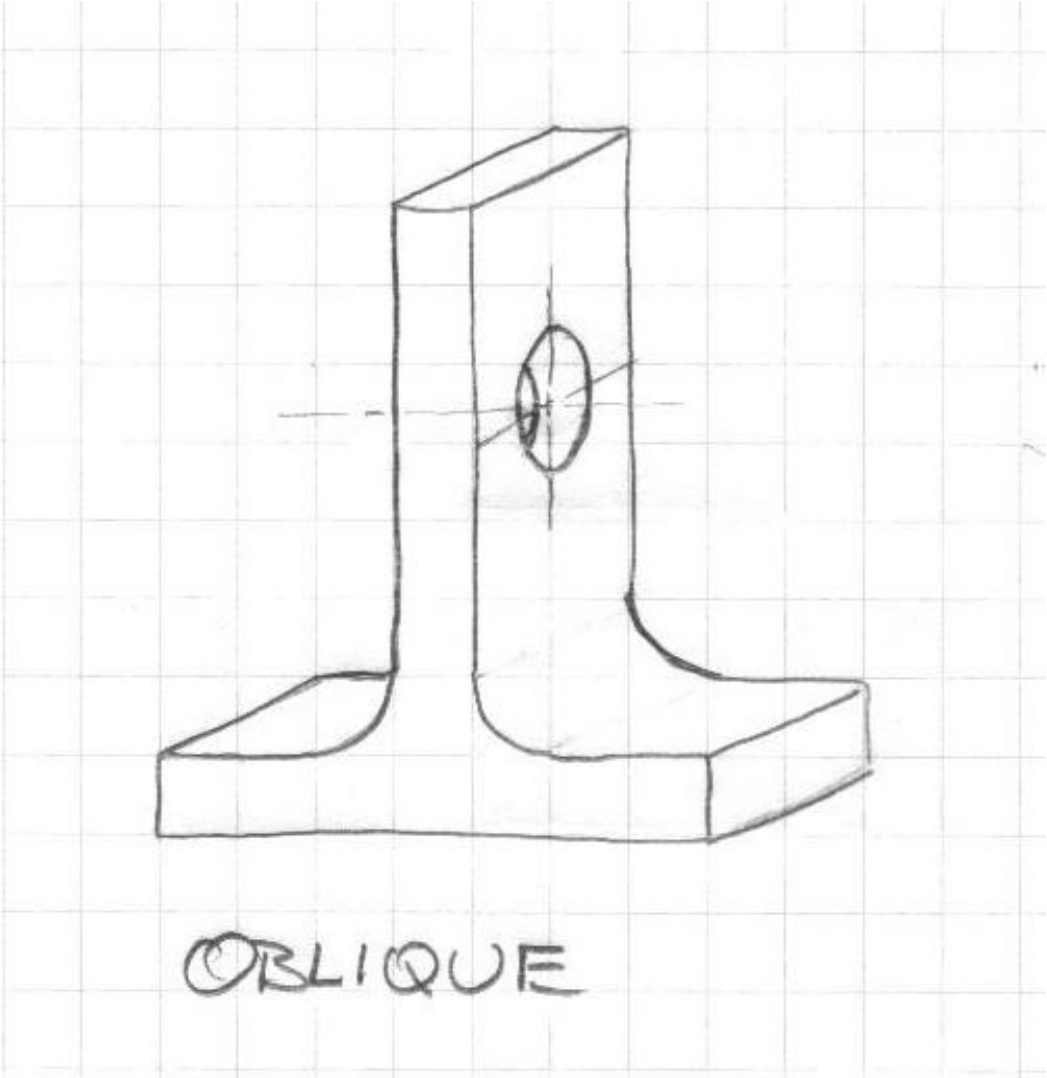


Orthographic Sketching

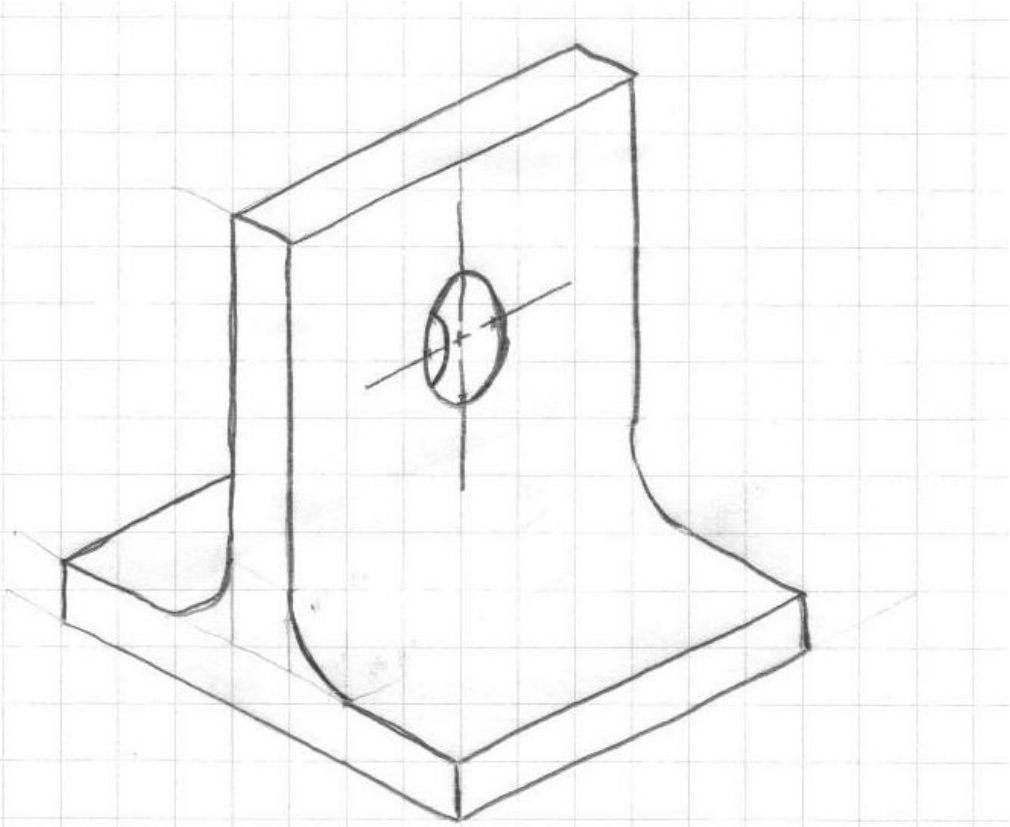




Oblique Sketching



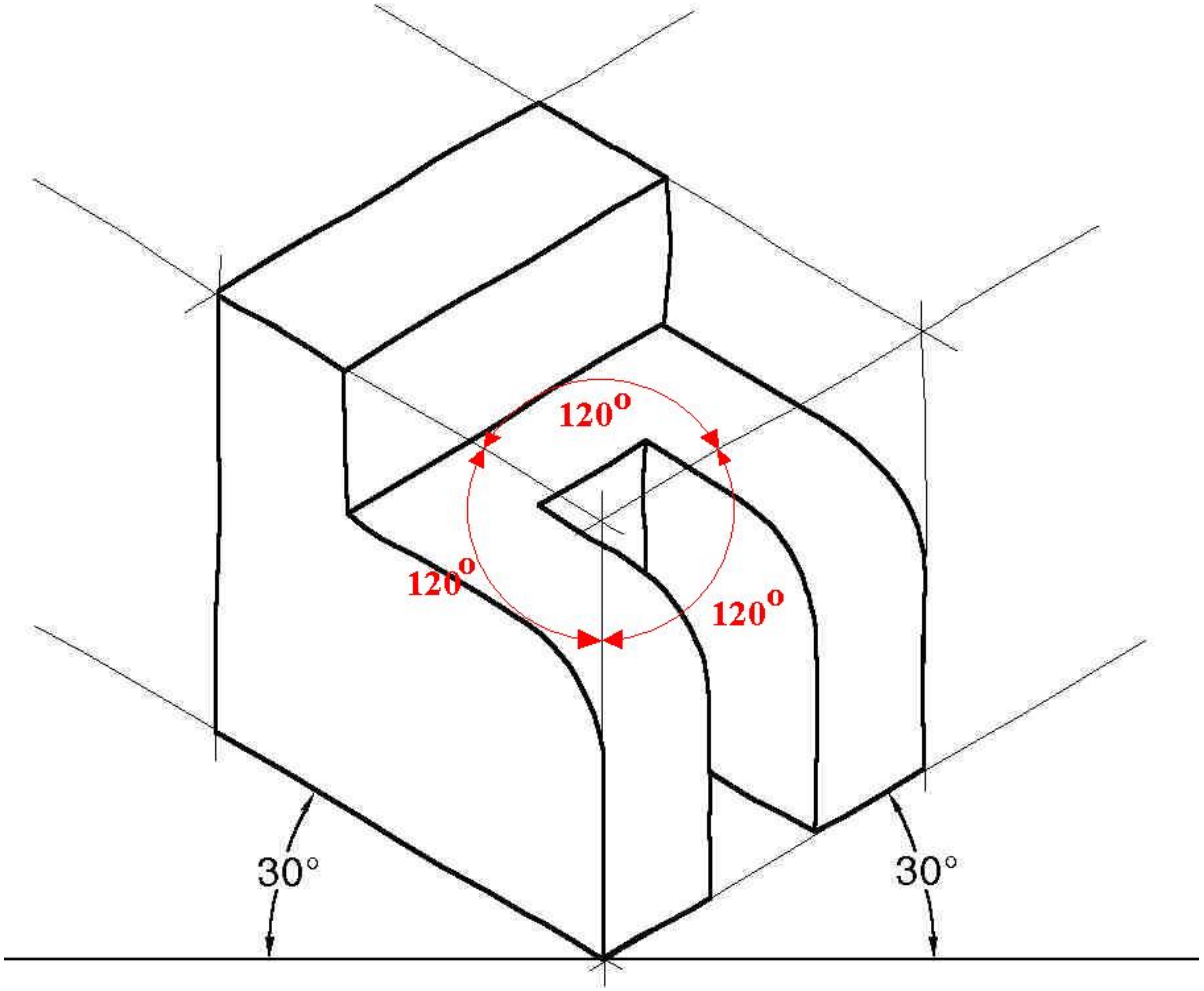
Axonometric Sketching



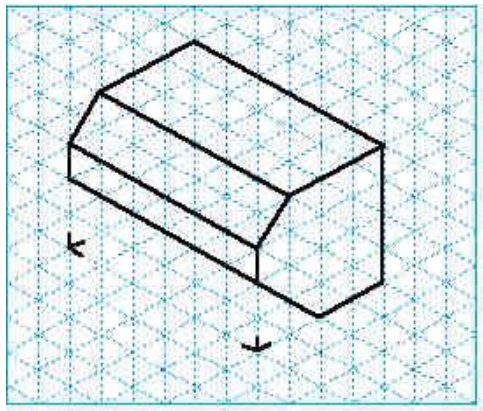
AXONOMETRIC

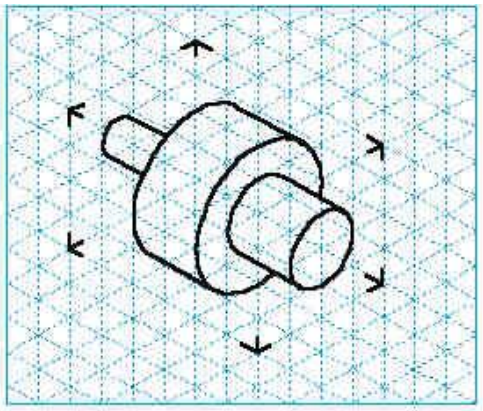
(APPROXIMATELY ISOMETRIC)

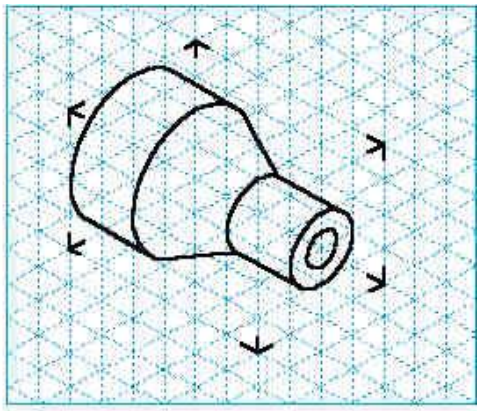
Isometric Sketching

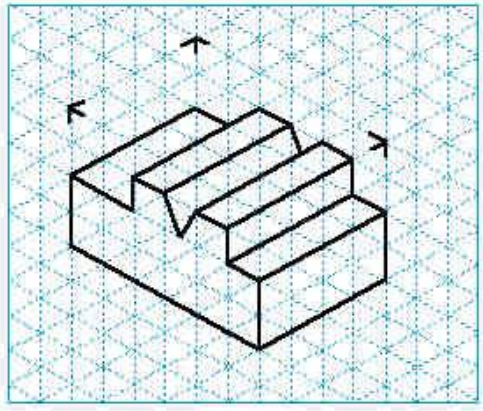


Isometric Sketch Paper









Reading Assignment

- You should have read Chapters 12 to 14 already.
- For next lecture Read Chapters 15 & 16.

ECOR 1010
Lecture 8

Introduction to Design

"Scientists investigate that which already is; engineers create that which has never been"

Albert Einstein

What is Design?

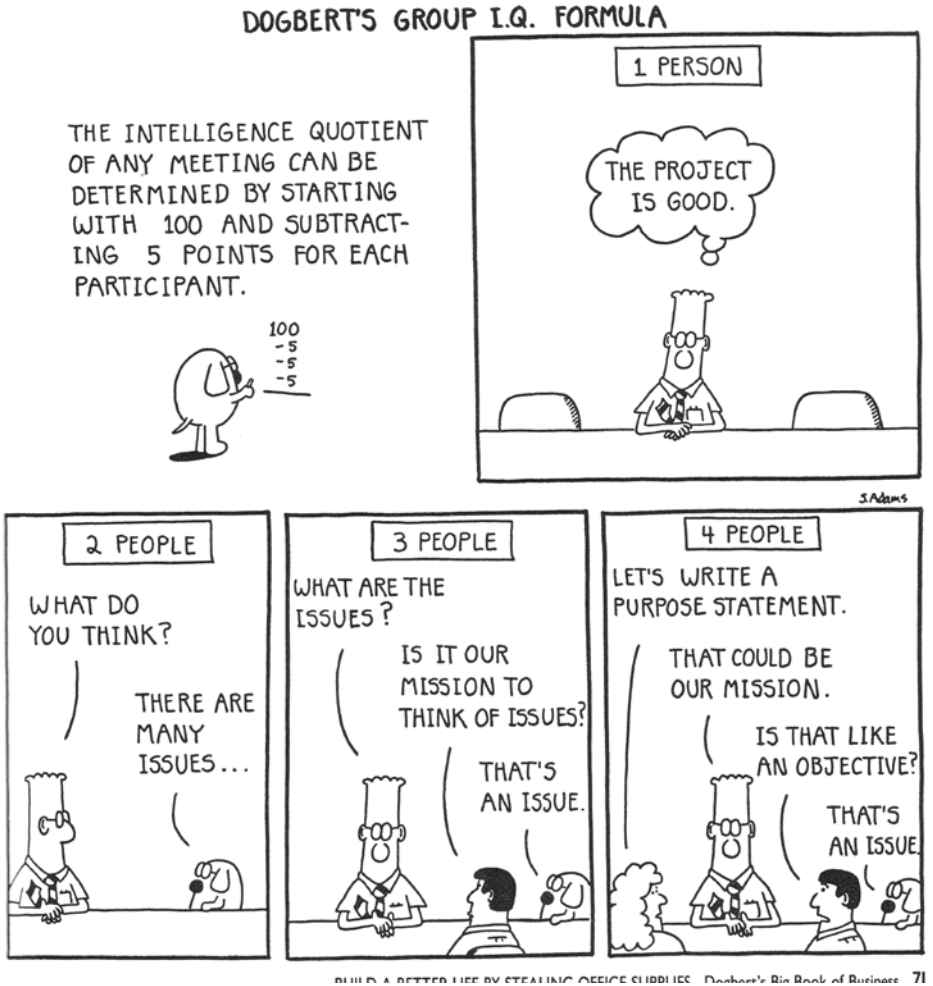
- Design is a creative process
- Incorporates all areas of an engineering education
- Design is basically what engineers do
- Almost always involves a team effort
- An iterative process
- Open-ended problems, often with many possible solutions
- Usually only a handful of good solutions

Engineering Design

- Engineering design
  - Identifying problems, solving them, and implementing the solutions
- The textbook gives the following definition of design:
  - "Process of developing workable plans for the construction or manufacture of devices, equipment, machinery or structure, to satisfy some observed need"
- Canadian Engineering Accreditation Board (CEAB) definition:
  - "Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative, and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social, or other pertinent factors."

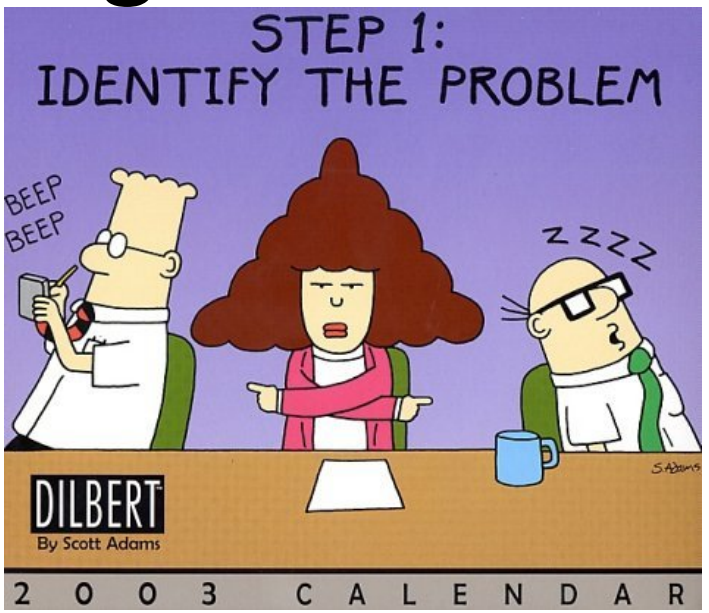
Design Ingredients

- Good design requires
  - Organization
  - Teamwork
  - Communication
- In addition, creativity and criticism are essential
- The key is knowing when to be creative and when to criticize



Engineering Design

- Before a problem can be solved, it must first be identified!
  - Evaluate the present state and determining how it differs from the goal state.

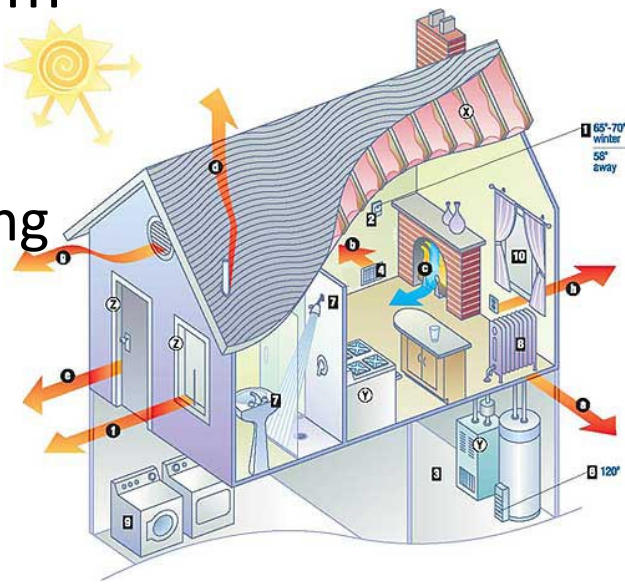


- Needs should be categorized and defined in a Statement of Requirements (SoR)
- Most design problems can be categorized as:
  - **Systems design**
  - **Product design**

Systems Design

Systems design deals with the arrangement of available products into a unique combination that yields the desired result

- A residential building is a complex system consisting of many components and products
  - Heating-ventilation and/or air conditioning systems (HVAC)
  - Plumbing systems (water and/or natural gas)
  - Electrical systems
  - Window, door, floor systems, etc.



- A commercial tool shed is not a complex system, but it still has to be designed; it is a product

Systems Design

- Systems design requires additional professionals
- Consider designing a highway
  - Lawyers: traffic laws; zoning ordinances; right-of-way; liability, …
  - Historians: past trends and historical data must be reviewed, …
  - Social Scientists: highways bring commercial development, shopping centres, gas stations, …
  - Psychologists: driver characteristics and tendencies, other human factors affecting safety and function, …
  - Scientific principles developed through research can be applied to building more durable driving surfaces, bridges, underpasses and overpasses, improving the system in general

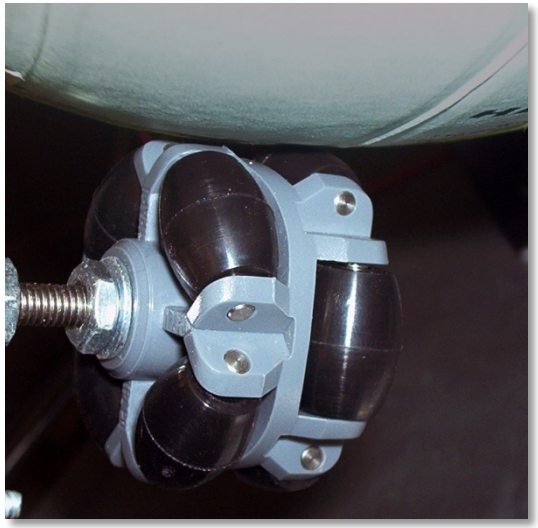
Systems Design Example #1:

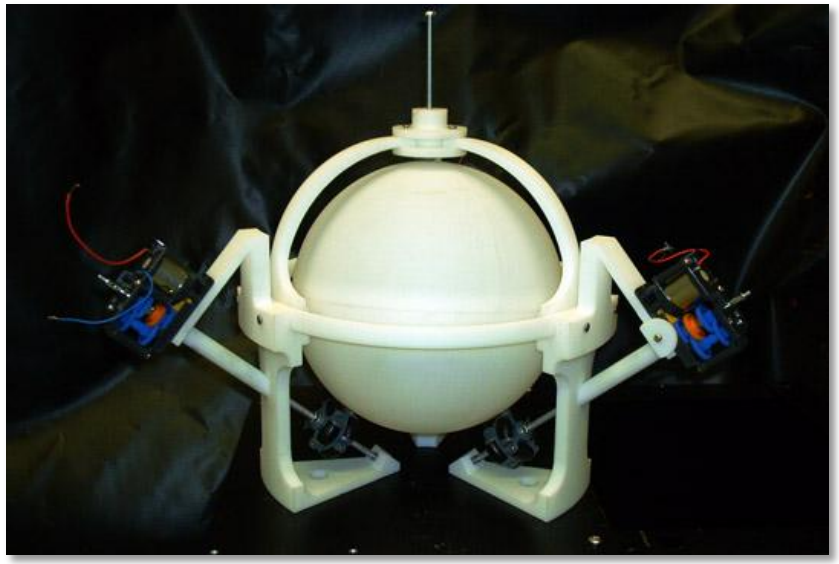
CU Simulator Project (CUSP)

- Multi-year project (4th-year)
- The intention is to design and build a full-scale reconfigurable simulator facility
- The full-scale simulator is scheduled to be completed at the end of the fifth year
- By nature the project is multidisciplinary
  - Mechanical, Aerospace and Computer Systems Engineering
  - Department of Psychology

ATLAS Platform

- The 6 DOF platform is novel architecture
- 3 AC synchronous motors; 3 dual-action electromagnetic rams
- Projection, control, and simulation systems are interoperable RTI's (Run-Time Infrastructure) that are IEEE (Institute of Electrical and Electronics Engineers) HLA (High-Level Architecture) compliant





Systems Design Example #2:

Formula FSAE

- Open Wheel Race Car
  - Dynamics
  - Structure
  - Propulsion
  - Electrical
  - Brakes
  - Safety

Systems Design Example #3:

UAV – Unmanned Aerial Vehicle

- Designed for Geophysical Survey
  - Structures
  - Aerodynamics
  - Control
  - Payload
  - Safety & Airworthiness

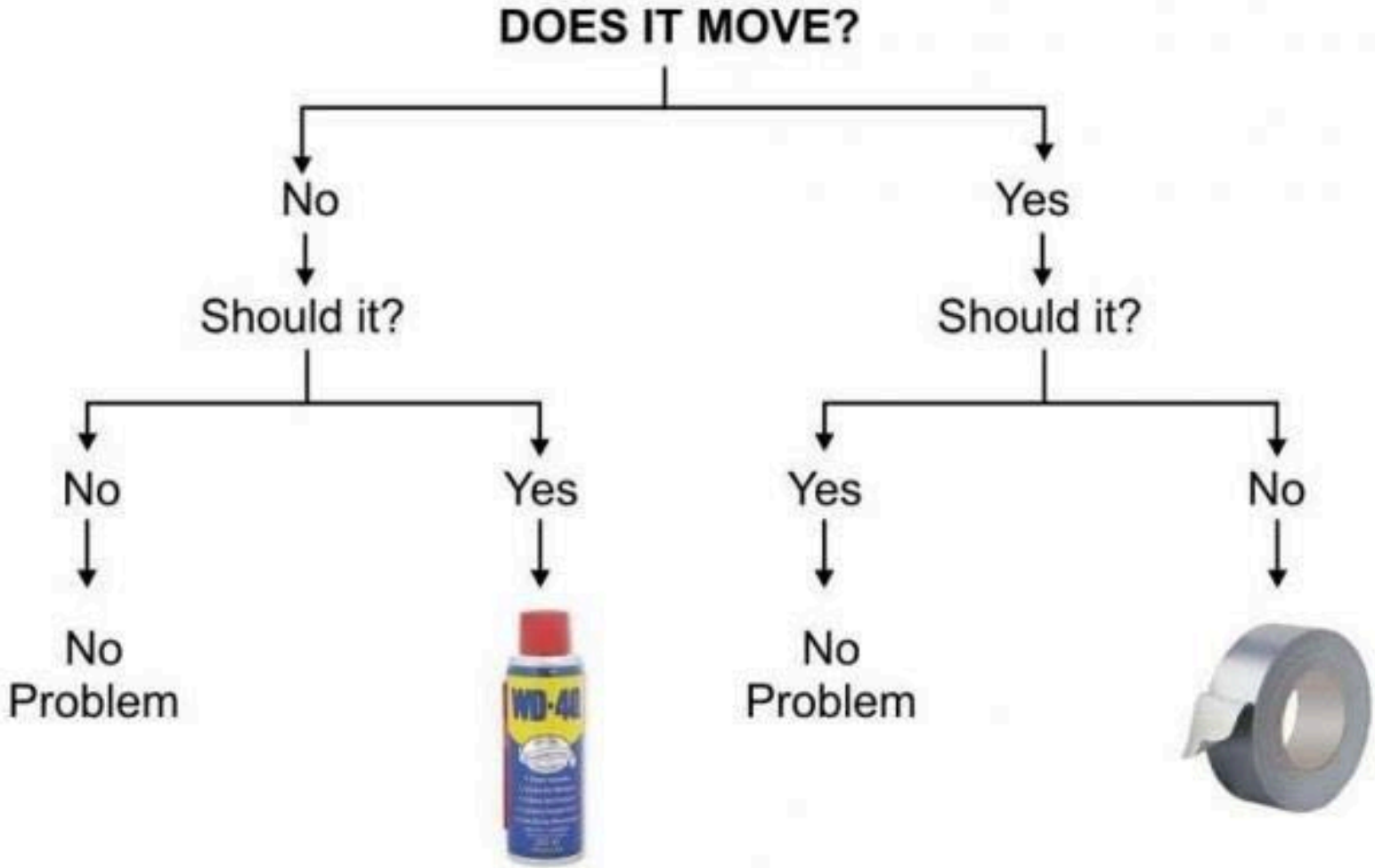
Product Design

- Product design deals with design, testing, manufacture and sale of (generally) mass-produced goods
  - Appliances, tools, televisions, toys, cars …
- Product designers must deal with
  - Current market needs, production costs, function, sales, distribution, profit expectations …
- Some products are complex systems
  - High-rise office building, container ship, car, space shuttle, robotic devices …
- Others are not
  - can opener, nail clipper…

The Design Process

- Design involves as much art as science
- The process from idea to finished product involves a series of sequential steps …

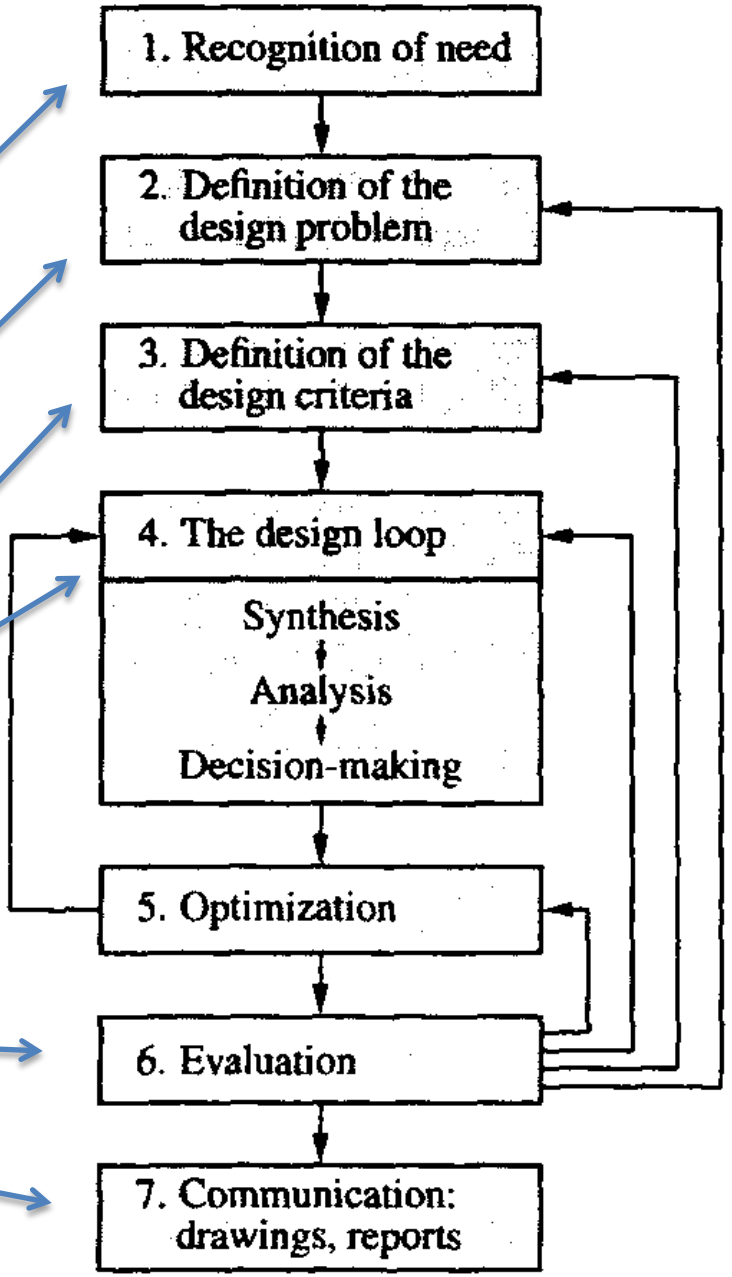
Engineering Flowchart

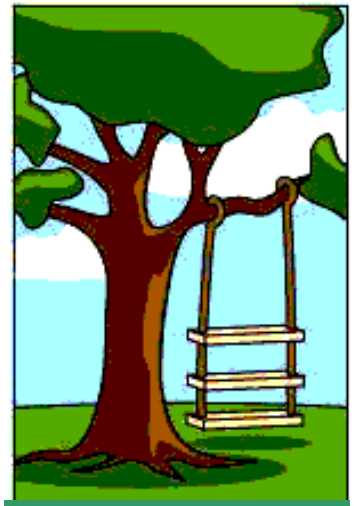


Method Of Design

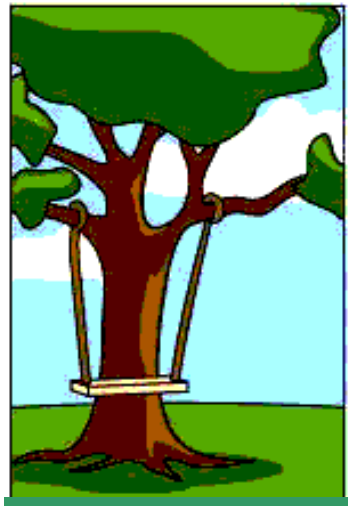
Seven steps:

1. Recognition of need
2. Definition of the design problem
3. Definition of the design criteria
4. The design loop
5. Optimization
6. Evaluation
7. Communication



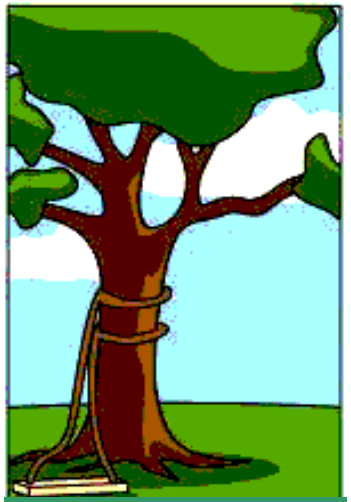


How the customer explained it

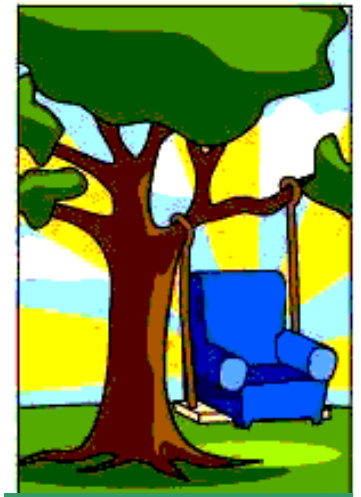


How the project manager understood it

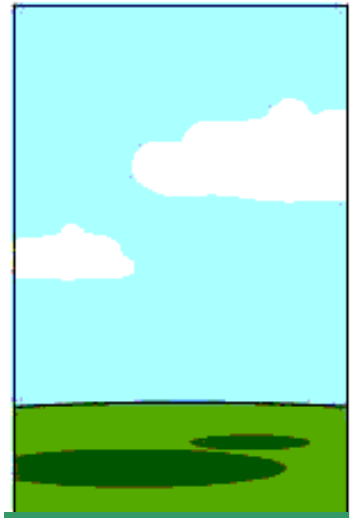
How the engineer designed it



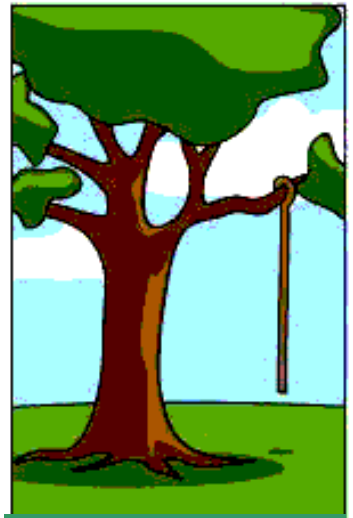
How the programmer wrote it



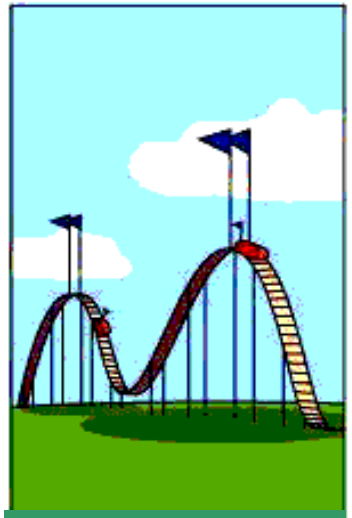
How sales & marketing sold it



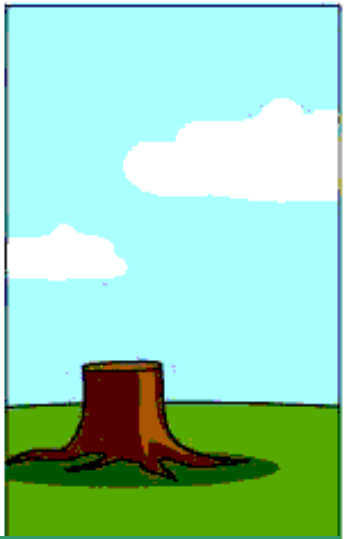
How the project was documented



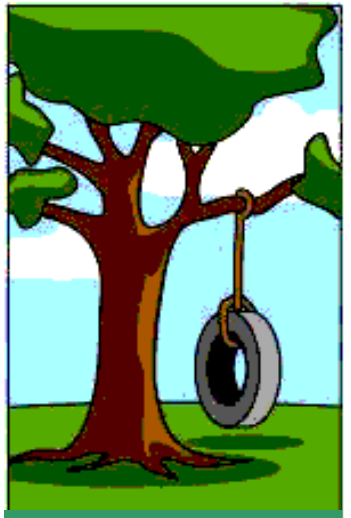
What operations installed



How the customer was billed



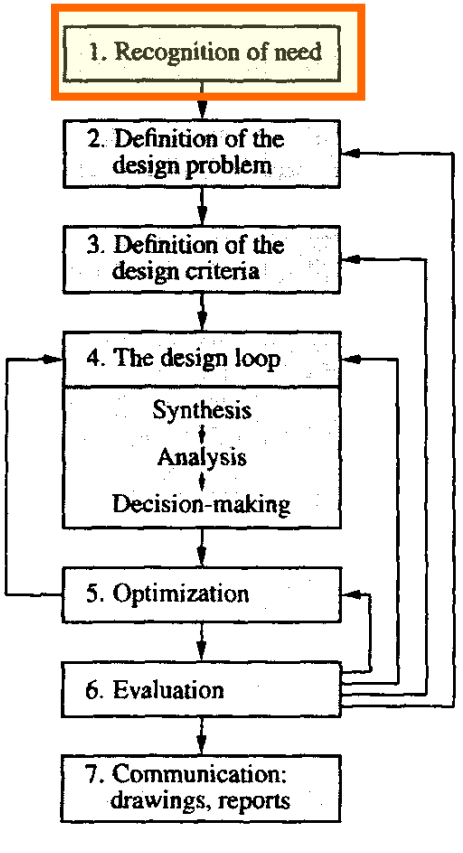
How it was supported



What the customer really wanted

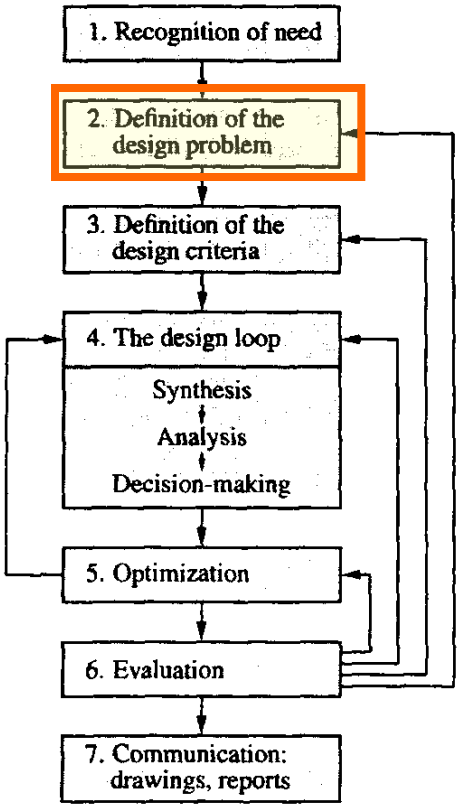
Method Of Design

- Recognition of need
  - A need can be either very obvious or hidden
  - Usually very vague
  - The vagueness of the need can cause the design process to become open-ended
  - Often the need is written in a Statement of Requirements (SoR)



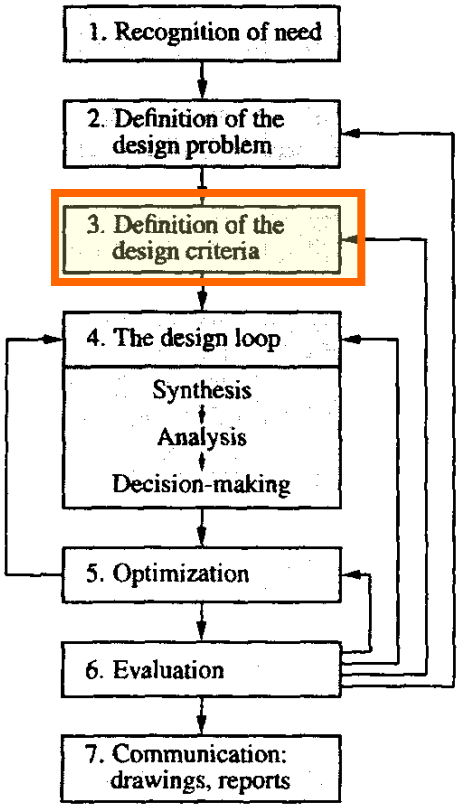
Method Of Design

- Definition of the design problem
  - Critical for a good design
  - May require the gathering of information on the topic (*i.e.,* Research)
  - Must define the problem correctly in order to provide a solution



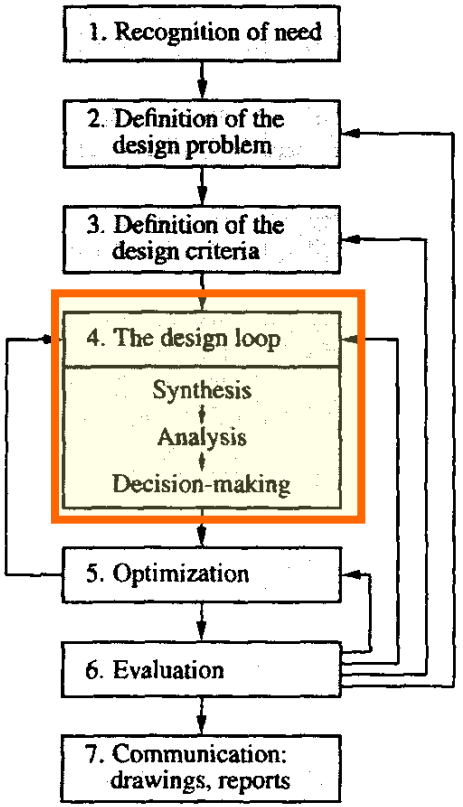
Method Of Design

- Definition of the design criteria
  - Design criteria are performance standards to be met by the design
  - Design constraints are limitations placed on the designer
  - The design criteria and constraints must be quantitative values, otherwise it may be impossible to agree on whether the final design is acceptable



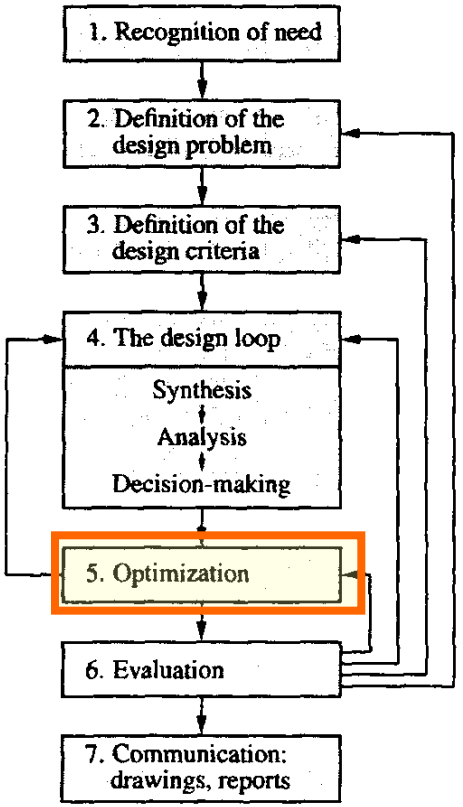
Method Of Design

- The design loop
  - Synthesis
    - Suggesting ideas or methods to solve the problem
  - Analysis
    - Calculating the expected result of each idea or method
  - Decision-making
    - Deciding which alternative is best



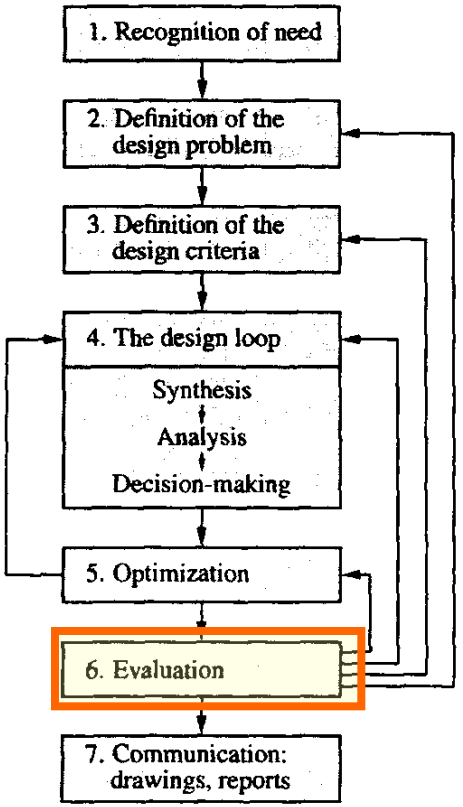
Method Of Design

- Optimization
  - Optimum implies a compromise between costs and benefits – the best design at a reasonable cost
  - In order to judge whether the design is optimum, the design criteria in step 3 are used
  - If the design is not optimum, the design loop may need to be reiterated



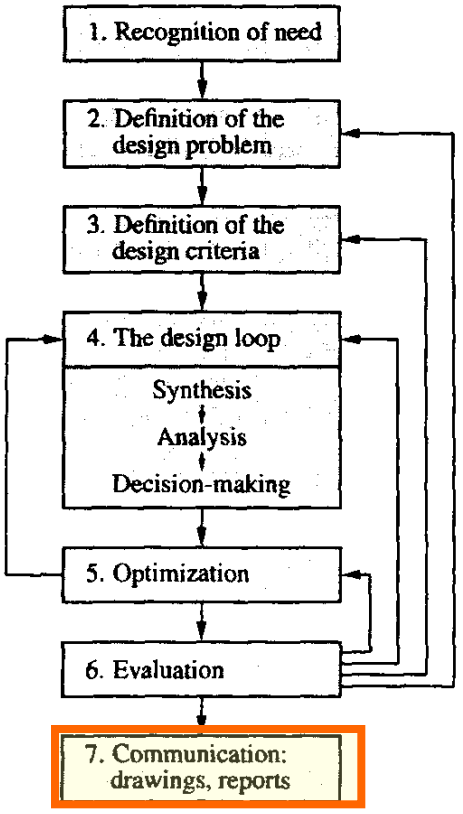
Method Of Design

- Evaluation
  - Once the design is completed, it is reviewed
  - The senior engineer, and ‘others’, must approve the design before it is finalized
  - If flaws are detected, the design must be iterated, beginning at step 2 if necessary



Method Of Design

- Communication
  - Once the design is approved, it can be built or manufactured
  - The final design must be communicated effectively
    - Reports
    - Technical drawings



Codes and Standards

- Code
  - A code is a set of specifications for the analysis, design, manufacture, and construction of things
  - The purpose is to achieve a specified degree of safety, efficiency, performance, or quality
- Standard
  - A standard is a set of specifications for parts, materials, or processes intended to achieve uniformity
  - Places limits so as to provide reasonable inventory of tooling, sizes, shapes, varieties, etc.

Codes and Standards

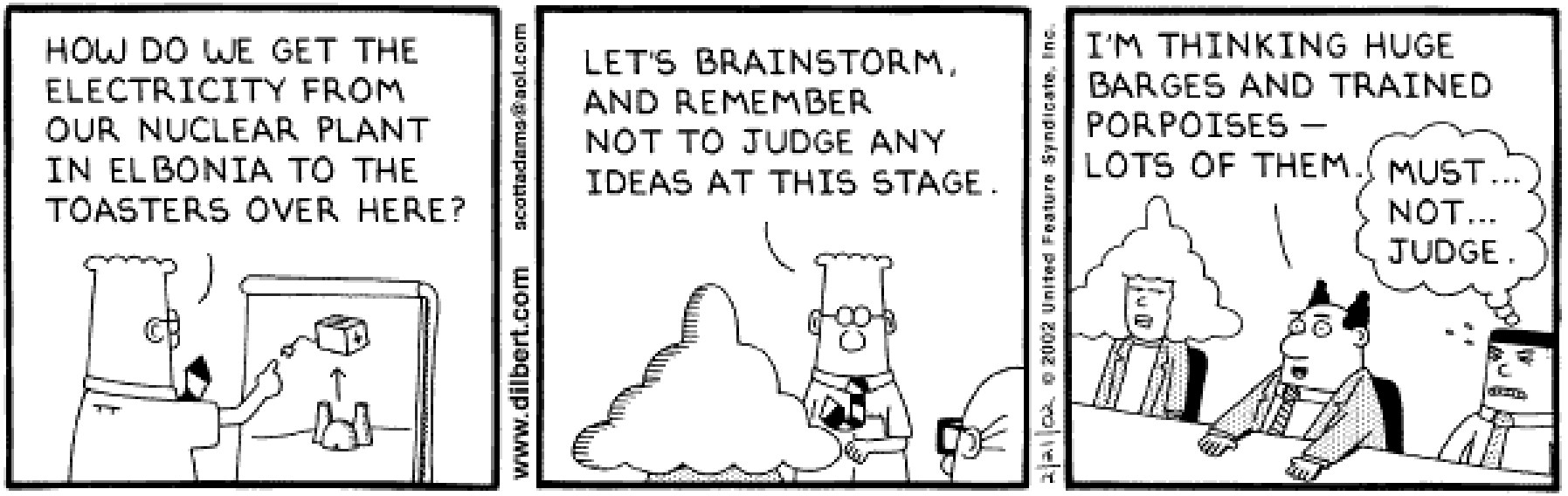
- Standards Organizations
  - International Standards Organization (ISO)
  - American National Standards Institute (ANSI)
  - Canadian Standards Association (CSA)
  - Canadian Society for Mechanical Engineering (CSME)
  - American Society of Mechanical Engineers (ASME)
  - Institution of Mechanical Engineers (I. Mech. E.)
  - Institute of Electrical and Electronics Engineers (IEEE)
  - Society of Automotive Engineers (SAE)
  - Society of Manufacturing Engineers (SME)

Creativity and Innovation

- Creativity and innovation are very important in the design process as a whole
- They are especially important during the design loop stage of synthesis
- Is it something that can be taught?
  - There are ways to stimulate creativity and innovation …

Stimulating Creativity and Innovation

- Brainstorming
  - A group of people generate a number of solutions to a problem
  - Judgment of ideas is prohibited at this point



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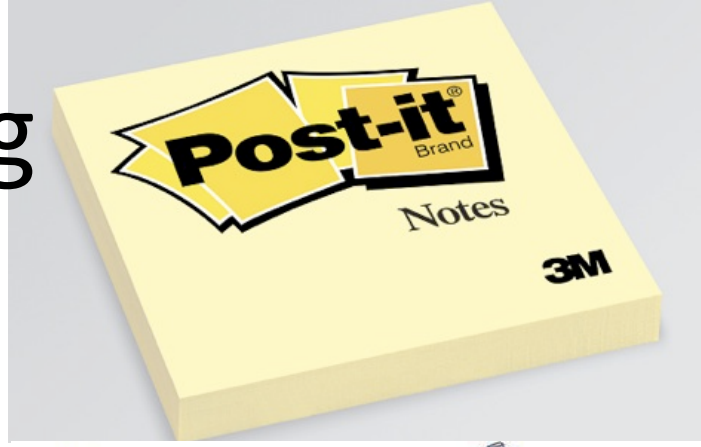
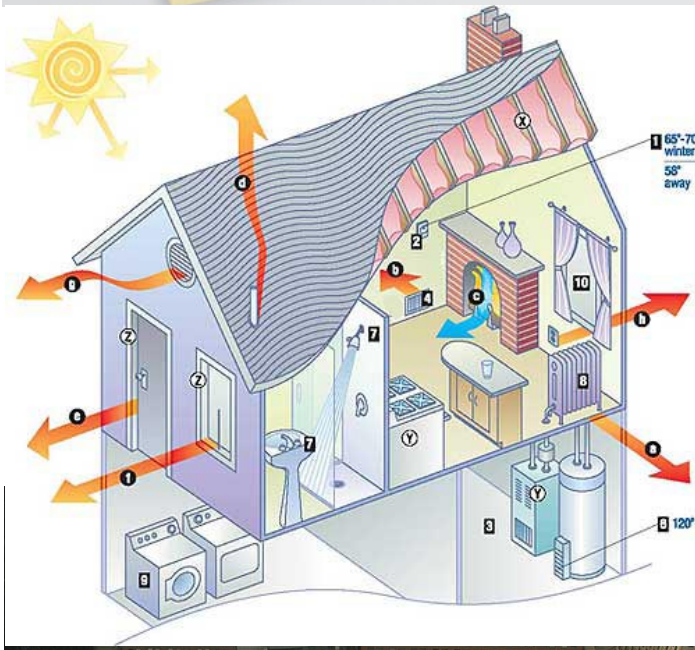
Stimulating Creativity and Innovation

- Brainstorming
  - A group of people generate a number of solutions to a problem
  - Judgment of ideas is prohibited at this point
  - All ideas are considered equal until evaluation
  - After a set period of time, all ideas are discussed, evaluated, and perhaps ranked
  - The best ideas are examined further

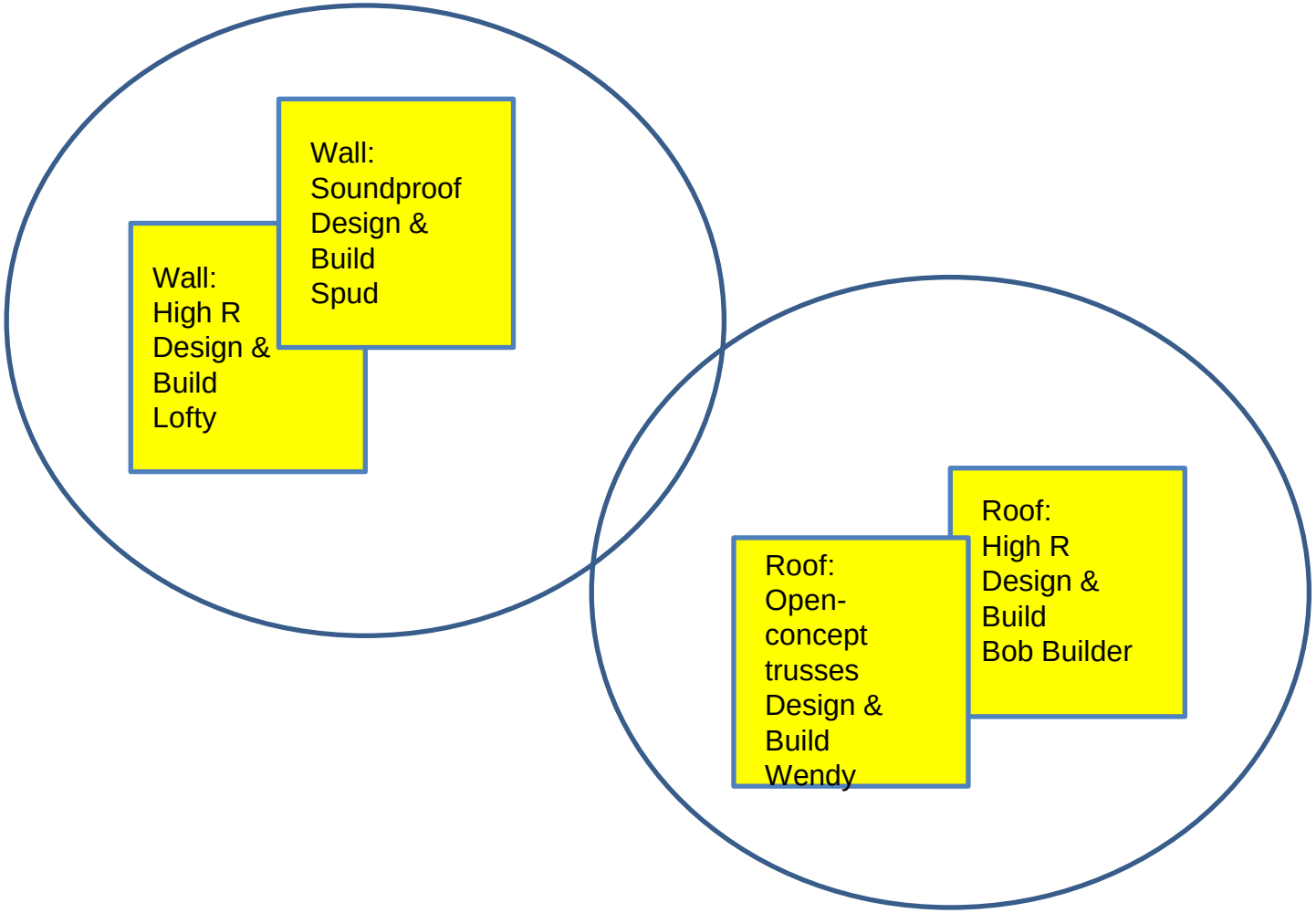
Sticky-note Brainstorming



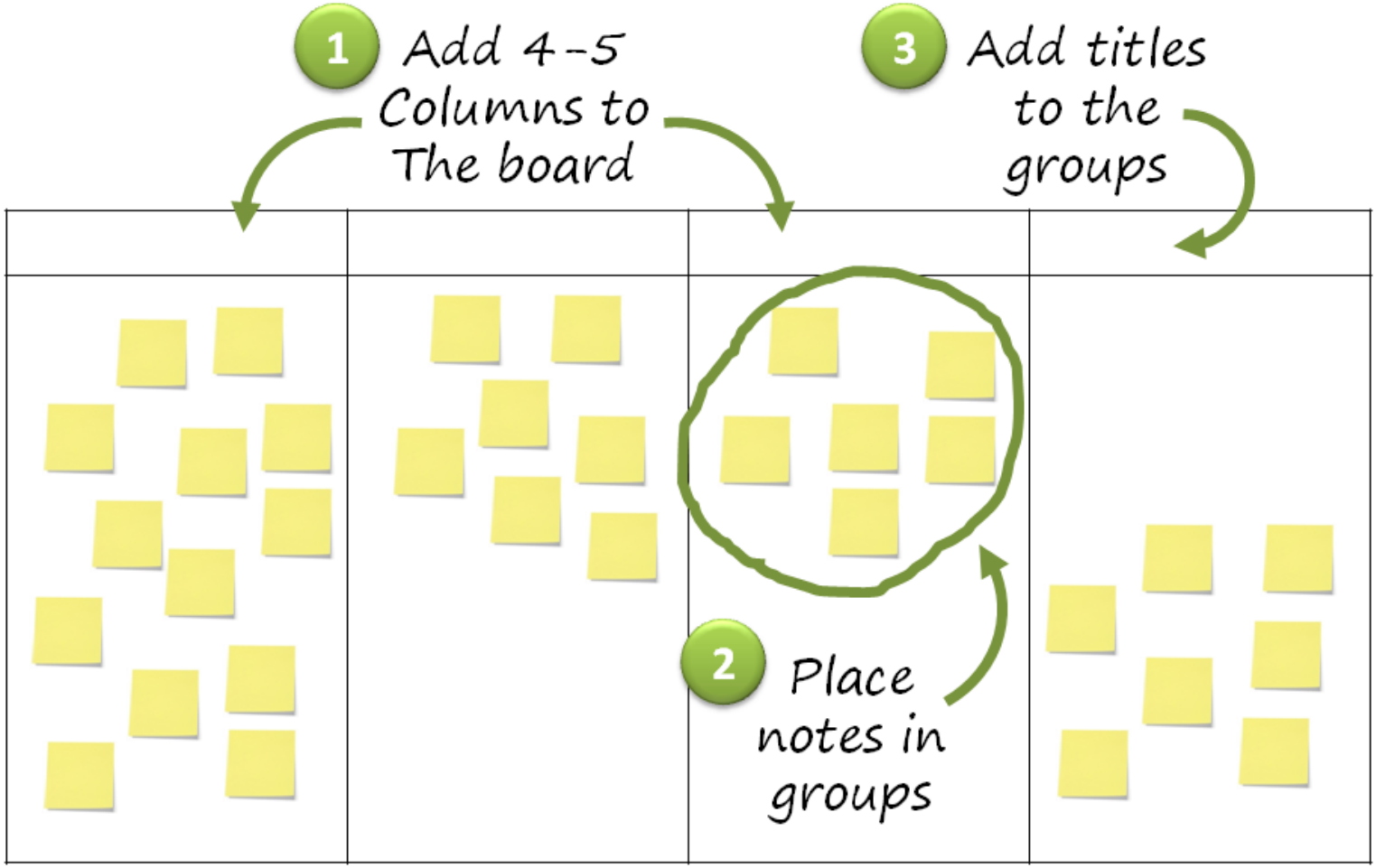
- Come up with at least one idea for a project to design a more energy-efficient house
- Describe it generally in one or two words: door, window, roof, etc.
- Describe what we might do: design and build a **green** roof with a high thermal resistance.



Sticky-note Brainstorming

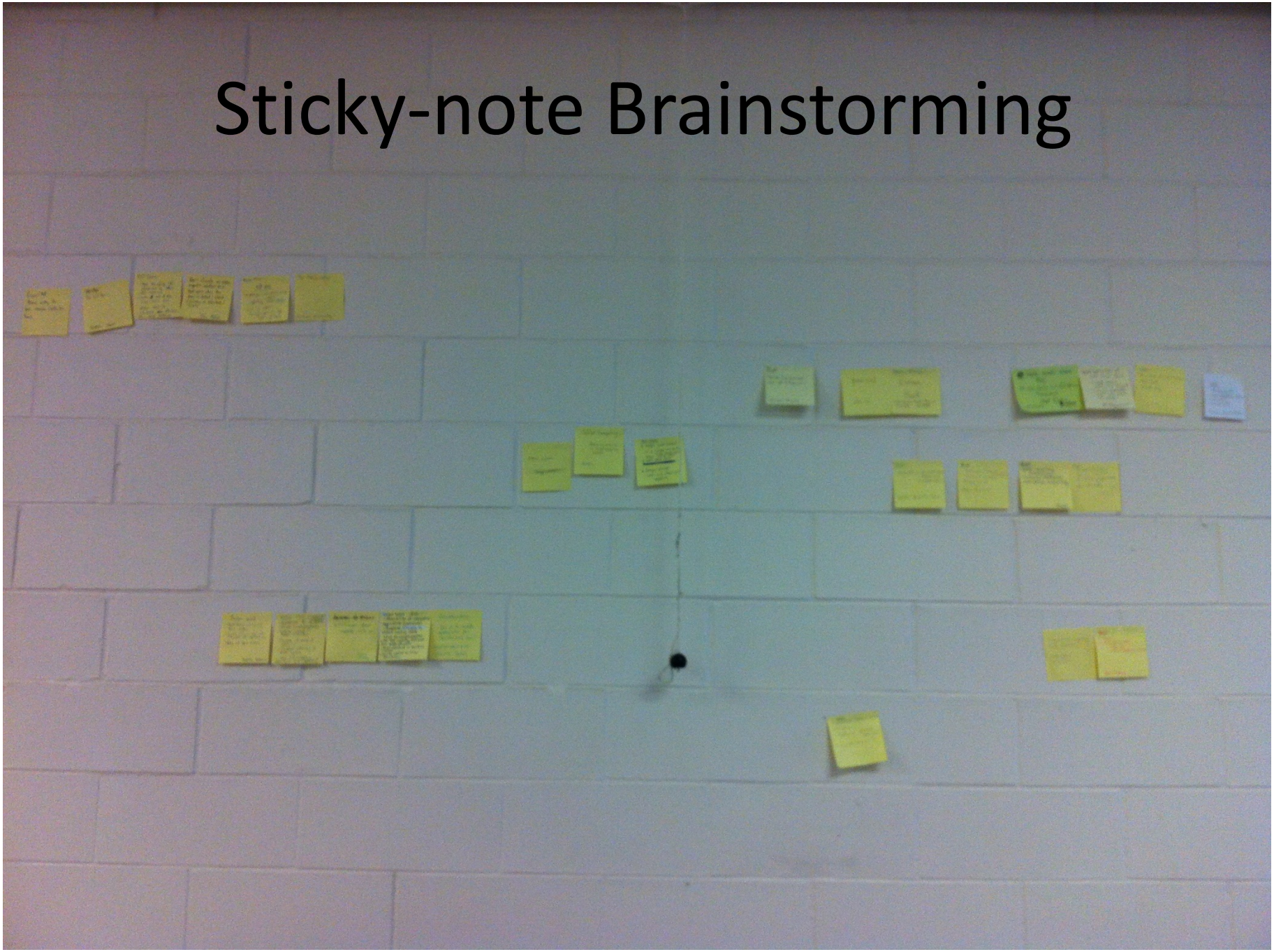


Sticky Notes: Bottom Up Grouping



Use: Organizing items into a whole

Sticky-note Brainstorming



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- international competition held every two years
- 20 university teams design, build and operate solar-powered houses that are cost-effective, and energy-efficient
- winning team of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency

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Stimulating Creativity and Innovation

- Brainwriting
  - Similar to brainstorming – instead of sticky notes, ideas are written out in more detail
  - After some time, the sheets with the written ideas are swapped
  - You then try to expand on the ideas listed on the new sheet of paper
  - Forces constructive ideas without negative feedback
  - Evaluation of the ideas takes place later

Stimulating Creativity and Innovation

- Tips for overcoming creative blocks
  - Don’t assume there is only one answer
  - Don’t avoid new ideas for fear of making mistakes
  - New ideas don’t have to be hard work – simplicity is a good thing
  - Don’t worry about unworkable ideas – having no ideas is much worse
  - Say or write anything because your ideas may stimulate other people

Design Reports

- There are three primary means of communication
  - written
  - oral
  - graphical
- To be successful as an engineer you must be not only technically competent, but versatile with all three forms of communication!
- All three forms of communication are of critical importance in each design step
- The design process is documented in the design report

Written Reports

- The keys to writing great reports:
  - Organize logically
  - Pay attention to detail
    - Never any spelling errors
    - Never any grammatical errors
  - Proof Read, Proof Read, Proof Read
  - **If you don't know how to write well, get help!**
  - **Have someone review your report before you submit it!**

Written Reports

- There are generally three types of written report:
  - Proposal
  - Progress Report
  - Final Report

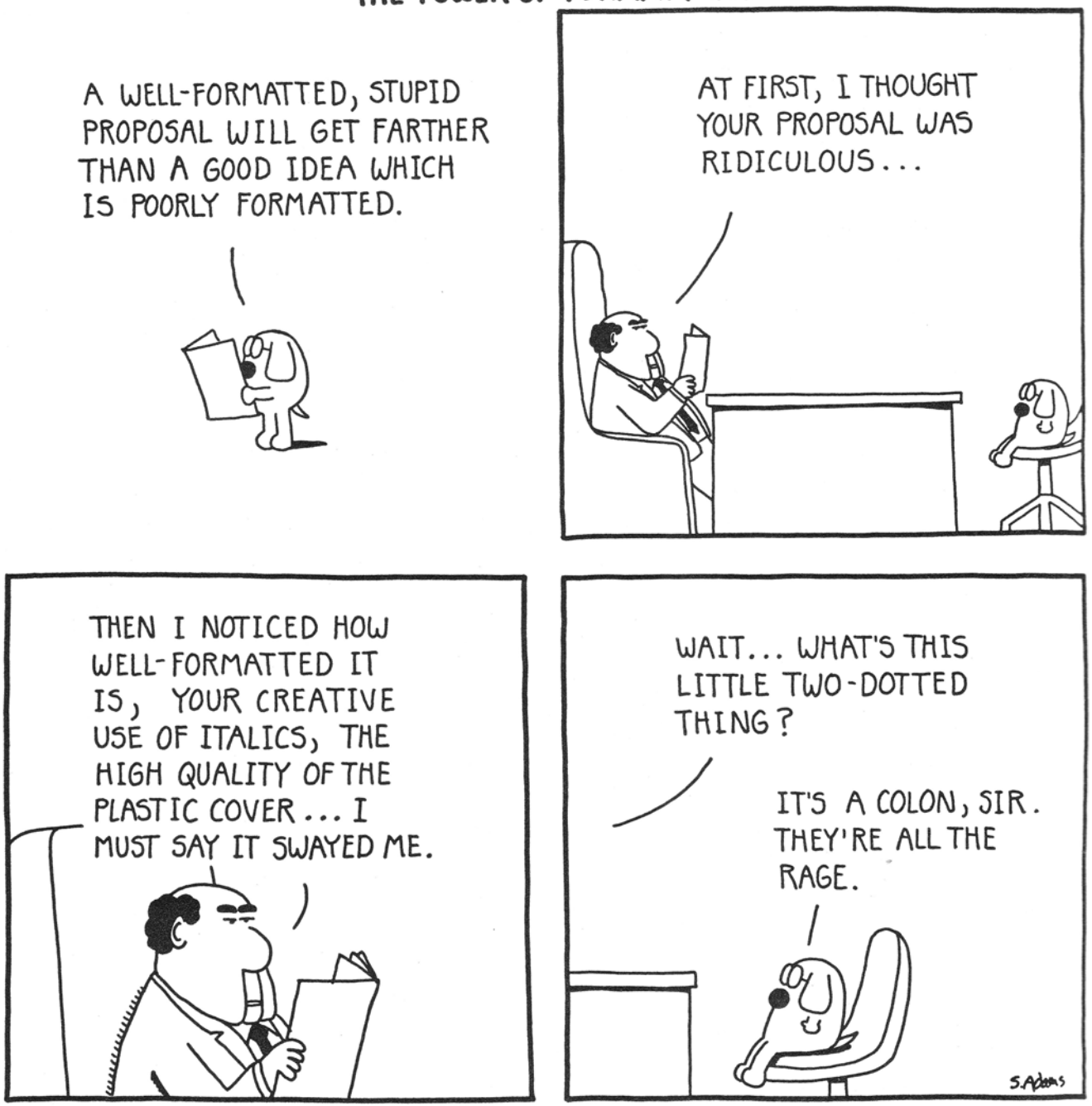
Proposals

- Proposals are written to convince people with money that they should pay for the project
- Proposals should reflect the interests and language of the reader (*i.e.*, know your audience)
  - Investors are interested in profits and returns
  - Managers are interested in benefits and costs to the company
  - Engineers are more concerned with function and feasibility

Proposals

- A typical proposal may contain the following fundamental elements
  - Problem statement; benefits of the work
  - Proposed work plan; how are you going to do it
  - Personnel and facilities needed
  - Schedules for milestones and deliverables
  - Budget
  - Summary

THE POWER OF FORMATTING



Progress Reports

- Periodic reports (i.e., quarterly reports) on the status of the project
- Usually brief letters or memos
- Tells your customer how things are going:
  - Have you discovered something?
  - What problems are you having?
  - Are you on time?
  - Are you on budget?
  - What are you doing to correct any problems?

Progress reports are usually easier to write if you have done some work! Even if you made no progress.

Final Report

- The final report is the final step in the project
- It generally contains:
  - Abstract (Executive Summary, Implications, etc.)
  - Introduction (Problem Statement)
  - Methods Used
  - Body (Results, Findings)
  - Discussion
  - Conclusions

Final Report Format

- A final report typically contains the following elements, or variations on them, depending on the nature of the particular project and on the requirements of the customer
  1. Cover
     - The report should be bound with the title, authors and their affiliations on the cover
  2. Letter of Transmittal (optional)
     - Letters of transmittal are simply cover letters sent with documents to intended readers summarizing the contents

Final Report Format

3. Title Page
   - Contains the title of the report, the authors names and affiliations, and the date (usually the same as the cover)
4. Abstract and/or the Executive Summary
   - The ‘take-home’ message, and the value and implications of the work → what you want the big boss to know
5. Table of Contents
   - The major sections, sub-sections, and their page numbers are listed
6. List of Figures, List of Tables (optional)
   - Usually required for long formal reports
7. Acknowledgements
   - Here any help, financial or technical, in completing the project is recognized

Final Report Format

7. Introduction
   - The problem statement is discussed
   - Explains importance of and need for a solution
   - Background information is outlined
8. Method (actual section title may vary)
   - Covers the general methods and approach used to solve the problem
   - Experimental methods and apparatus are described
9. Body (actual section title may vary)
   - This is the main section
   - It describes collected data, analysis, and steps taken to solve the problem
   - This section usually contains sub-sections that describe distinct components of the solution

Final Report Format

10. Discussion (may be included in the Body)
    - Project findings should relate clearly to the data and analysis presented in the Body
11. Conclusions
    - The findings are summarised and major results listed
12. Recommendations (Suggestions for Further Work)
    - These may also be presented in a sub-section of the Conclusions
13. Appendix
    - Drawings, sketches, raw data, letters, and any supplemental, but extraneous, information related to the project but does not need to be in the main body

Final Report Format

14. References (Bibliography)
    - All reference material not developed by the authors must be listed according to an accepted bibliography style (examples of which you can find in the Library)
        - Reference books
        - Scientific Journal Articles
        - Codes and Standards
        - Magazine Articles
        - Private Communications
        - Theses
    - Always cite your sources, no matter how trivial

Reading Assignment

- For next lecture read Chapters 16 & 17.

ECOR 1010
Lecture 9

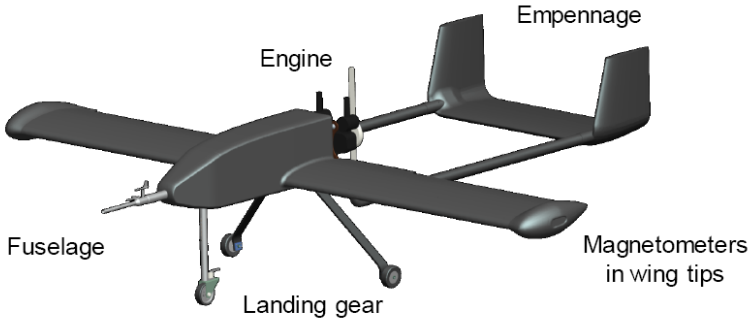
Part 1 - 3D Computer-based Rendering with Pro/E Wildfire

Pro/Engineer Wildfire

- Pro/Engineer® is a set of programs used in the design, analysis, and manufacturing of products
  - Developed by Parametric Technologies Corporation (PTC), MA, USA

Pro/Engineer Wildfire

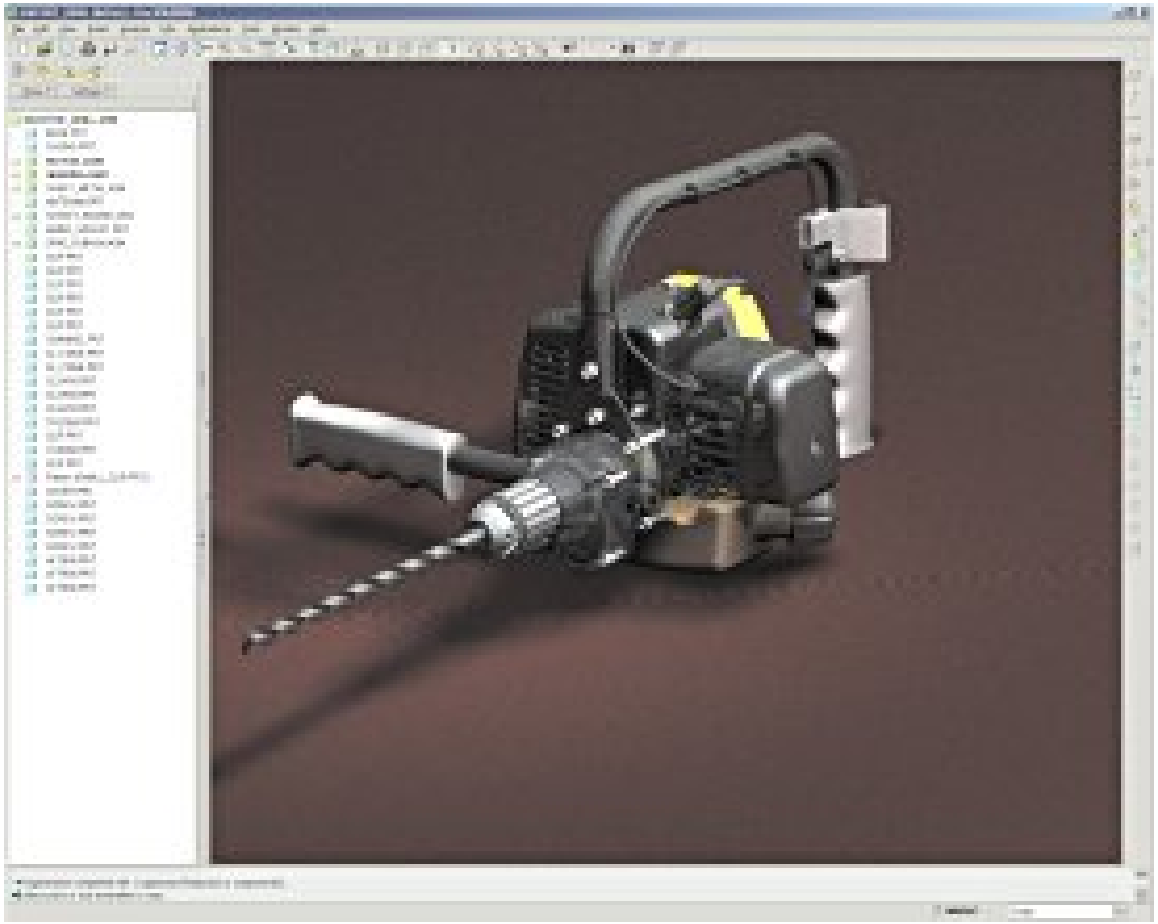
- Pro/Engineer revolutionized the CAD world in the late 1980s
- PTC was the first vendor to offer a ***parametric***, feature-based solid-modeling design platform
- Pro/E Wildfire includes visual realism with real-time photo rendering
  - adds textures, reflections, shadows, and backgrounds to your model



Parametric

- The values of the parameters assigned to the different attributes/dimensions of the model features define the physical shape of the part
- Important changes can be easily incorporated at any point during the design process
- The changes propagate through the model automatically

Pro/Engineer Wildfire



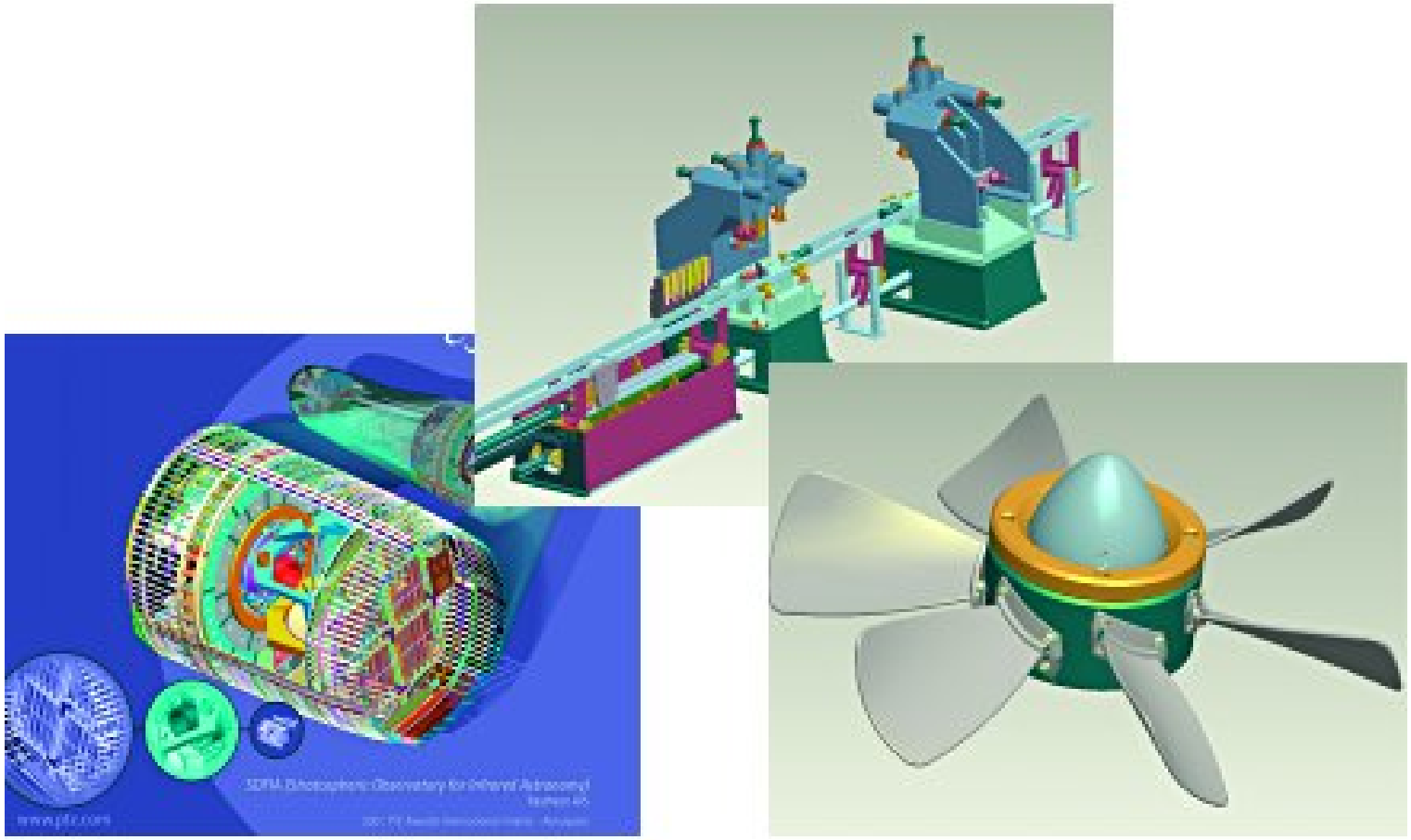
Who Uses Wildfire?

- Pro/E is often the software of choice for product development because it is ‘relatively’ easy to use and you can work with people over the Web
- Used in aerospace, automotive, consumer products and electronics, defence, education, heavy equipment, industrial equipment, life sciences, plastics, shipbuilding, telecommunications, transportation, and more …

Pro/E as an Industry Standard

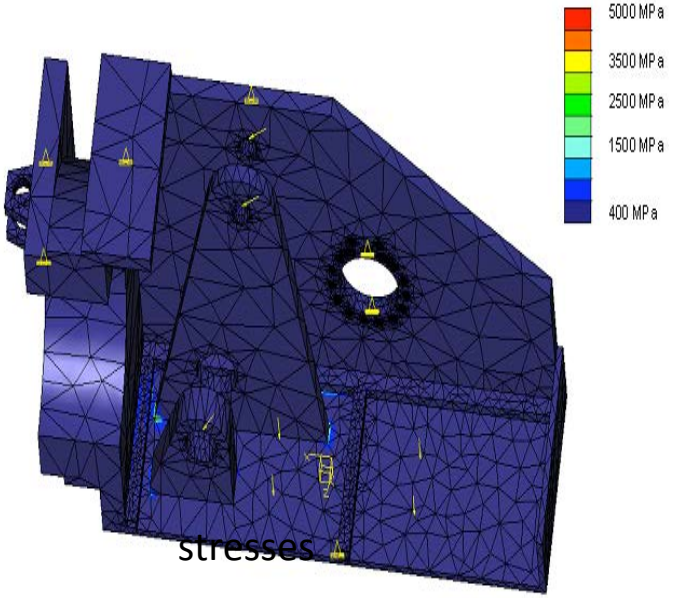
- Since its first release, PTC has developed an assortment of additional software modules for just about every product development industry
  - sheet metal operations,
  - piping layout,
  - mold design,
  - wiring harness design,
  - NC (numerical control) machining,
  - etc ...

Wide Range of Products designed with Pro/E

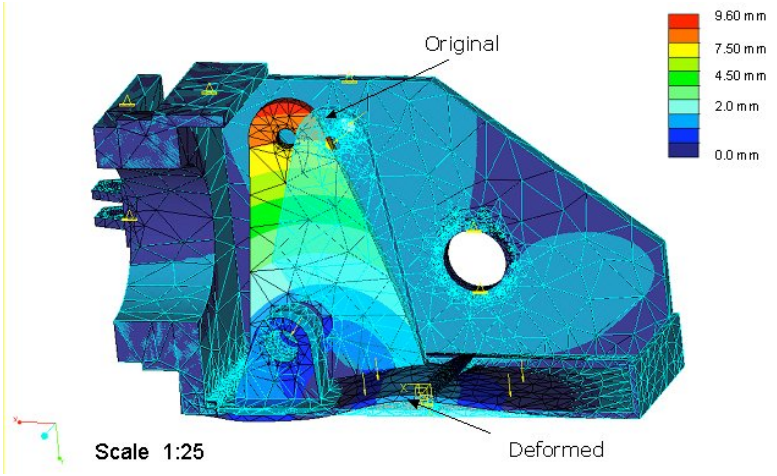


Pro/E as an Industry Standard

Pro/MECHANICA
FEM analysis



stresses



deformations

Pro/E as an Industry Standard

- Pro/E enables the user to create fully detailed standard engineering working drawings almost automatically after model generation

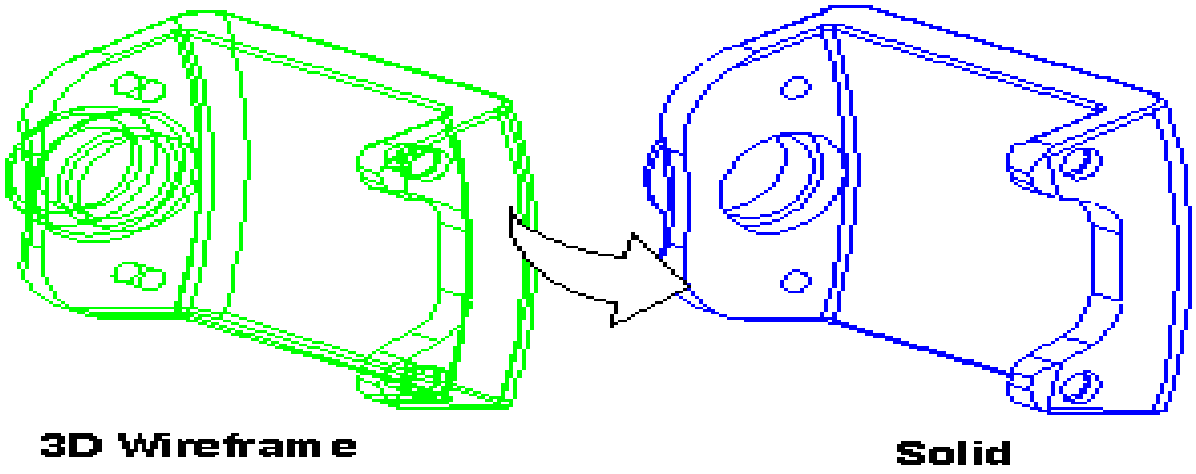
Pro/E as an Industry Standard

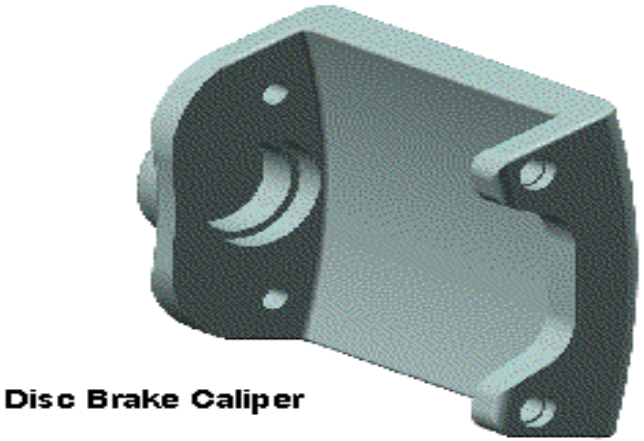
- 3D visualization and modeling capabilities save time during the design phase – you can see what you are proposing
- If a dimension is changed, the solid model will be automatically upgraded
- Prototypes can be produced directly from solid models because they are based on highly accurate geometric models

Solid Modeling

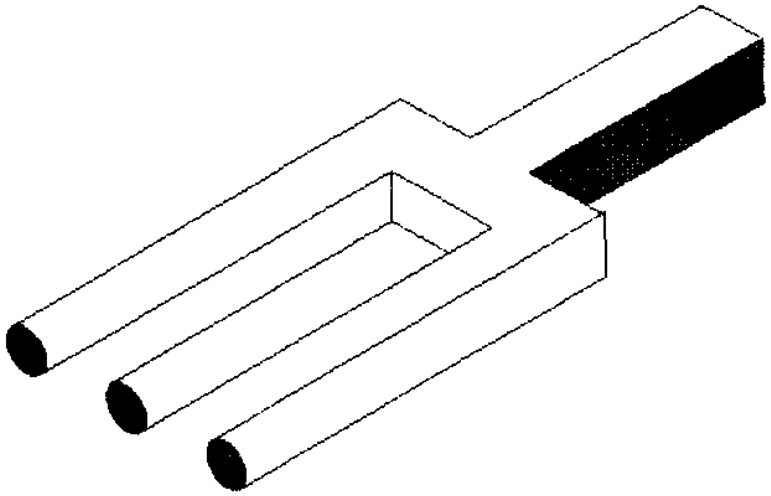
- Solid models are representations of the part or product as it will appear when manufactured
- Solid models are a collection of elements that act as a single object
  - A Pro/E solid has the intelligence to understand that it is a single body with volume, and mass (if assigned density)
- The computer model will contain all the ***parametric*** information that a real solid object has
- Wireframe models (as done with 2D CAD systems) are inadequate for many design, manufacturing and visualization tasks

Solid Modeling

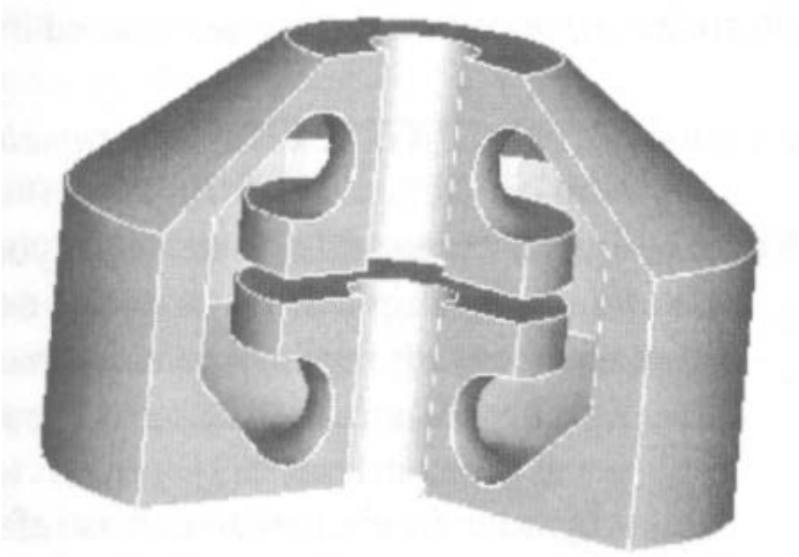




Solid Modeling



The 3-Pronged Blivot -
A Non-realizable Object



Could your machine shop make this?

Today you can !

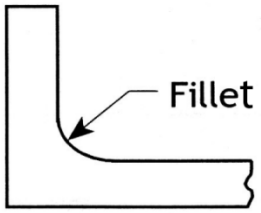
Feature-Based

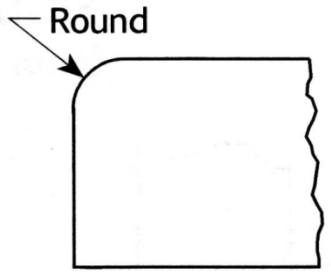
- In Pro/ENGINEER, solid parts (or bodies) are constructed with a series of geometric operations, much like a sculpting process
- Each separate operation (or shape) is called a “feature”
  - Each feature has its own defining characteristics
- A model is created by defining a series of features which can be added to, or subtracted from, the previous set of features

Feature-Based

There are many types of features that you can use…

- **Protrusion** is a profile used to add material.
- **Cut** is a profile used to remove material from an existing body
- **Rounds** and **Fillets** are added to strengthen the part





- **Holes** can be created using a number of different options

Reading Assignment

- Read Chapter 16
  - It will help you in your labs and in your project
  - Check out the Pro/E primer slides on WebCT

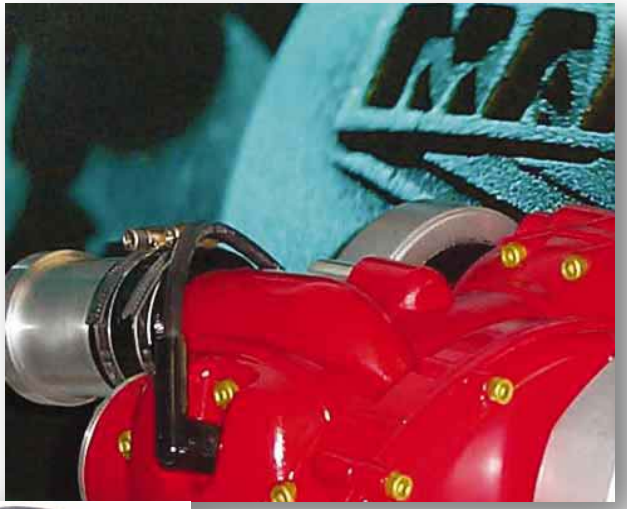
Pro/E Video

ECOR 1010
Lecture 9

Part 2 - Rapid Prototyping
with 3D Printing

What is 3D Printing?

Like the ‘Replicator’ in StarTrek



What is 3D Printing?

See: **Lisa Harouni: A primer on 3D printing**
http://www.ted.com/talks/lisa_harouni_a_primer_on_3d_printing.html
or
http://www.youtube.com/watch?v=OhYvDS7q_V8

3D Printing means we can Rapidly make Prototypes

- Ideal complement to CAD
- Process to build concept and working models from 3D CAD data
  - Several different techniques available
- Used for
  - Communication/collaboration
  - Time reduction
  - Cost reduction

Benefits of Rapid Prototyping

- Real-time prototype design
- Better communication and collaboration
  - Allows design participants to view design iterations, offer firsthand input
  - Allows designers/developers to go from flat screen to exact part
  - Participants can make better informed design decisions throughout a faster product development cycle (reduced costs, fewer engineering changes)
  - Can examine more concepts, check design changes

Benefits of Rapid Prototyping

- Time reductions
  - Life spans shorter (6 months)
  - Design cycles, time-to-market shorter
  - Multiple design iterations and immediate feedback are possible during the early stages of the development process
  - Quickly refine “form, fit, function”
    - Affects production costs and time to market

Benefits of Rapid Prototyping

- Cost reductions
  - Design changes
    - proof-of-concept - $100
    - development - $1,000
    - production - $100,000
    - field - $1,000,000
  - You can afford to do numerous design iterations
  - Can explore more designs more efficiently
    - Can do this without extensive time or tooling expense

The Basic Process of Rapid Prototyping with 3D Printing

- All current rapid prototyping techniques employ the same basic five-step process
  1. Create a CAD model of the design
  2. Convert the CAD model to STL format
  3. Slice the STL file into thin cross-sectional layers
  4. Build the model one layer atop another
  5. Clean and finish the model

STL Files

- Stereolithography (STL) files were introduced in software by 3D Systems of Valencia, CA, as a method for storing info about 3D objects
- The STL (.stl) file format is an industry standard data transmission format
  - Used in Rapid Prototyping to produce physical 3D models or replicas

STL Files

- STL files reproduce an object's 3D geometry by storing a set number of facets or 3D triangles in a complex digital model
- After storing the outer and/or inner surface of a 3D object as facets in an STL file, the digital model can be manipulated, and a physical representation of a 3D model can be made

STL Files

- The more complex the model, the more triangles produced, and the larger the STL file

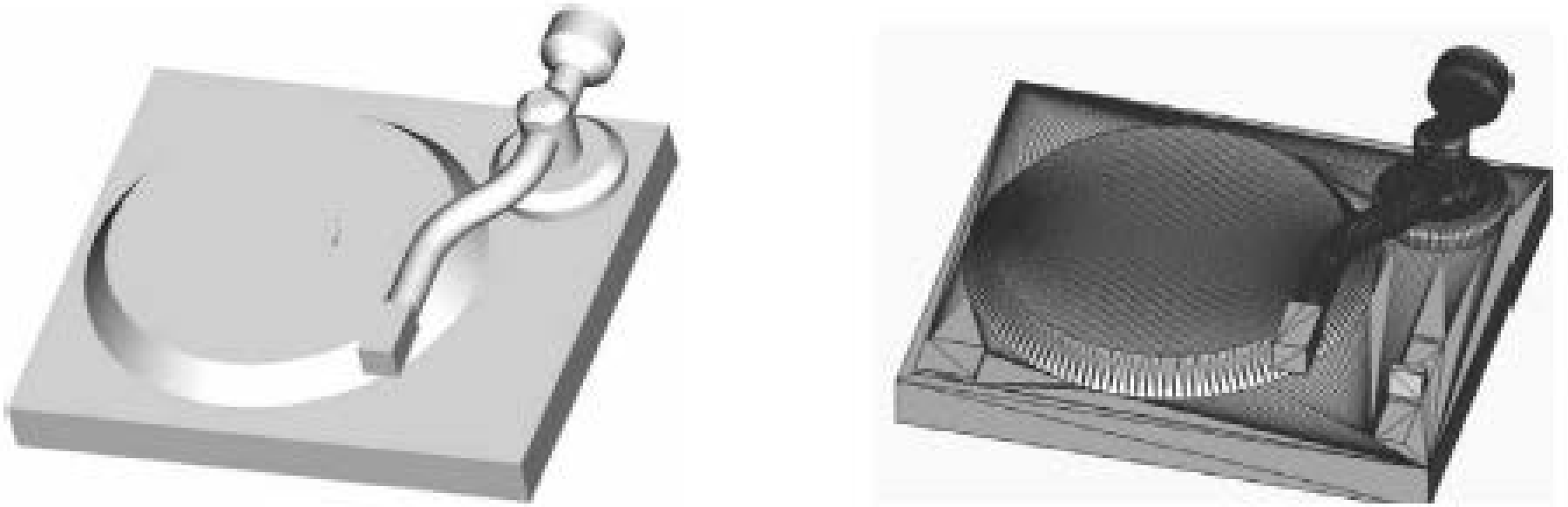


Figure 17.1 Conversion from Pro/E. prt file to. stl file.

Additive and Subtractive RP

- There are two main methods of rapid prototyping, which are derived from similar approaches in sculpture
  - Additive Rapid Prototyping (ARP)
  - Subtractive Rapid Prototyping (SRP)

Additive and Subtractive RP

- Subtractive Rapid Prototyping (SRP):
  - The machine starts out with a block of plastic and uses a delicate cutting tool to carve away material, layer by layer to match the digital object; this is similar to numerical controlled (NC) machining
- Additive Rapid Prototyping (ARP):
  - The machine reads in data from a CAD drawing, and lays down successive layers of liquid plastic, or some other building material, and in this way builds up the model from a long series of planar cross section layers

Subtractive Rapid Prototyping

- Great for testing as the final material can be milled
- Uses a wide variety of inexpensive materials, including polyurethane, resin, ABS* plastic, aluminum and brass
- Prototypes take less time to produce and also are less expensive
- When the prototype is done, it requires no hand finishing

* (acrylnitrilebutadene styrene)

Subtractive Rapid Prototyping

Subtractive Rapid Prototyping Machine

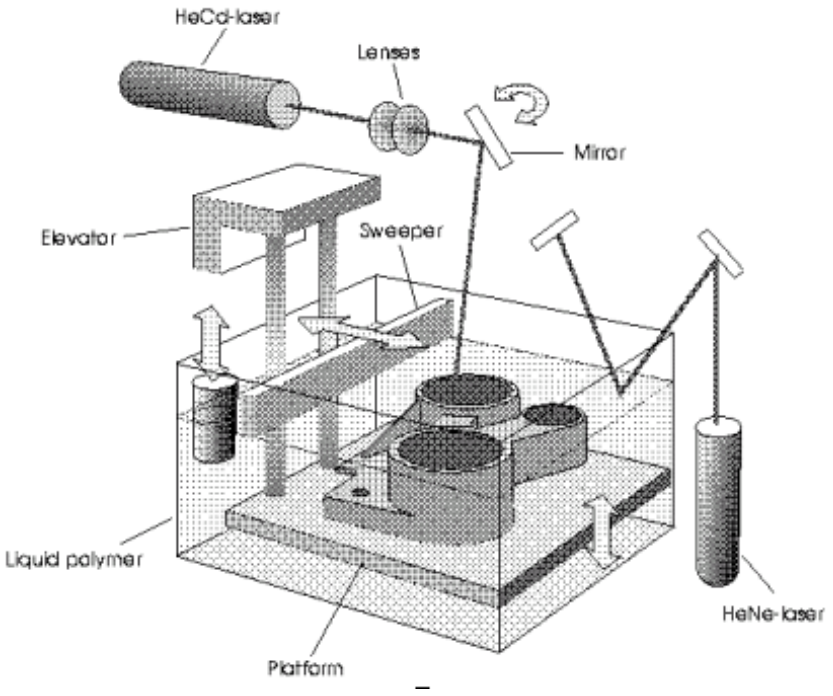
Roland DG – MDX 540

Additive Rapid Prototyping Techniques

- Most commercially available additive rapid prototyping machines use one of 6 techniques:
  1. Stereolithography
  2. Laminated Object Manufacturing
  3. Selective Laser Sintering
  4. Fused Deposition Modeling
  5. Solid Ground Curing
  6. 3-D Ink-Jet Printing

1: Stereolithography (SL)

- Patented in 1986, stereolithography started the rapid prototyping revolution
- Uses a light-sensitive liquid polymer
- Builds 3D models from liquid photosensitive polymers that solidify when exposed to ultraviolet light



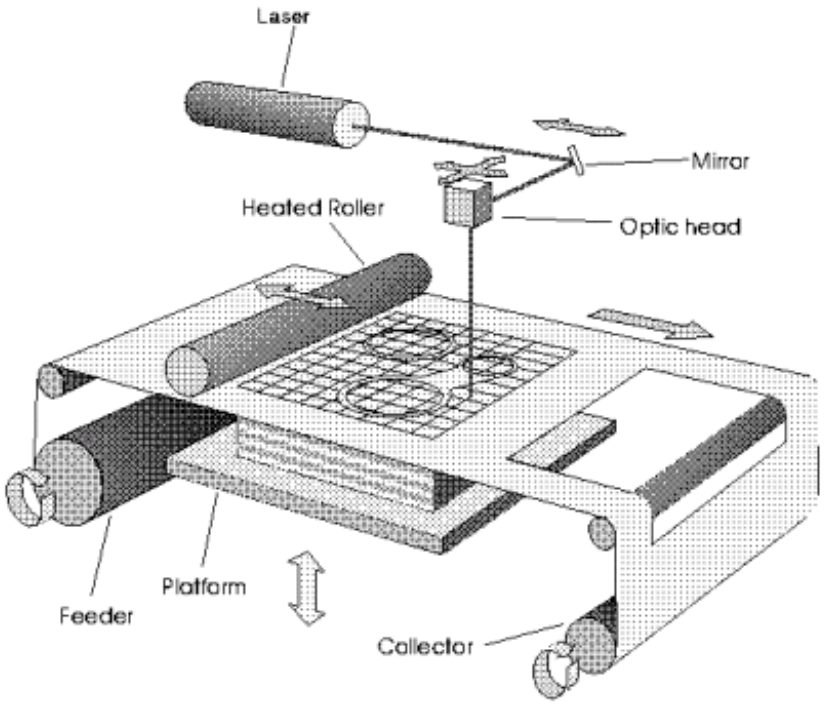
Schematic diagram of the stereolithography process

1: Stereolithography (SL)

- Excellent for making complex prototypes with fine details
- Favourite in the aerospace industry
  - the most common application is producing wind tunnel models
- Inexpensive compared to traditional machining

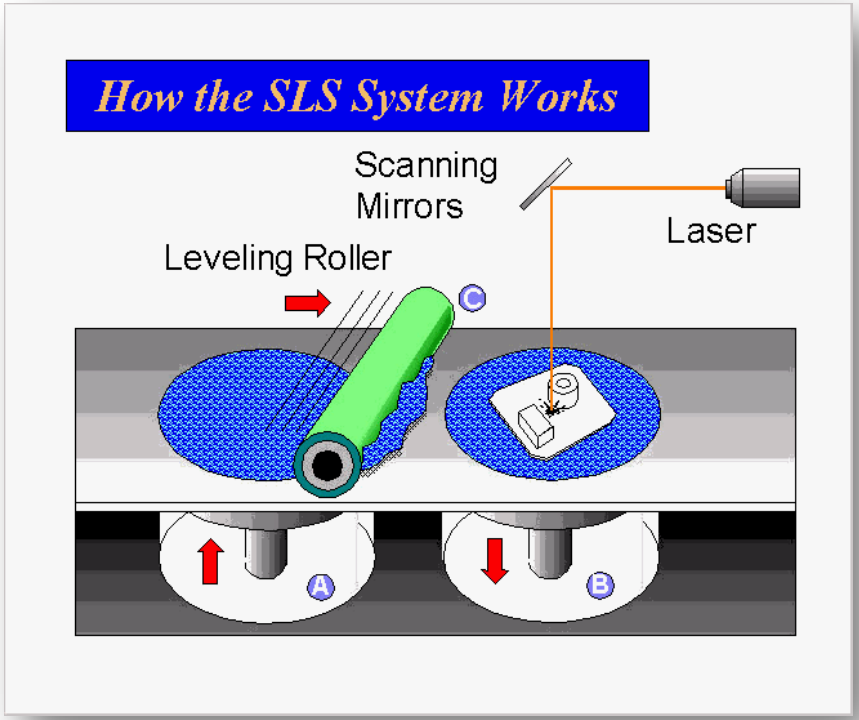
2: Laminated Object Manufacturing

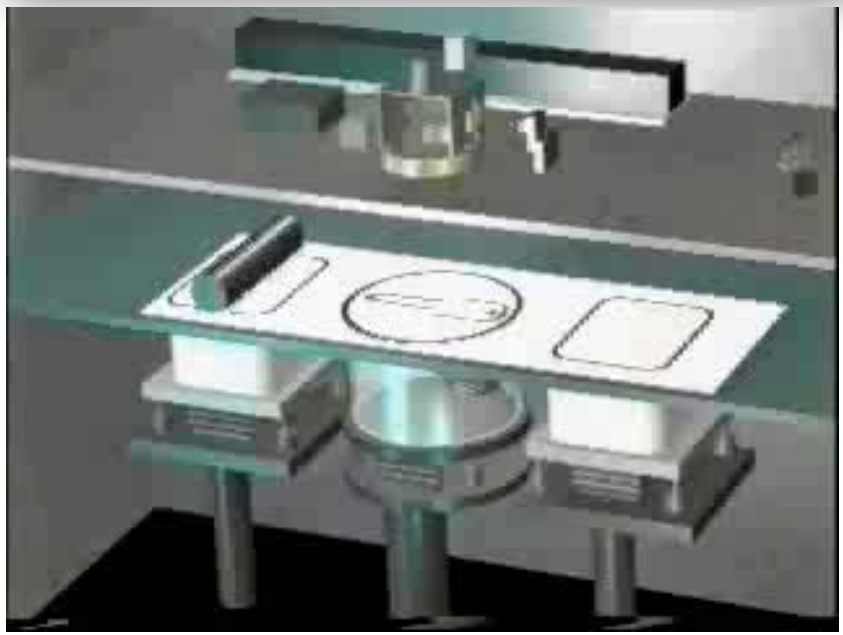
- Developed by Helisys of Torrance, CA
- Layers of adhesive-coated sheet material are bonded together to form a prototype
- Low cost as raw material is readily available
- Because there is no chemical reaction involved, parts can be made quite large



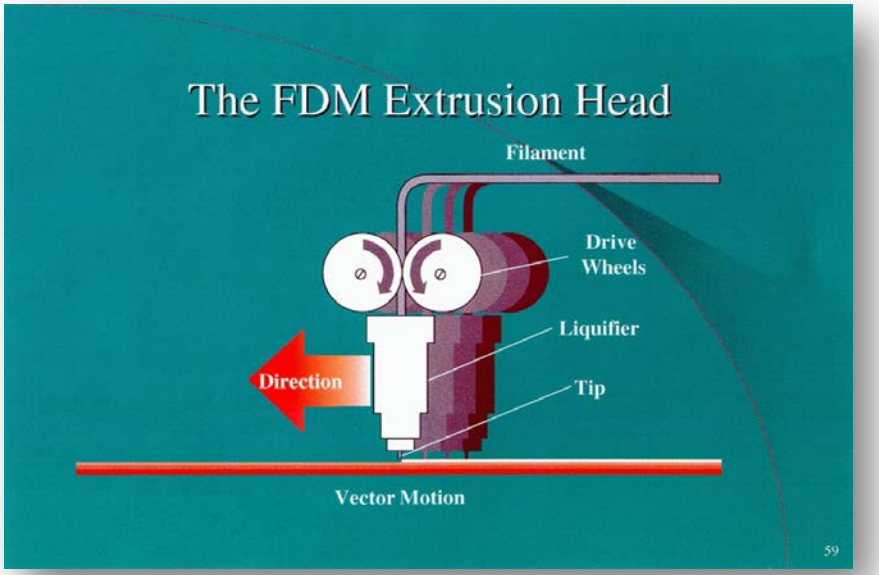
3: Selective Laser Sintering

- Developed by Carl Deckard for his master's thesis at the University of Texas and patented in 1989
- Uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object





4: Fused Deposition Modeling (FDM)

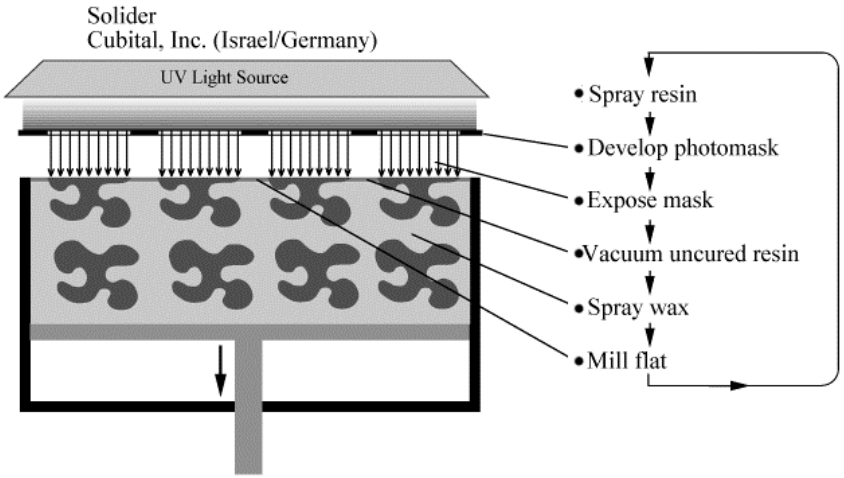


- Developed by Scott Crump in 1988
- Stratasys, of Eden Prairie, MN makes a variety of FDM machines ranging from fast concept modellers to slower, high-precision machines
- Materials include ABS, elastomer, polycarbonate, polyphenolsulfone, and investment casting wax

4: Fused Deposition Modeling (FDM)

- Specializes in building small, durable, handheld components
- Although improved in recent years, surface finish and accuracy are not among the strongest points of FDM
- The Dimension BST 3D-Printer in 2230 uses the FDM Process

5: Solid Ground Curing (SGC)



- Invented and developed by Cubital Inc. of Israel
- Similar to stereolithography (SL) in that both use ultraviolet light to selectively harden photosensitive polymers
- Unlike SL, SGC cures an entire layer at a time

6: 3-D Ink-Jet Printing

- Ink-Jet Printing refers to an entire class of machines that employ ink-jet technology
- The first was 3D Printing (3DP), developed at MIT and licensed to several selected companies
- Parts are built upon a platform in a bin of powder material selectively hardened with binder deposited with the print head
  - This process is very fast, but produces brittle parts with a slightly grainy surface
- The 3D-Printer Z-Corp 400 in 2260 is an example of this technology

3D Printing

- 3D printing is a variation of rapid prototyping
- A 3D printer is less expensive, easier to use and usually faster than a RP system

3D Printing

- Most importantly a 3D printer can fit in an office environment
- Unlike a big rapid prototyping system a 3D printer can be located next to the design engineers so they can turn around jobs promptly and efficiently

The Dimension BST

- One of the 3D-printers available for your use

The Dimension BST

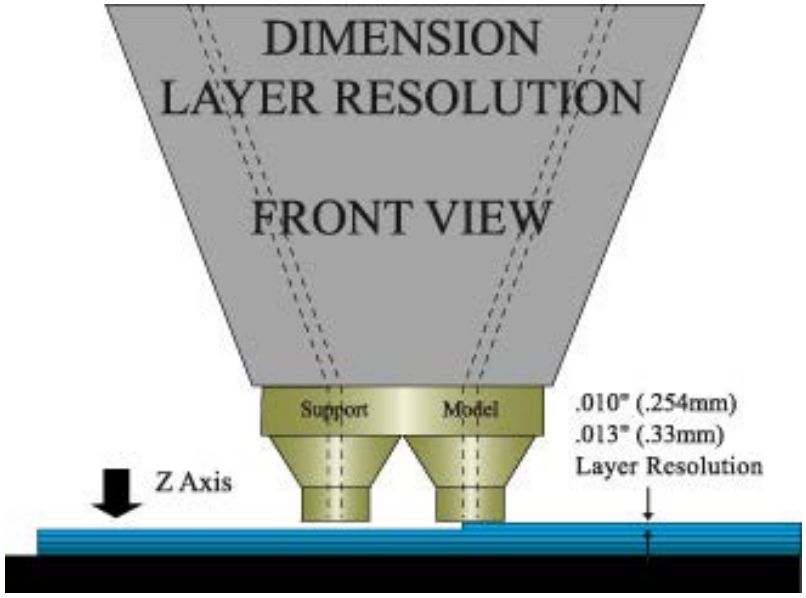
- Dimension is a business unit of Stratasys, Inc., located at Eden Prairie, Minnesota
- The Dimension 3D Printer is a networked, desktop modeling system
- Used in evaluating design concepts, testing 3D models for functionality, form and fit

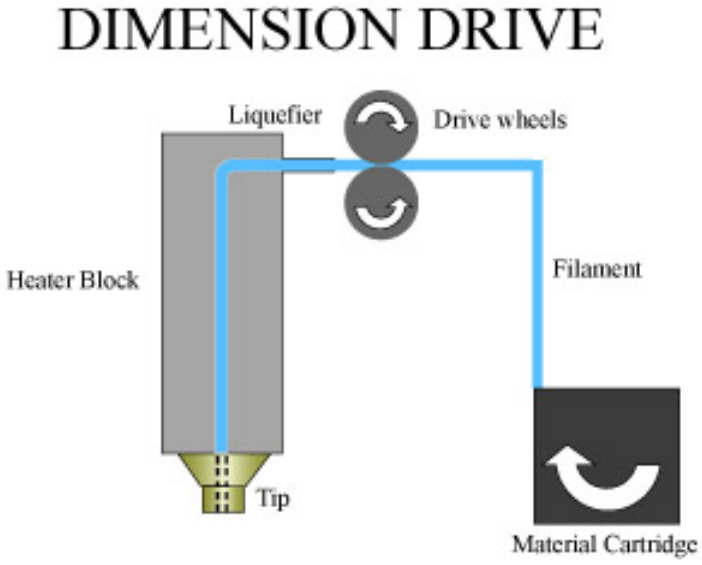
The Dimension Process

- Based on the patented Stratasys FDM process, Dimension builds functional 3D models from the bottom up, one layer at a time using ABS (acrylnitrilebutadene styrene) plastic
- STL files are imported into Catalyst™ software which automatically slices and orients the parts and creates any necessary support structures

The Dimension Process

- A thin filament of ABS plastic is passed through a liquefier
- An extrusion head deposits the material in layers in a semi-molten state and the prototype is produced
- After completion of the build, support structures are simply removed





The Dimension Process

- Two materials are used: one for the prototype and one for the breakaway supports
- The Catalyst software determines where ABS plastic should be deposited and where the support material should be deposited

The Z400 3D-Printer

- One of the 3D printers available for your use

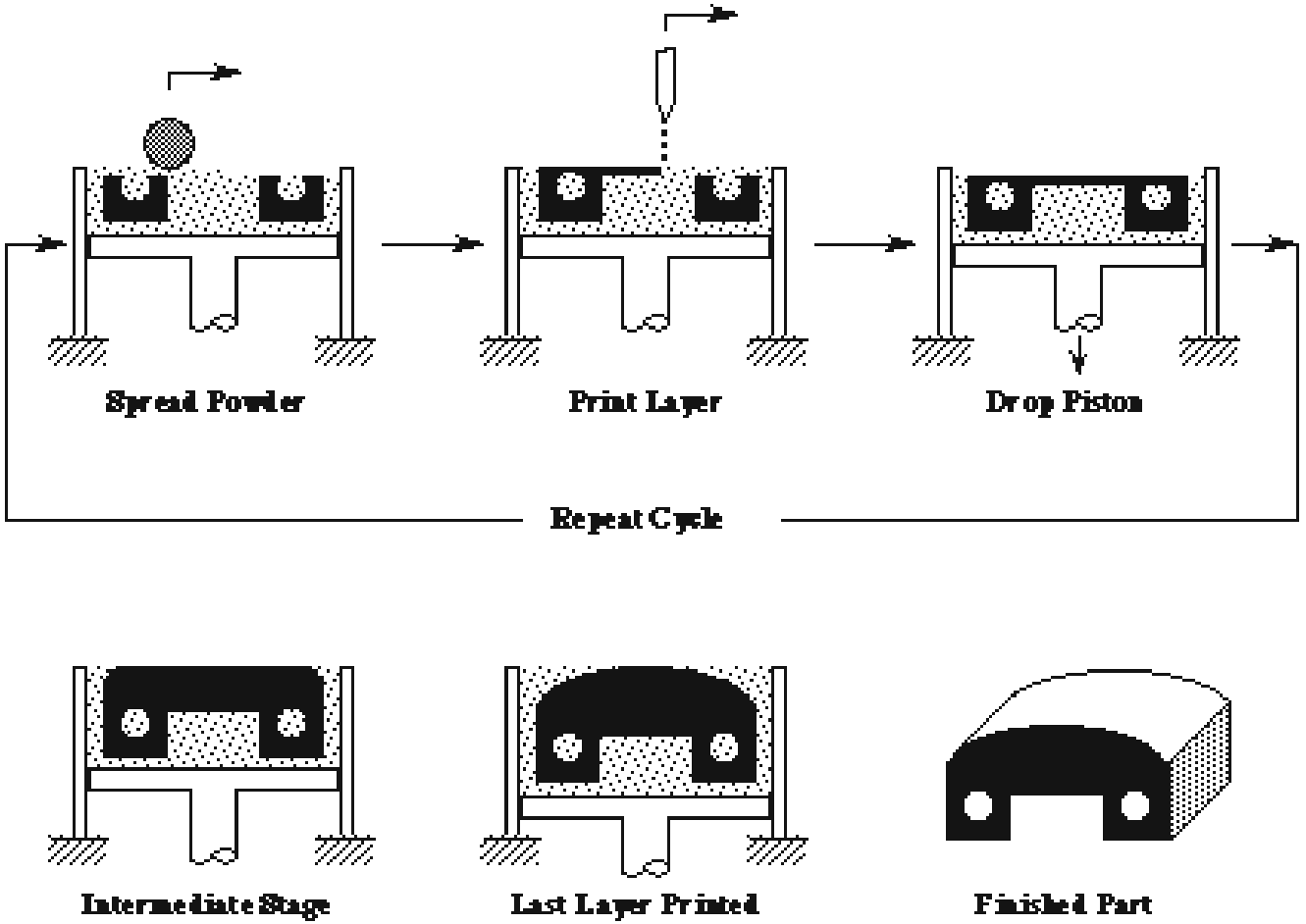
The Z400 3D-Printer

- Developed by Z-Corporation in Burlington, MA
- This system is fast, convenient and easy to operate
- Used in concept modeling, functional testing, model presentation and finite element analysis

3-D Ink-Jet Process

- An ink-jet printing head selectively deposits or "prints" a binder fluid to fuse the powder together in the desired areas and unbound powder remains to support the part
- After each layer is complete the platform is lowered, more powder added and levelled, and the process repeated

3-D Ink-Jet Process



3-D Ink-Jet Process

- When finished, the part is then removed from the unbound powder, and excess unbound powder is blown off
- Finished parts can be infiltrated with wax, glue, or other sealants to improve durability and surface finish

Efficient Use of RP

- Different RP systems yield prototypes best suited for different applications. Selecting the right one will help you save time and money and achieve better results as an engineer

See:
http://www.ted.com/talks/anthony_atala_printing_a_human_kidney.html

Reading Assignment

- You should have now read Chapters 12 to 17

Mid-Term Exam Thursday Oct. 11

- All Lecture Material to today
- All Textbook Reading Assignments
- Laboratory Assignments 1 to 3
- Review Class Next Week

ECOR1010

Engineering Statistics

Motivation

- To learn methods of statistical analysis:
  - What is available.
  - How to interpret results.
  - What are the pitfalls and caveats.
  - The necessity of good experimental design, technique and data-analysis to achieve high quality results.

Overview of Statistics

- Statistical Analysis is the science of data collection and data interpretation.
  - Uses formal ***probabilistic*** methods for **drawing inferences** and **making decisions** from these data.
    - Summarize data
    - Maximize information derived from data
    - Test alternate hypotheses or models
    - Compute probabilities of future occurrences
    - Make rational decisions based on data and information.
  - Quantifies our Ignorance (uncertainty)

What are Statistics?

- Statistics are about ways to describe our previous experience
- Statistics are useful as guides and motivators
- Statistics are generally poorly understood and often abused
- “Oh, people can come up with statistics to prove anything, 14% of people know that”, Homer Simpson.

Definition of a Statistic

- **A statistic is a specified, determinable function of a set of observations (data set)**

- Given n measures of some "random" quantity: x_i

you can calculate various statistics such as these examples:

n is the sample size

$\sum_{i=1}^{n} x_i$ is the sample sum $= x_1 + x_2 + x_3 + \ldots x_n$

$\frac{1}{n}\sum_{i=1}^{n} x_i$ is the sample mean (arithmetic average)

$\sum_{i=1}^{n} x_i^2$ is the sample sum of squares

$R = \max(x) - \min(x)$, the sample range

Definition of a Statistic

- Statistics are numbers that we use to describe a large number of measurements
- Depending on what is being measured, some statistics are better than others, and some statistics are of no real value.
  - Just because you can calculate something does not make it useful !!
- An example of a silly statistic:
  - If you have one hand in cold water and the other hand in hot water, does the mean (average) temperature tell you anything about how comfortable you feel?

$$T_{avg} = \frac{(T_{cold} + T_{hot})}{2}$$

Sometimes an arithmetic average (Mean) is relevant:

- because it gives an indication of where the ‘center’ of the measurement distribution is.
- Median is another statistic used to indicate the ‘center’
- Mode is a statistic used to indicate the most probable measurement

Mean

- **Mean** (or arithmetic average) is the sum of all the data divided by the number of data points
  - Notation depends on whether we are computing the mean of a **population** (N) or of a **sample** (n)

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad \overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Recall: $\sum_{i=1}^{N} x_i = x_1 + x_2 + \cdots + x_N$

Median

- **Median** is the value of the data point in the centre of the data set when arranged in ascending (or descending) order
- E.g., 2.98, 3.18, 3.25, 3.50 and 3.74
  - Median is 3.25
- If there is an even number of points, the median is the mean of the two centre data points
  - E.g., 2, 3, 6, 7, 12, and 15
  - Median is (6 + 7)/2 = 6.5

Mode

- **Mode** is one (or more) sets of numbers that occurs with the greatest frequency
- e.g., 2, 2, 5, 7, 9, 9, 9, 10, 10, 11, 12, and 18
  - Mode is 9 (is unimodal)
- e.g., 2, 3, 4, 4, 4, 5, 5, 7, 7, 7, 9
  - Modes are 4 and 7 (called bimodal)
- A data set can have no mode (e.g., uniform)

How to make a Histogram

- Start with a data set of observations
- Find the big Range

  (= max value - min value);
- Make a ‘number’ of bins with smaller equal-size ranges that span the big Range;
- Count how many of your data fit in the ranges of your bins

4.98	5.23	5.46	4.36	4.94
5.01	5.92	5.98	4.23	4.79
5.42	4.76	5.38	5.85	5.10
4.75	5.02	5.88	5.65	5.43
6.05	5.67	5.32	4.97	5.55
5.87	6.12	5.68	5.39	5.99
4.93	5.27	5.59	6.20	4.96
5.03	5.26	5.29	5.40	6.31
4.65	5.19	5.38	5.78	5.99
4.82	6.22	5.45	5.21	5.87
5.07	5.68	5.34	5.34	5.06
5.33	5.89	5.01	6.10	6.29
4.67	5.20	5.31	5.78	5.92
4.81	6.19	5.47	5.01	5.87
5.09	5.69	5.37	5.56	5.93
5.05	5.63	5.35	4.43	5.59
5.84	6.10	5.77	5.33	5.01
4.91	6.02	5.56	6.25	4.99
4.56	5.60	5.23	5.25	5.89
5.24	5.87	5.43	5.98	6.03

Heights of 100 Residents in Anytown, Canada (ft)

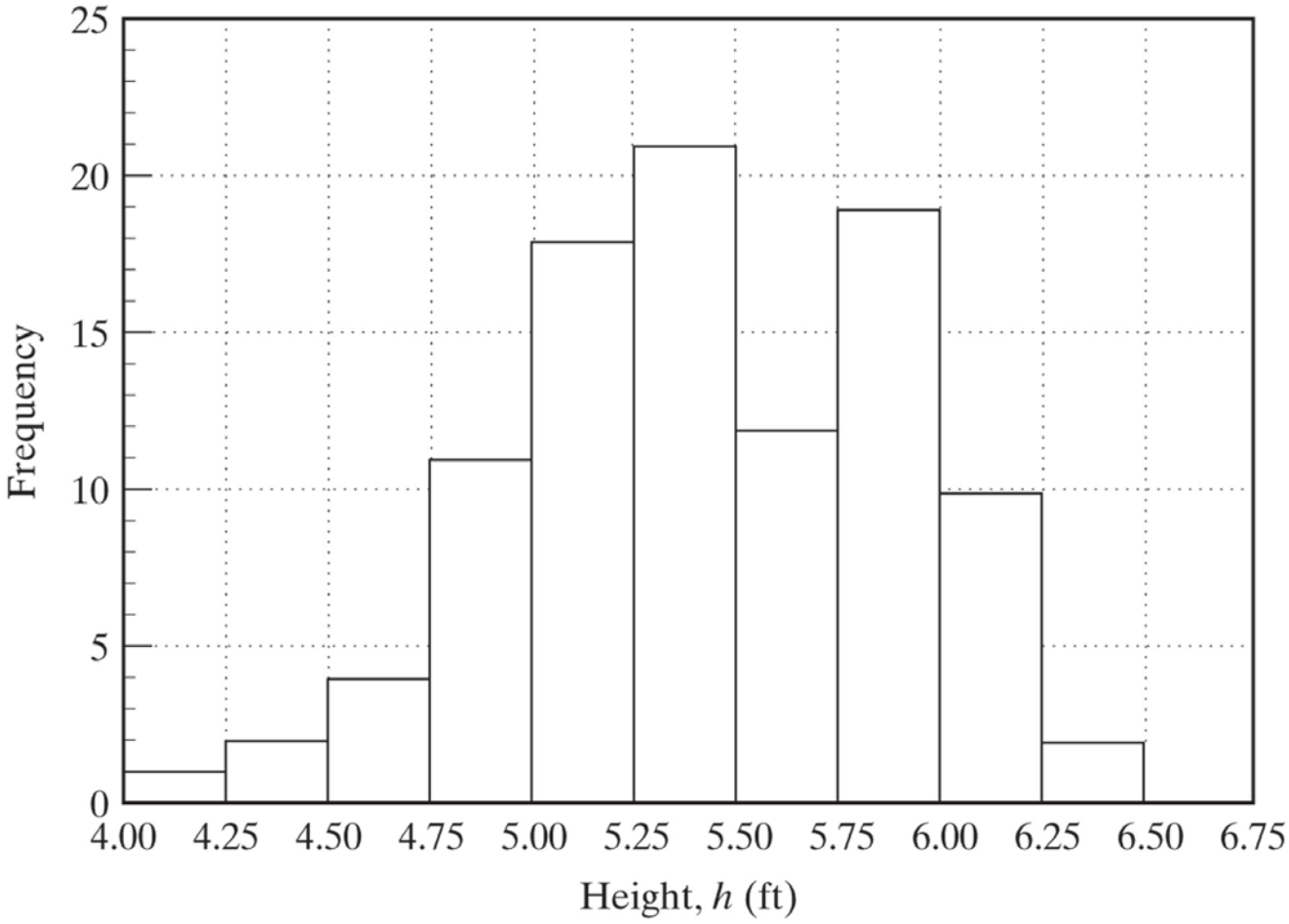
Introduction to Engineering Analysis, 3rd Edition, K. D. Hagen, 2008

Classification of Height Data

Class	Height range (ft)	Tally	Frequency
1	4.00–4.25	|	1
2	4.26–4.50	||	2
3	4.51–4.75	||||	4
4	4.76–5.00	𝍸 |	11
5	5.01–5.25	𝍸 𝍸 |||	18
6	5.26–5.50	𝍸 𝍸 𝍸 |	21
7	5.51–5.75	𝍸 ||	12
8	5.76–6.00	𝍸 𝍸 || ||	19
9	6.01–6.25	𝍸	10
10	6.26–6.50	||	2
		Total	100

Horizontal Histogram

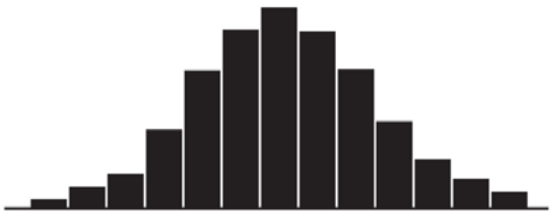
Histogram for Heights in Anytown



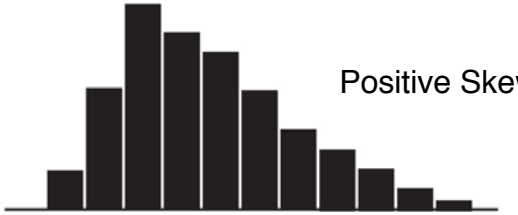
Histograms

- Valuable statistical tool for showing the **frequency distribution** of data
  - Information about location, spread, and shape that is portrayed can provide clues about the underlying process that generated the data

Frequency Distributions (Histograms)



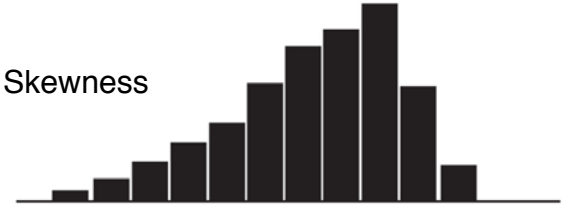
(a) Normal distribution



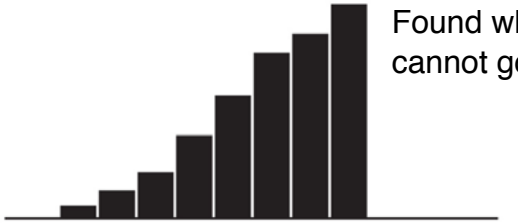
Positive Skewness

(b) Right-skewed distribution

Negative Skewness

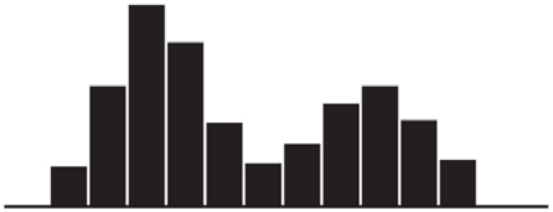


(c) Left-skewed distribution



Found when measurement cannot go above/beyond a value

(d) Truncated distribution



(e) Bimodal distribution

(f) Uniform distribution

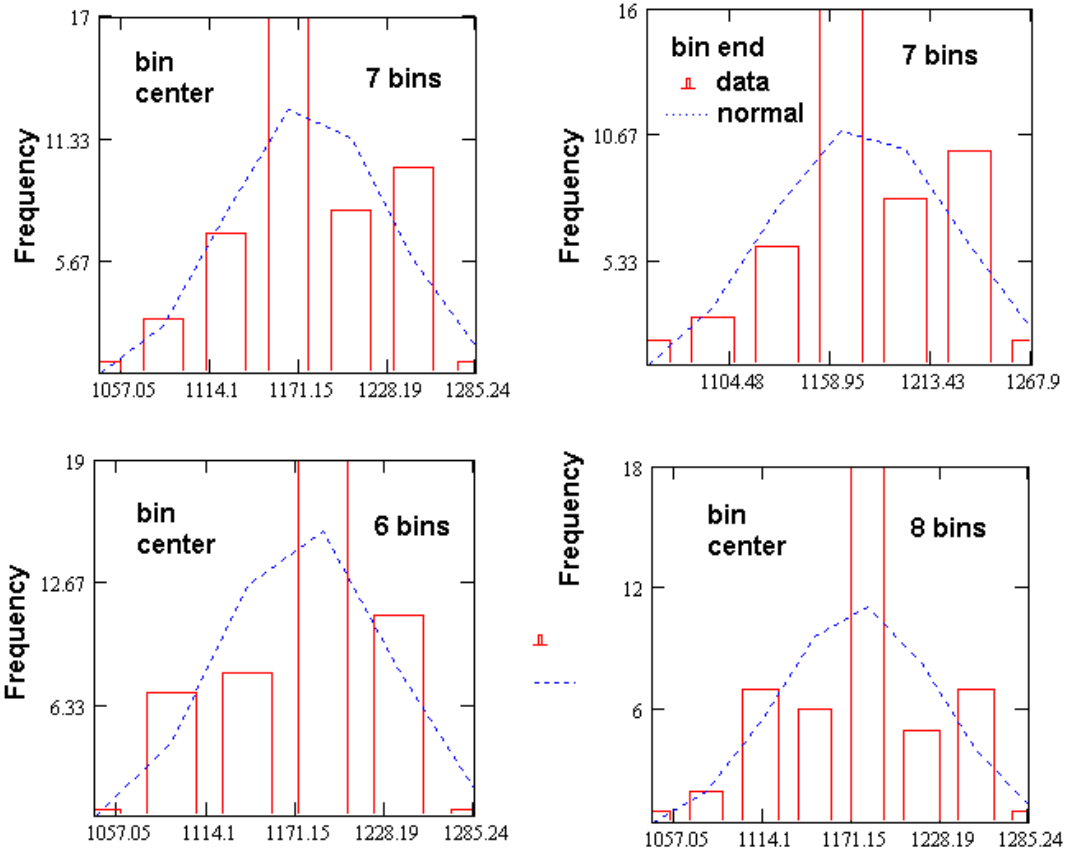
Note that Figure 18.4 in the textbook has left skew defined incorrectly.

Distributions

- Many types of distributions
- The distribution that best describes your data will depend on the 'physics'
- Many engineering measurements have **normal** (or near normal) distributions
  - Normal distributions are also called Gaussian distributions, and sometimes Bell curves
- Other distributions
  - Bimodal, multimodal, flat, skewed (either right or left), etc.

Aside on Histograms

- The appearance of histograms is quite dependent on the number of bins and how the bin boundaries are computed.



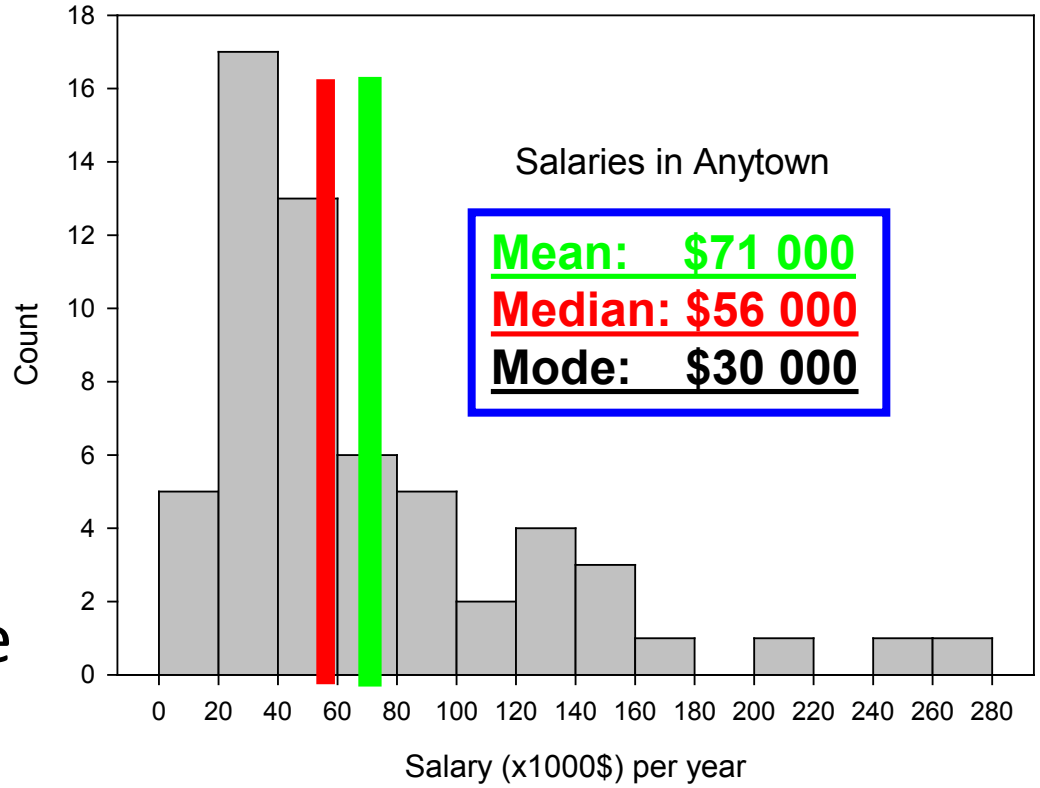
See also: onlinestatbook.com/rvls/index.html
Go to the 'Simulations/Demonstrations' link and then to 'Histograms' and then to 'Histograms, Bin Widths and Cross Validation'

Abuse of Statistics

- There is a famous expression that you might hear when people talk about statistics
- It is attributed to Mark Twain and/or Disraeli in the early 1900's.
- "There are three types of falsehoods, each worse than the one before – lies, damned lies, and statistics."
- This is meant to be funny, but it does reflect a feeling people have that statistics can be used to prove anything, hence, people mistrust statistics.

Stretching the truth with statistics

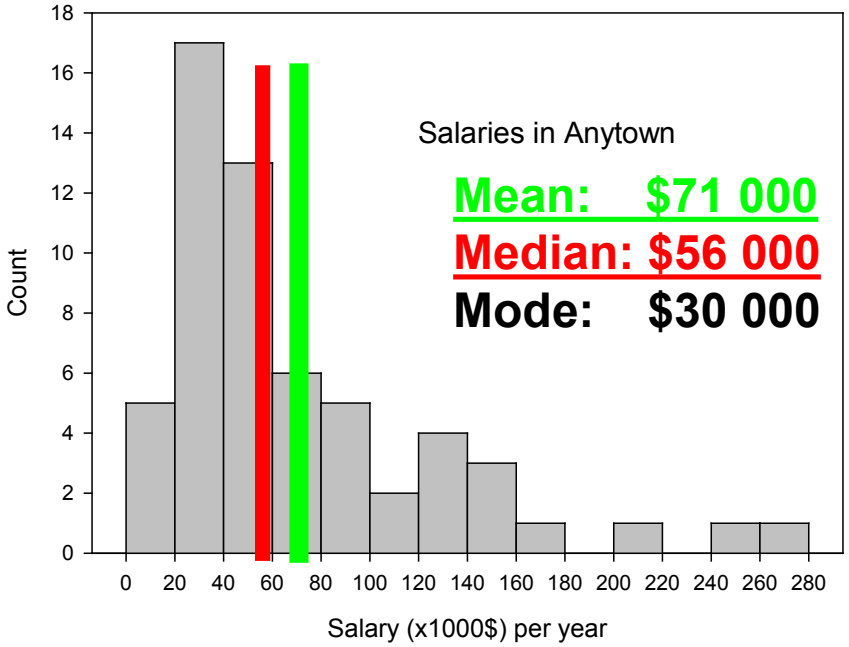
- A politician in power says: “My town is wealthy: the average salary is $71 000.”
- The leader of the opposition replies: “But half of our citizens make less that $56 000.”
- The third party leader says: “Most of the people make $30 000”

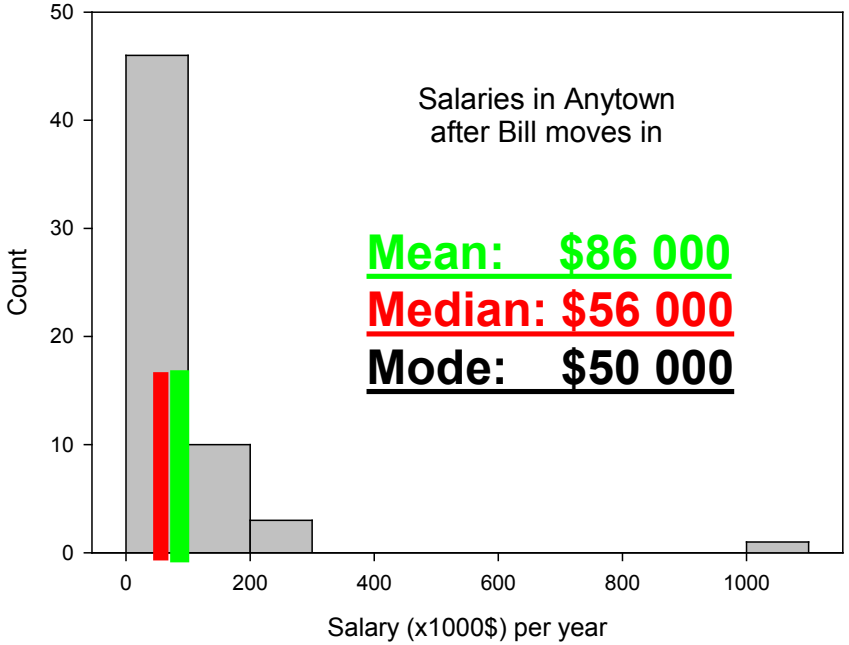


Everyone is correct: the first quotes the mean, the second the median and the third quotes the mode; but the messages are ‘different’.

Bill Gates moves into town ‘for an hour’

- A politician in power says: “My town is wealthy: the average salary is $86 000.”
- The leader of the opposition replies: “But half of our citizens make less that $56 000.”
- The third party leader says: “Most of the people make $50 000”





Bill Gates would be called an outlier

- An outlying observation, or outlier, is one that appears to deviate markedly from other members of the sample in which it occurs.
- Often people make arguments to ‘ignore’ outliers
- You should only eliminate outliers after very, very careful consideration:
  - Ignoring Bill Gates might hurt his feelings!

Interlude on Outliers and Censoring

- Extreme values (outliers) pose a problem
  - Are they valid extreme values or gross errors of measurement?
  - Extreme values should never be deleted (censored) without careful investigation.
    - Sometimes the extreme values are the most important data in the experiment; don't delete your Nobel Prize mindlessly!
    - Including erroneous data can seriously bias the results.
- Censoring of good data always introduces bias and always makes the data look better than it really is.
  - Automatic censoring, as is done by some instrument software is not generally an acceptable procedure.

Descriptive Statistics

When you wish to use a few numbers to describe your data set:

- Mean and Median give an idea of 'central tendency'
  - where is the middle?
- Mode tells you the most probable 'bin' range for your data
- Standard Deviation, and Range give indications of width
  - how wide is the distribution?

Next slide

Measures of Variation (Width)

- A measure of variation is a number that indicates the extent to which data are spread out around the mean
  - Standard deviation
  - Variance
  - Range

*Argument = Variable Component (inside bracket)
- Example:
sin(x), x is argument, sin(x) is function

- How far is a given data point from the mean? i.e., what is its **deviation from the mean**?

$x_i - \mu$ Distance from mean

$|x_i - \mu|$ Absolute distance from mean

$(x_i - \mu)^2$ Common for equation of bell curve

Three ways of indicating with a number how far x_i is from the (population) mean?

Standard Deviation (Population)

$$\sigma = \left[\frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N} \right]^{\frac{1}{2}}$$

Find the sum of EVERY (xi - u)^2
Divide everything by N
Square-root everything

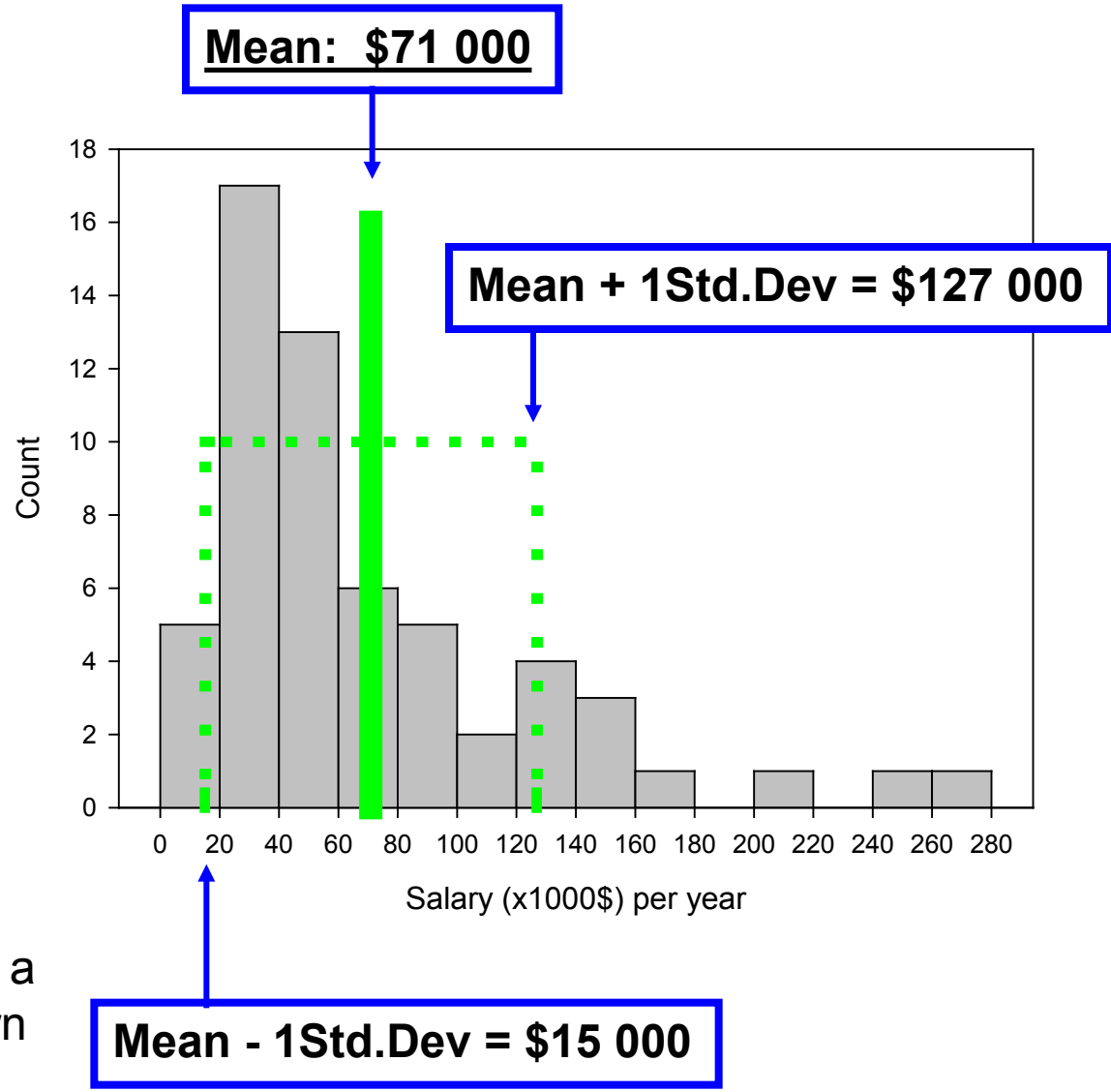
$N = \text{population size}$

$\mu = \text{population mean}$

The Standard Deviation (abbreviated Std.Dev below) gives an indication of the width of the distribution

Population Descriptive Statistics

	1
Mean	70.9153
Median	56.0000
Std.Dev	55.9376
Std.Err	7.2824
95% Conf	14.5777
99% Conf	19.3966
Size	59.0000
Total	4184.0000
Min	12.0000
Max	270.0000
Min.Pos	12.0000
Missing	0.0000
Other	0.0000

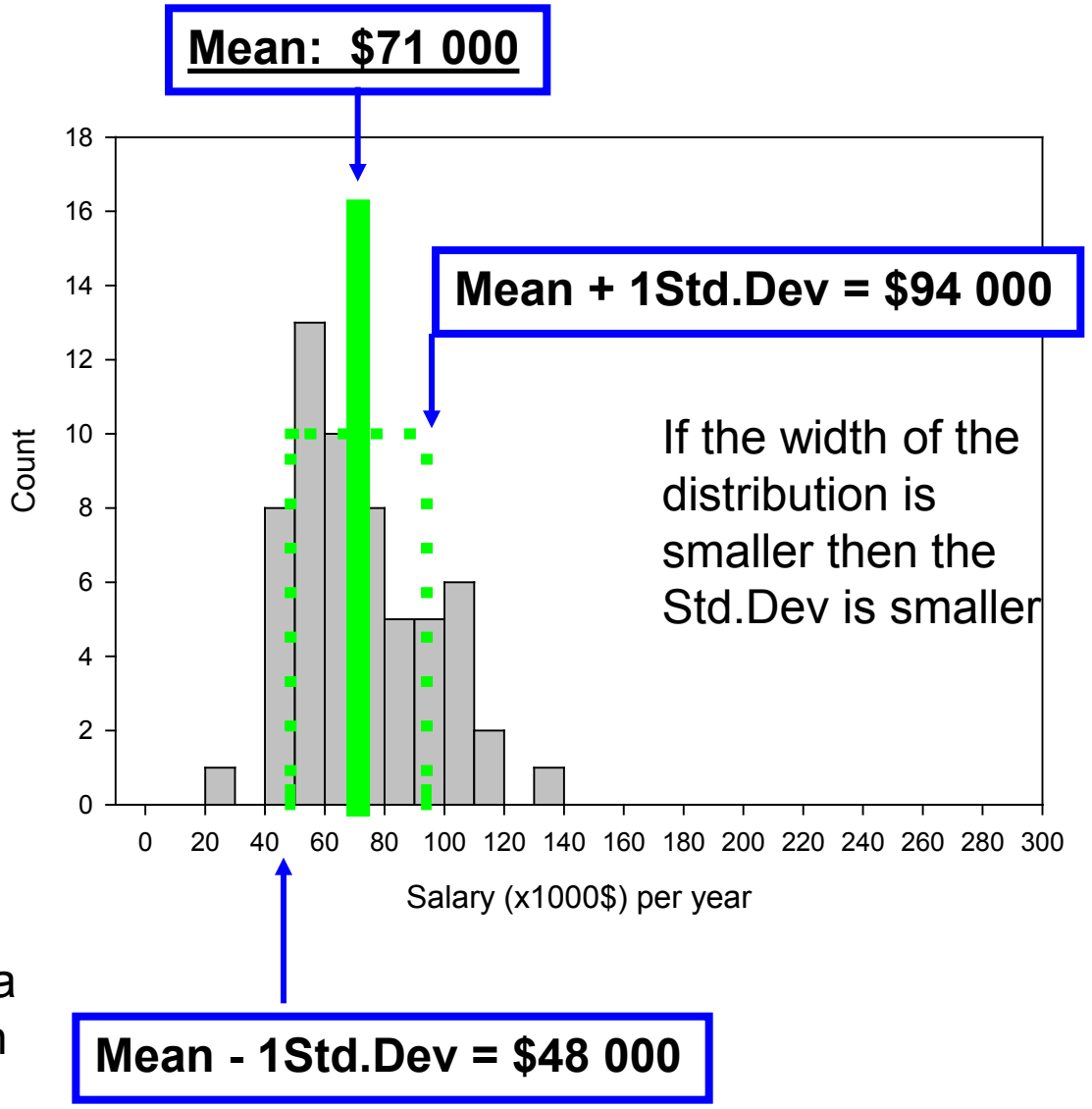


This is a 'population' because we have included the entire town population. If we only considered a small number of people in the town we would calculate statistics for a sample, see later slide.

The Standard Deviation (abbreviated Std.Dev below) gives an indication of the width of the distribution

Population Descriptive Statistics

Mean	71.1864
Median	68.0000
Std.Dev	22.7948
Std.Err	2.9676
95% Conf	5.9405
99% Conf	7.9042
Size	59.0000
Total	4200.0000
Min	24.0000
Max	132.0000
Min.Pos	24.0000
Missing	0.0000
Other	0.0000
14	



This is a 'population' because we have included the entire town population. If we only considered a small number of people in the town we would calculate statistics for a sample, see next slide.

Standard Deviation (Sample)

$$s = \left[\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1} \right]^{\frac{1}{2}}$$

n = sample size

$\overline{x}$ = sample mean

Statisticians have discovered that using the sample mean underestimates the true standard deviation, so $n-1$ is used here rather than n.

Variance

- Variance is simply the square of the standard deviation (population and sample variance is shown below, respectively)

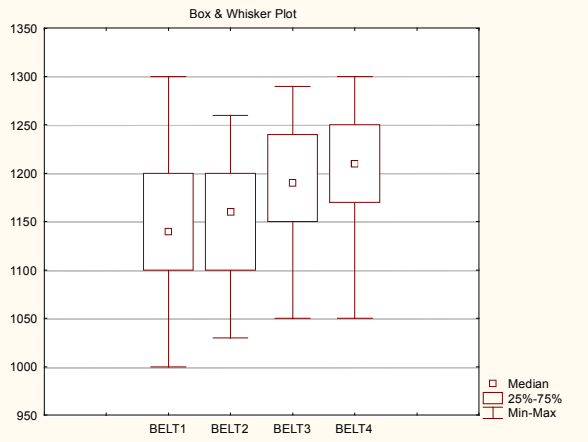
$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2$$

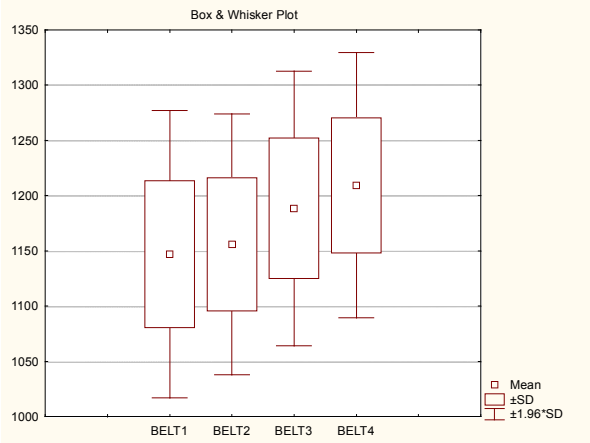
Descriptive Data Analysis

1. Graphics Displays:
   - Dot plots,
   - Box and Whisker Plots
   - Scatter plots,
   - Frequency plots (histograms)
2. Summary statistics:
   - mean,
   - median,
   - mode,
   - standard deviation,
   - range (and interquartile range)

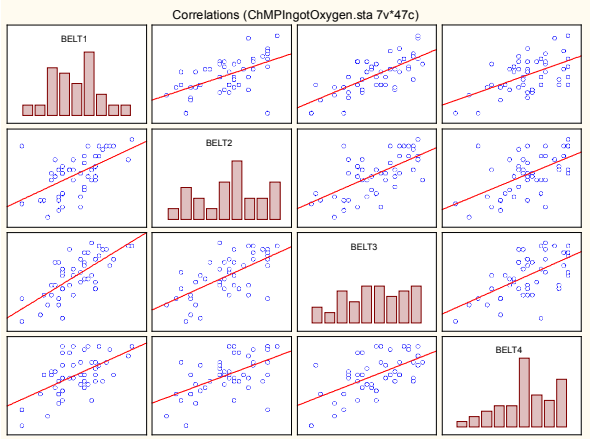
Descriptive Graphics of Data



Median, IQR, Range

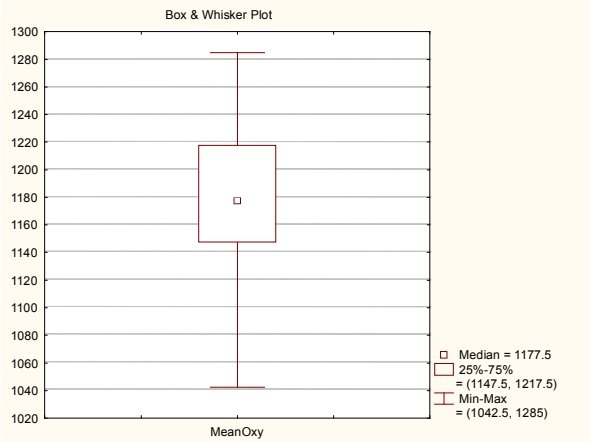


Mean, SD, 95%CL

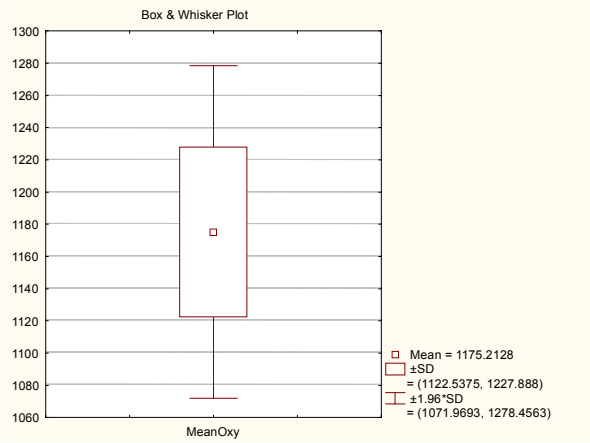


Correlation Plot of Oxy. Measurements

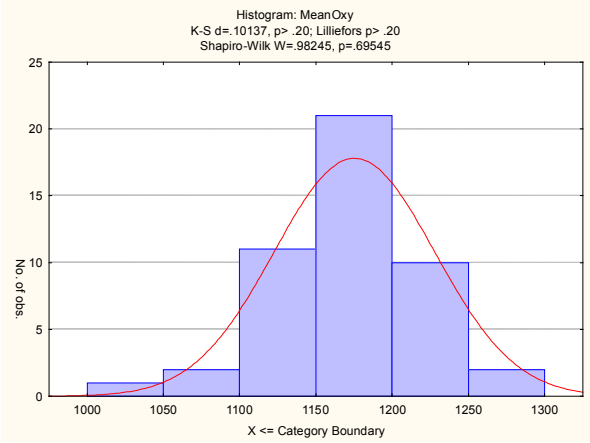
Descriptive Graphics of Data



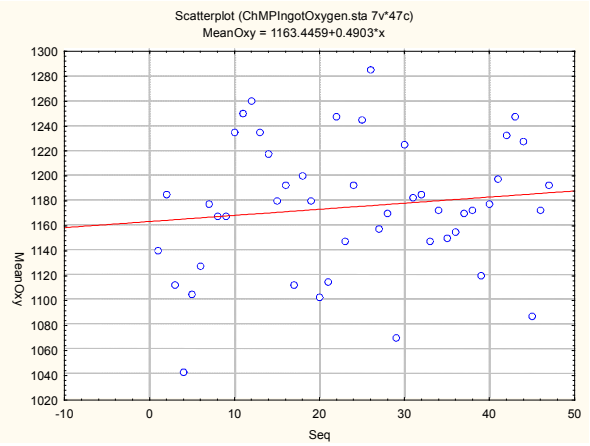
Median, IQR, Range



Mean, SD, 95%CL



Frequency Distr. Of Mean Oxy.



Scatter Plot of Mean Oxy. vs Seq. Num.

Summary Statistics (samples)

Measures of Location

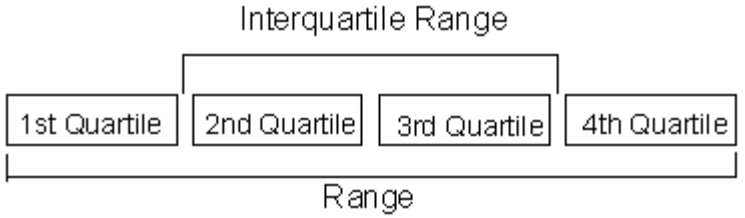
- Mean: $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
- Median: middle value when you order the values:

$$x_1 \le x_2 \le x_3 \ldots \le x_n$$

- Mode: position or positions of maximum probability
  - Not always easy to define in experimental data
- Remember: a statistic is any function of the data.

Measures of Spread

- Variance: $s^2 = \frac{1}{n-1}\sum_{i}^{n}(x_i - \bar{x})^2$
- Standard Deviation $s = \sqrt{Var} = \sqrt{s^2}$
- Range: $R = max(x) - min(x)$
- Interquartile Range:



- Full Width Half Max (FWHM)
  - Half width half max. (HWHM)

The first "Golden Rule" of Data Analysis

- Study the data
  - Use the descriptive methods above to get a 'feel' for the data.
  - Complicated data sets deserve several hours, days, or even weeks of study.
  - 'Outliers' must be carefully vetted.
  - Data are not simply numbers but rather measurements or counts of real entities.
  - Tentative conclusions should be made in the contexts of their meaning in relation to these entities, the real background of the data, and how the data were collected.
- **Valid conclusions are unlikely to be obtained from poor data.**

Aside on Mindlessness

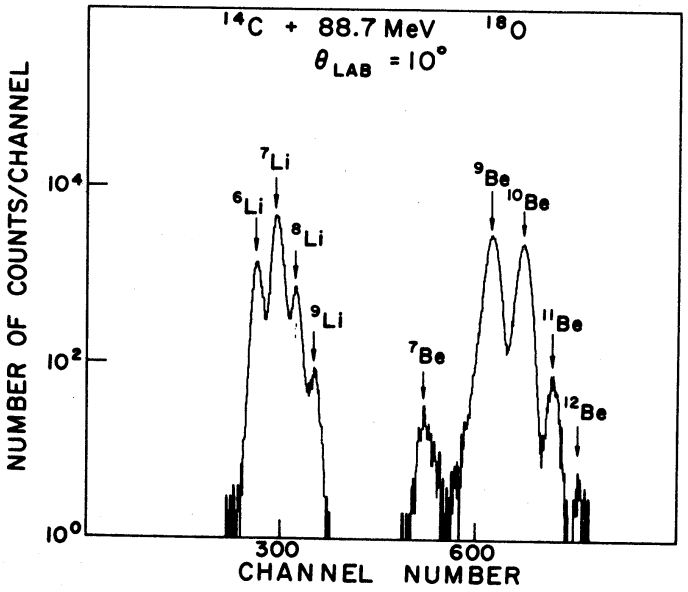


Fig. 1. A representative mass spectrum obtained using a ^{12}Be range table.

- Clearly, the use of any of the summary statistics described above is meaningless in this instance.
- Analysis can only be meaningful in the context of the purpose of the 'experiment', and how the data were collected.

Summary

- For the descriptive analysis to be valid
  - The data must be independent (exchangeable)
  - Arbitrary inclusion of repeat measurements is not allowed.
  - The data cannot be correlated such that exchangeability is violated.
- If these conditions aren't met, the standard interpretation of the results could lead to very, very, wrong conclusions.

What Statistics can't do

- Can't get blood from a stone
  - Can't rescue you from bad data.
  - Can't get good results from poorly designed and badly executed experiments.
  - Can't generate information where non exists.
- Statistics might help you understand and quantify just how bad your results are from your bad data.
- In other words, it is not a magic Mr. Fix-it in a black box.

How well do we know the mean value (i.e., arithmetic average) we determine from our data?

- The mean mark on the midterm was 22/30
- The mean salary in Anytown, before Bill, was $71 000.

? How many sig figs should we quote for these mean values ?

? Want is the error in these mean values ?

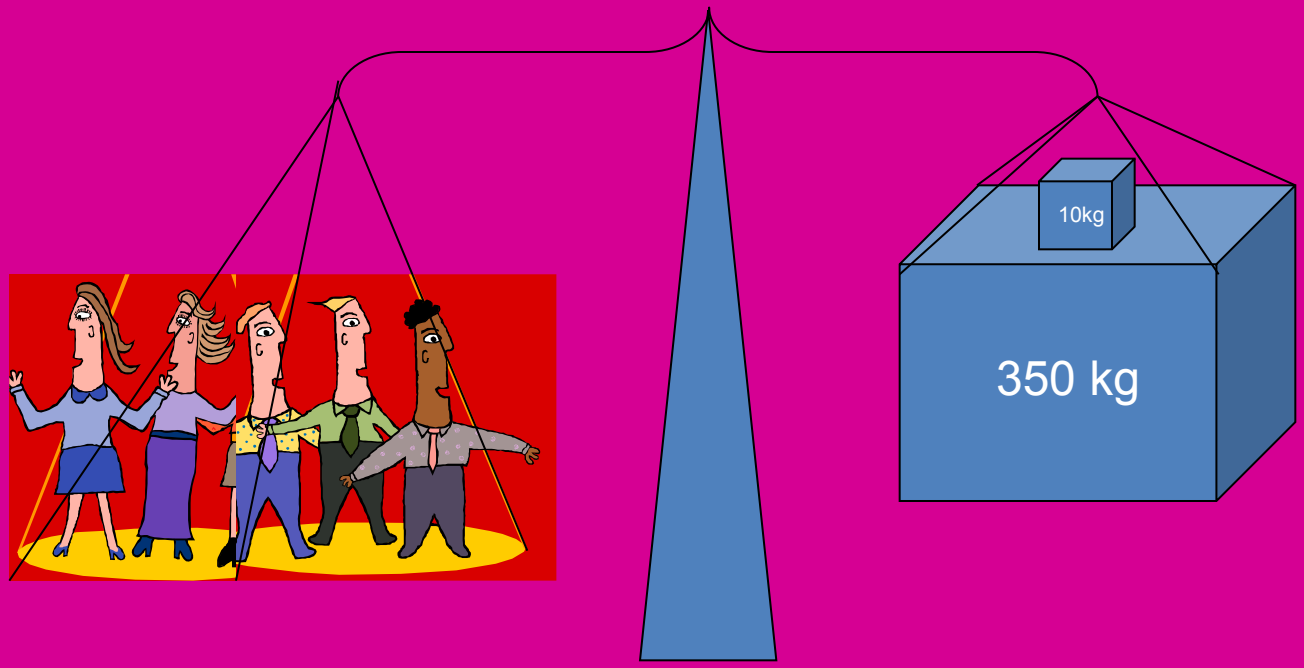
As an example:
The goal is to determine the average (mean) weight of students on campus

- You could weigh the entire population of students at Carleton and then calculate their average weight, but this takes time, and would cost a lot of money.
- Or, you can choose a sample of students, say 5 students, weigh them and calculate an average.
- How far would this average be from the real average of the total population of students?
- If you chose a second group of 5 students, how different would the second group's average weight be?
  - You would expect that the average weight of each group of 5 students would be 'slightly' different.

Make sure you ask how someone chose their sample.

Each group of 5 students must be chosen randomly. Why?

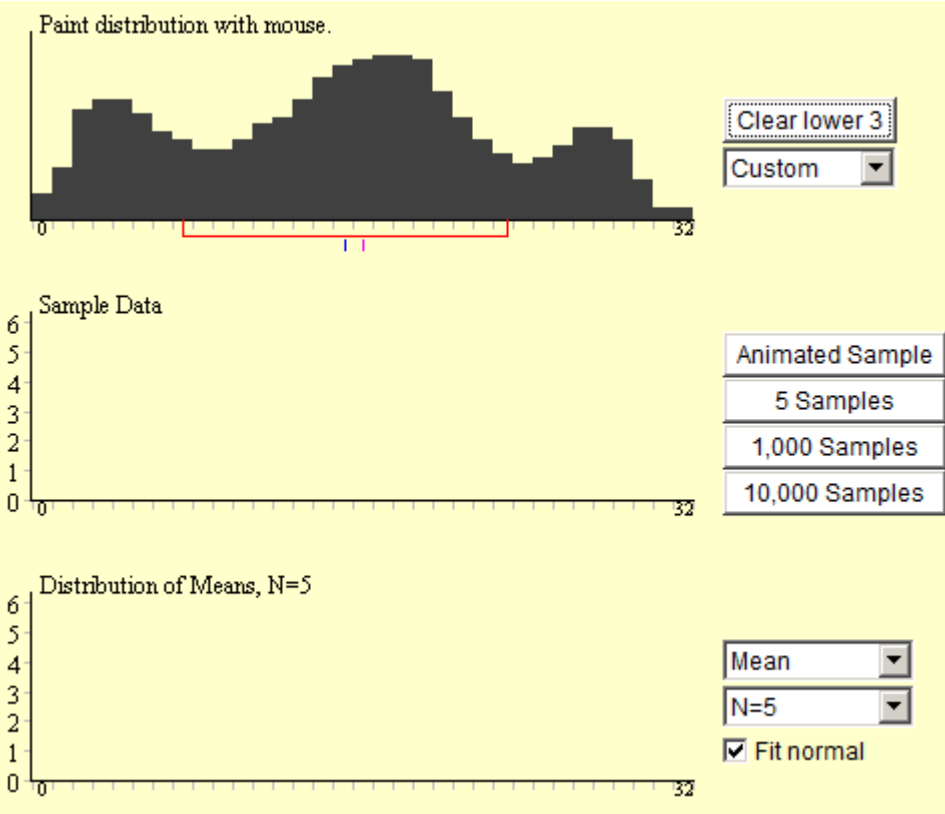
The N5 Student Weighing Machine



Standard Error in the mean value

- Start with any ‘arbitrary’ distribution that represents your population

1. Take, for example, n=5 samples from the starting distribution
2. Take the average of these n=5 samples
3. Put a ‘blue’ box in the lower histogram showing the average value calculated in 2.
4. Goto 1 until the histogram doesn’t change much.



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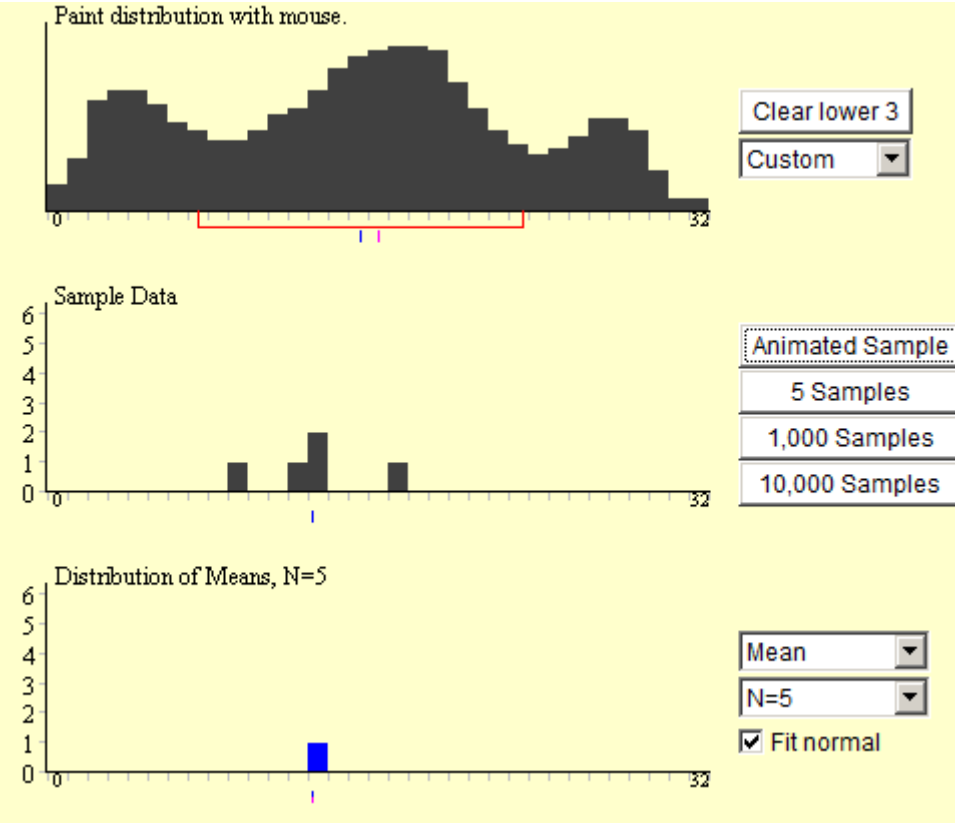

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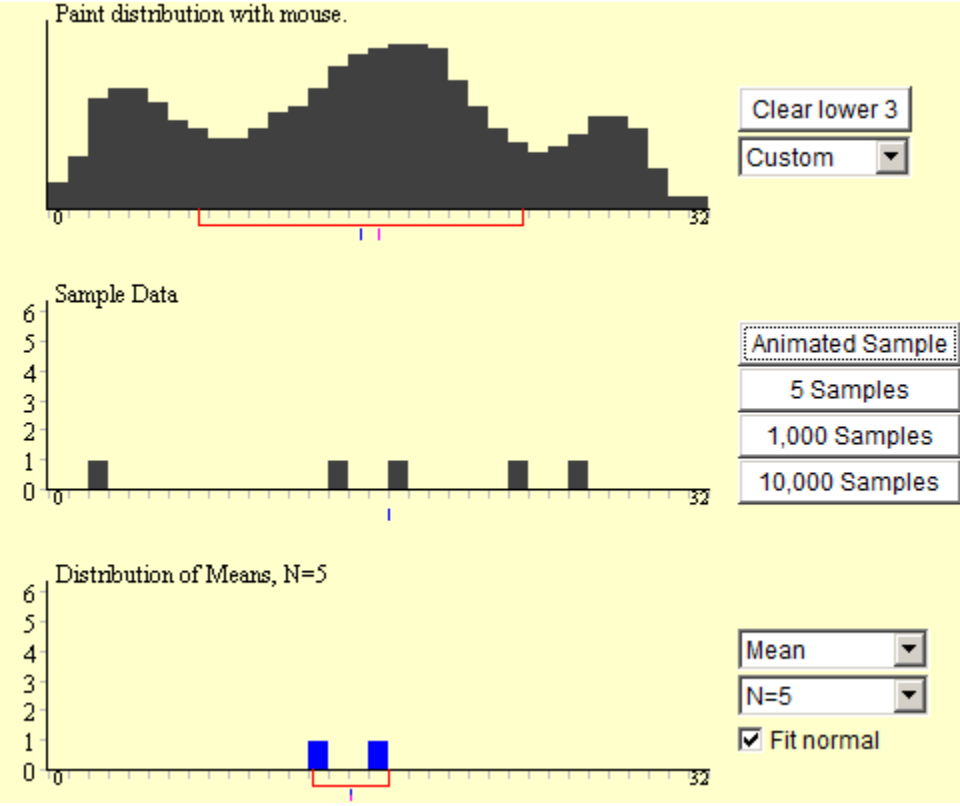

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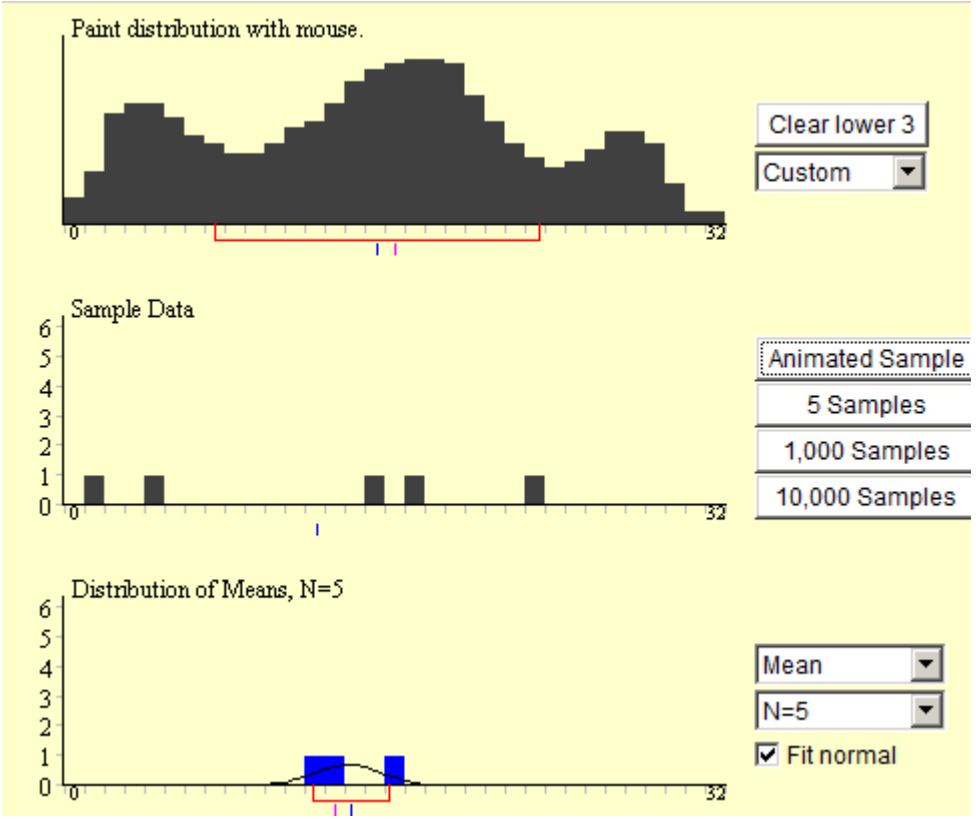

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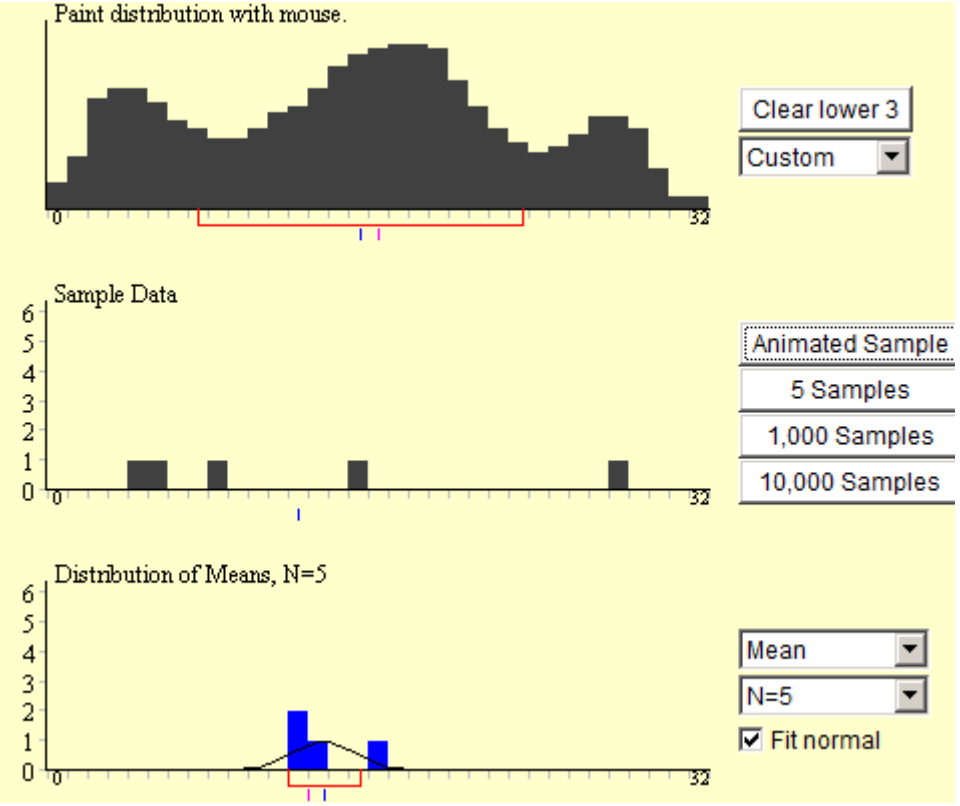

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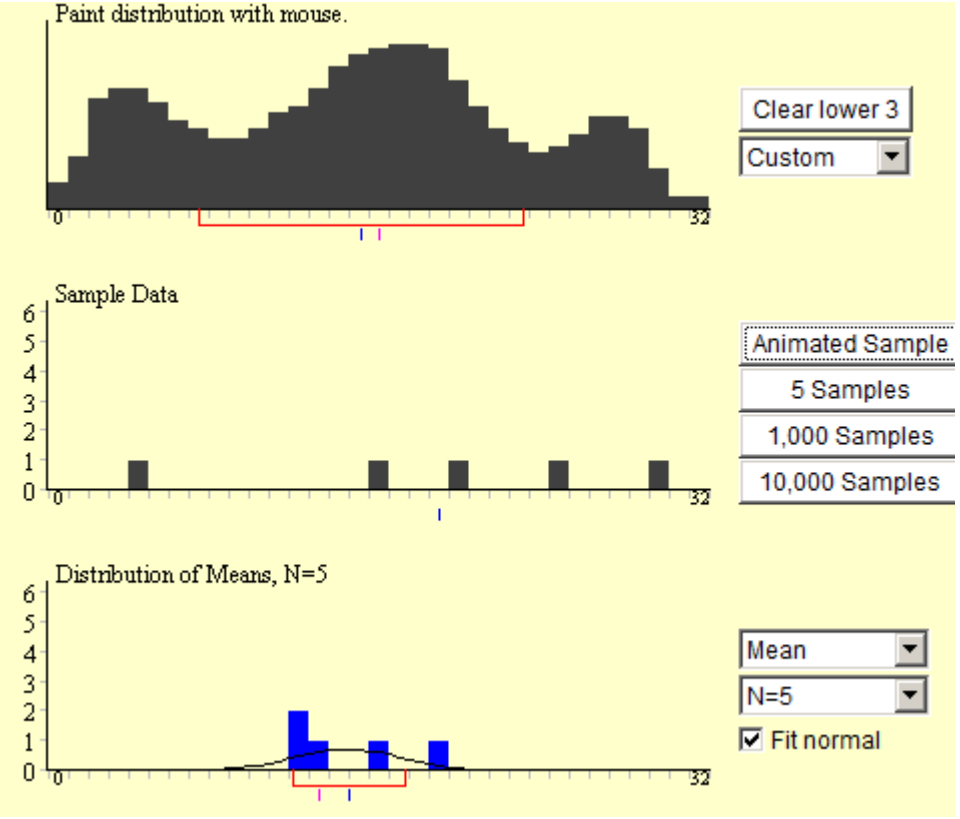

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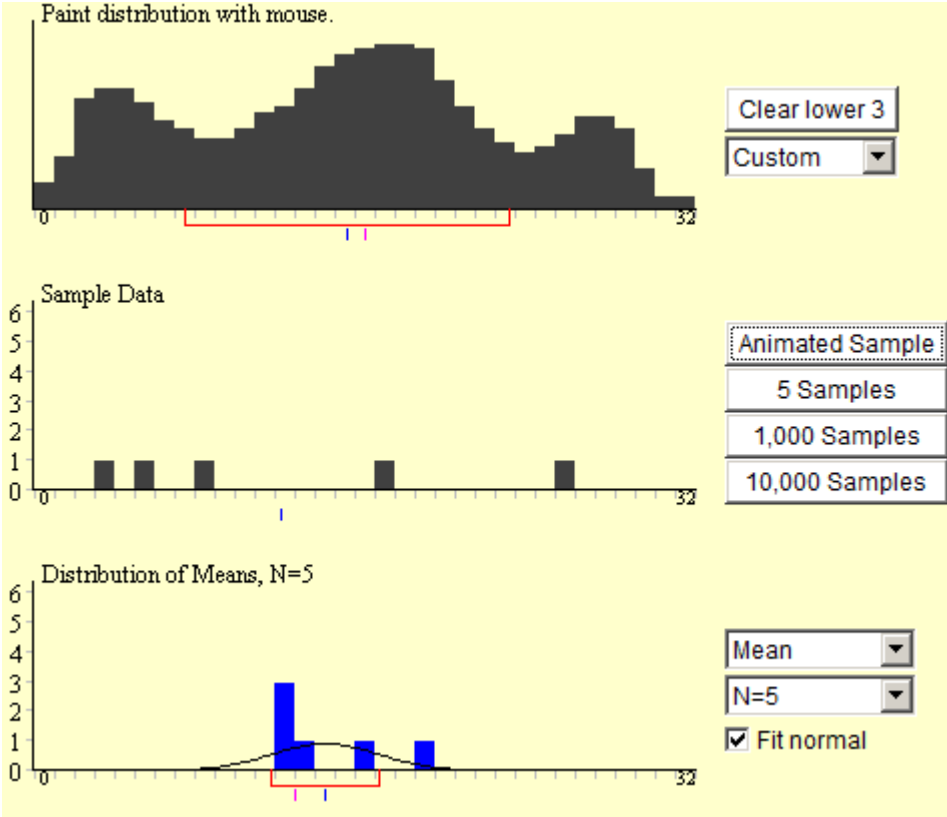

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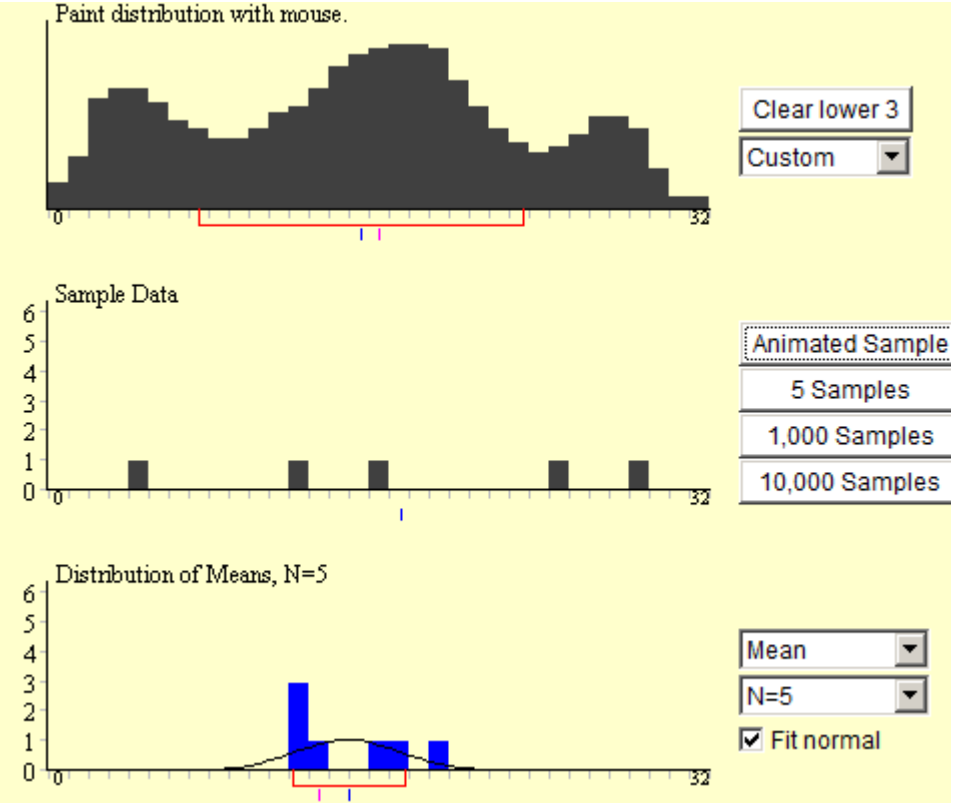

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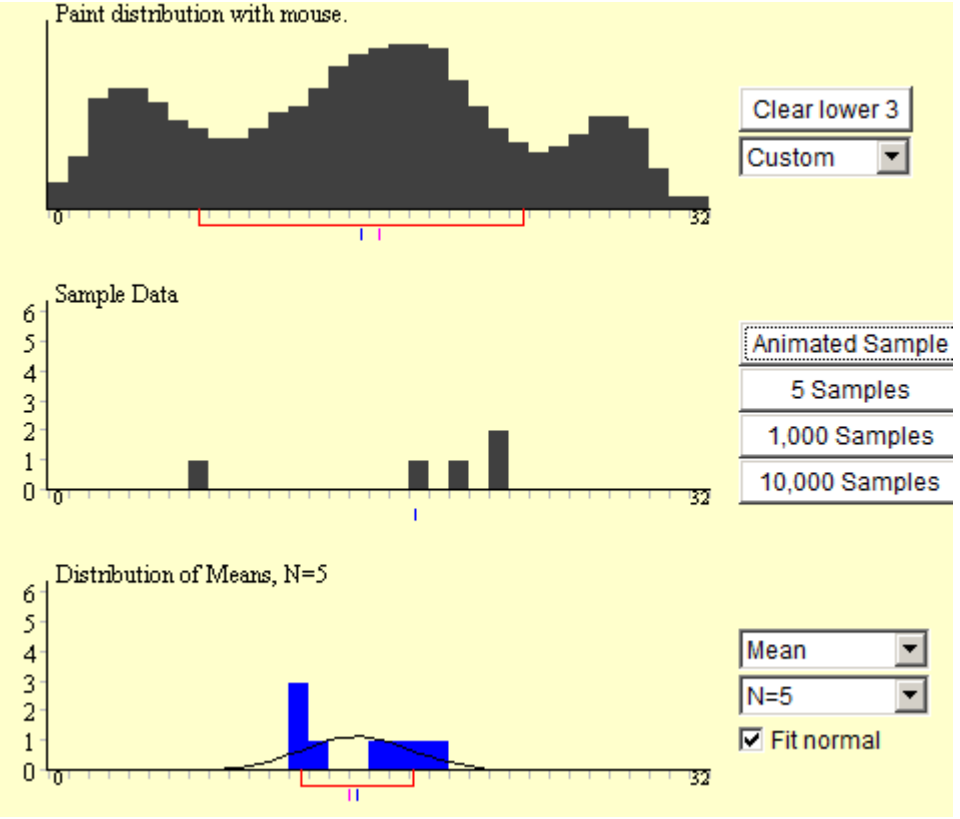

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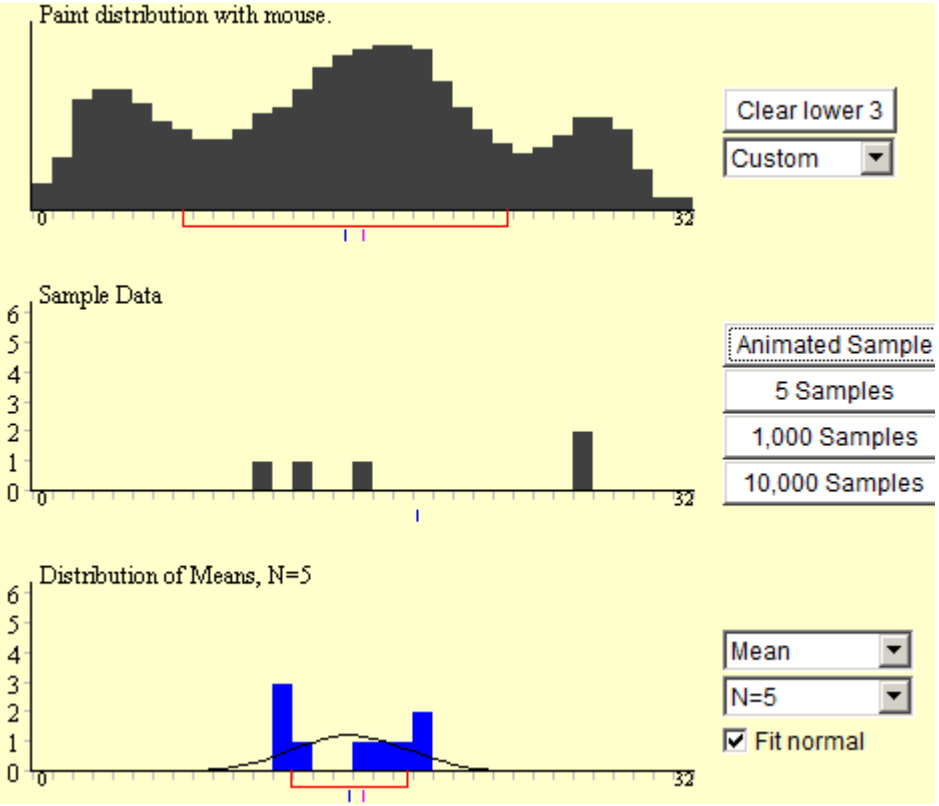

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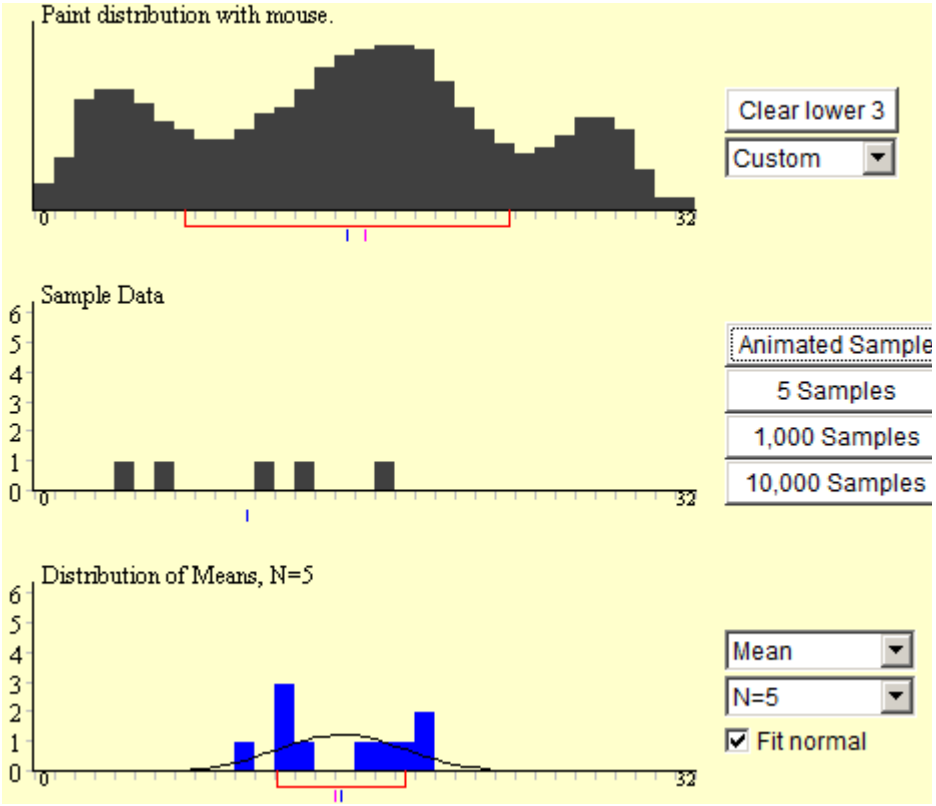

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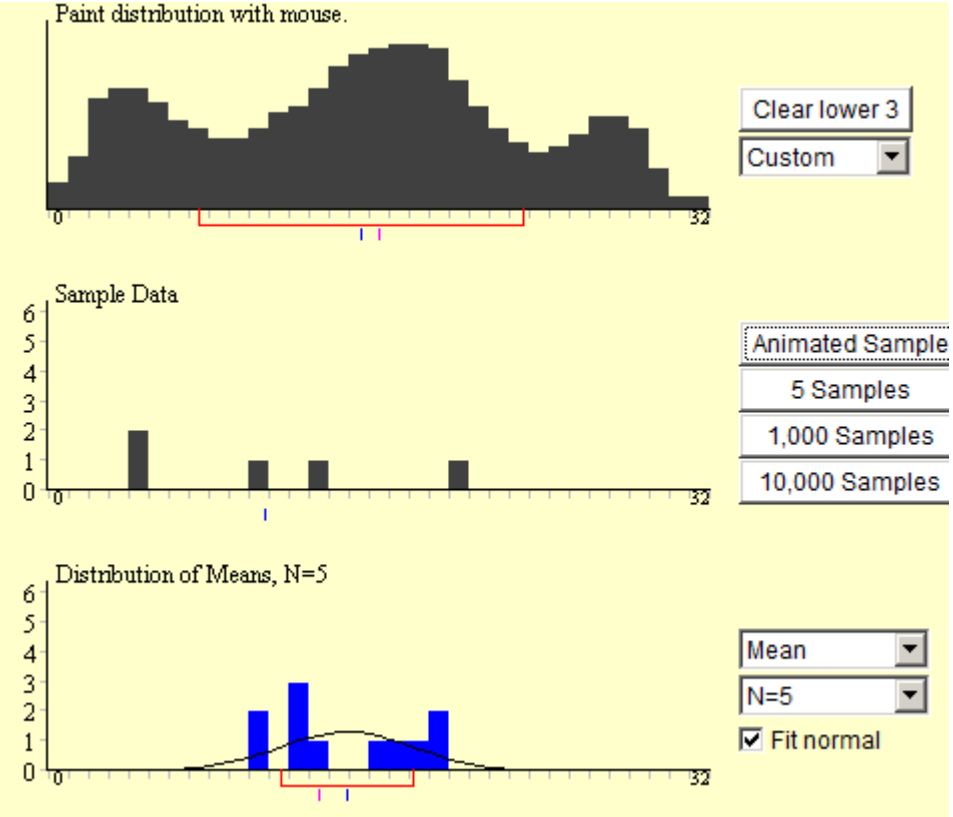

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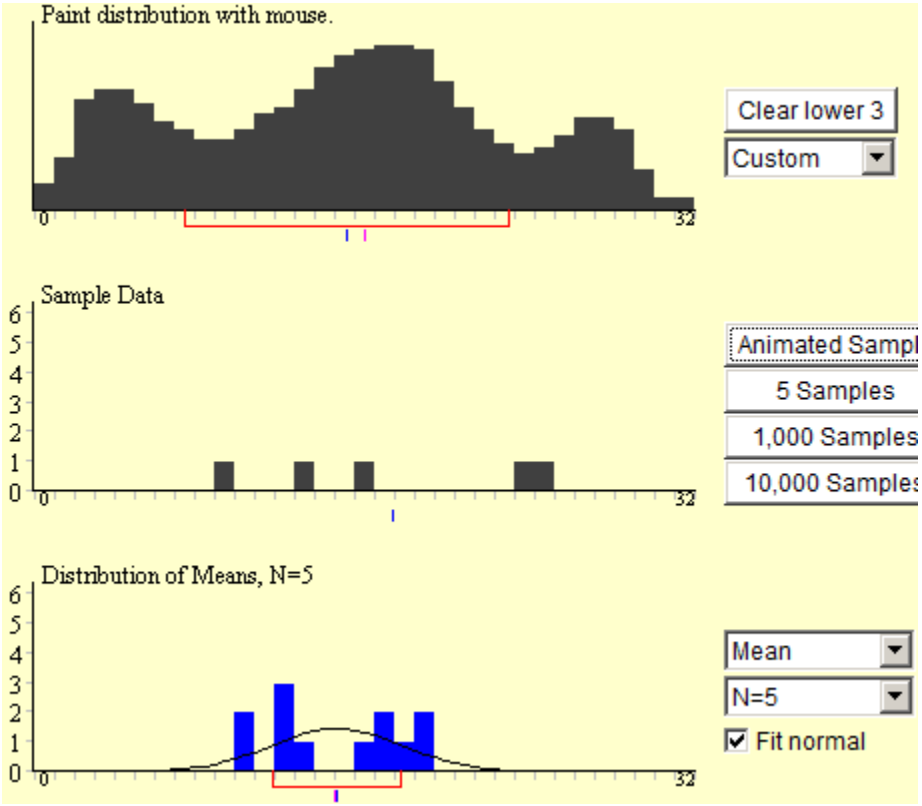

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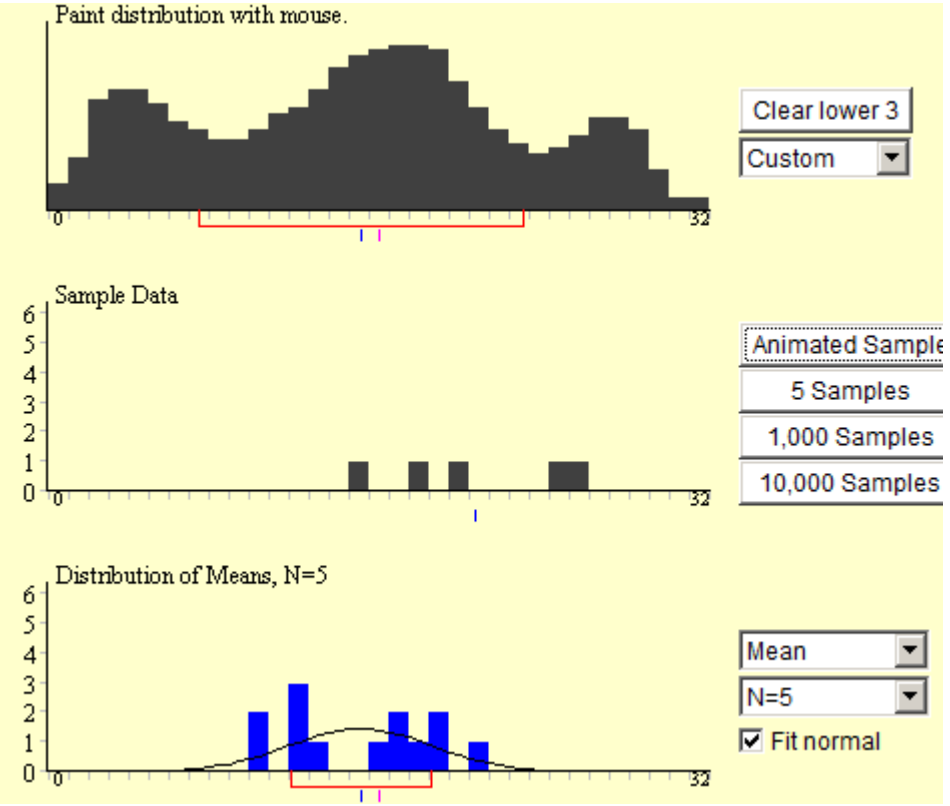

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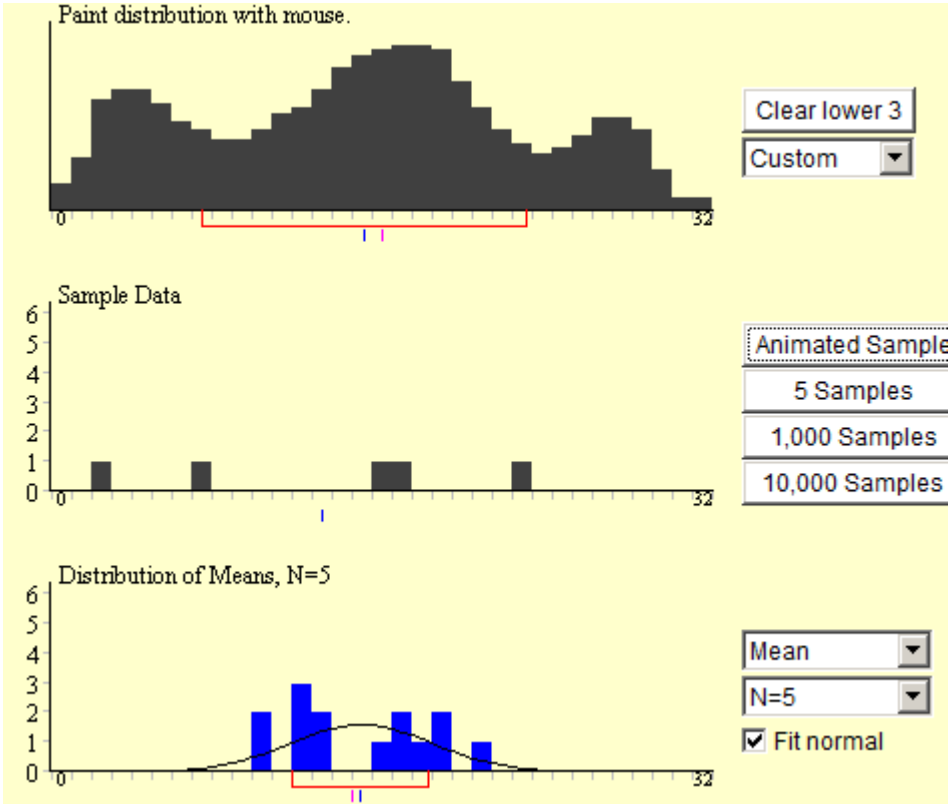

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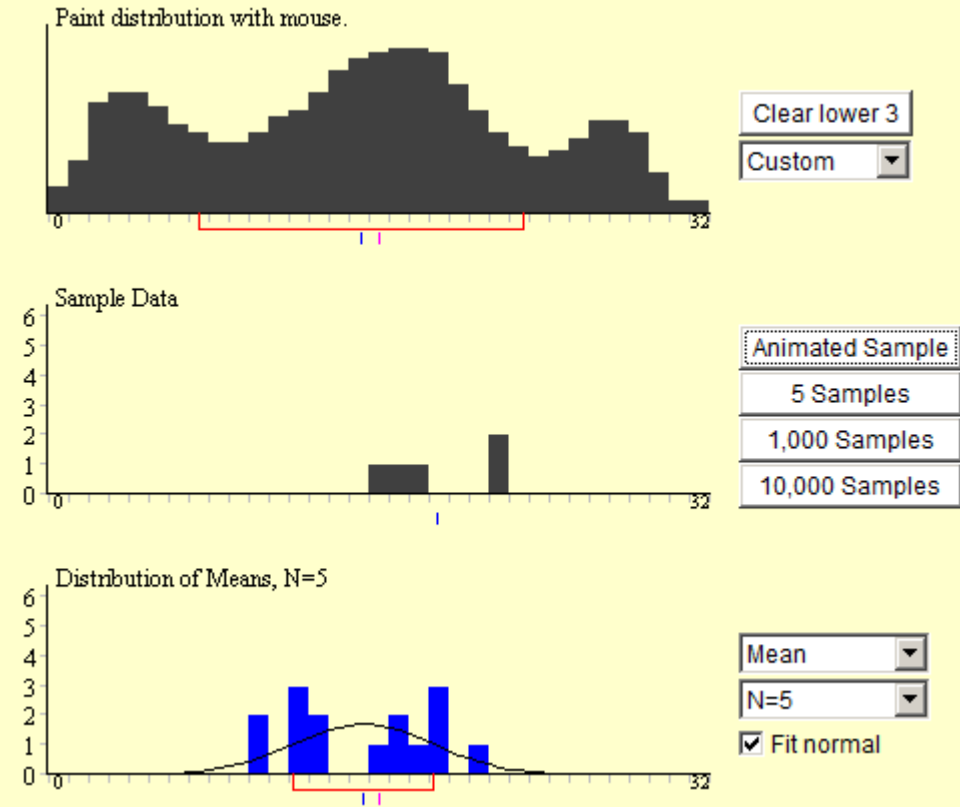

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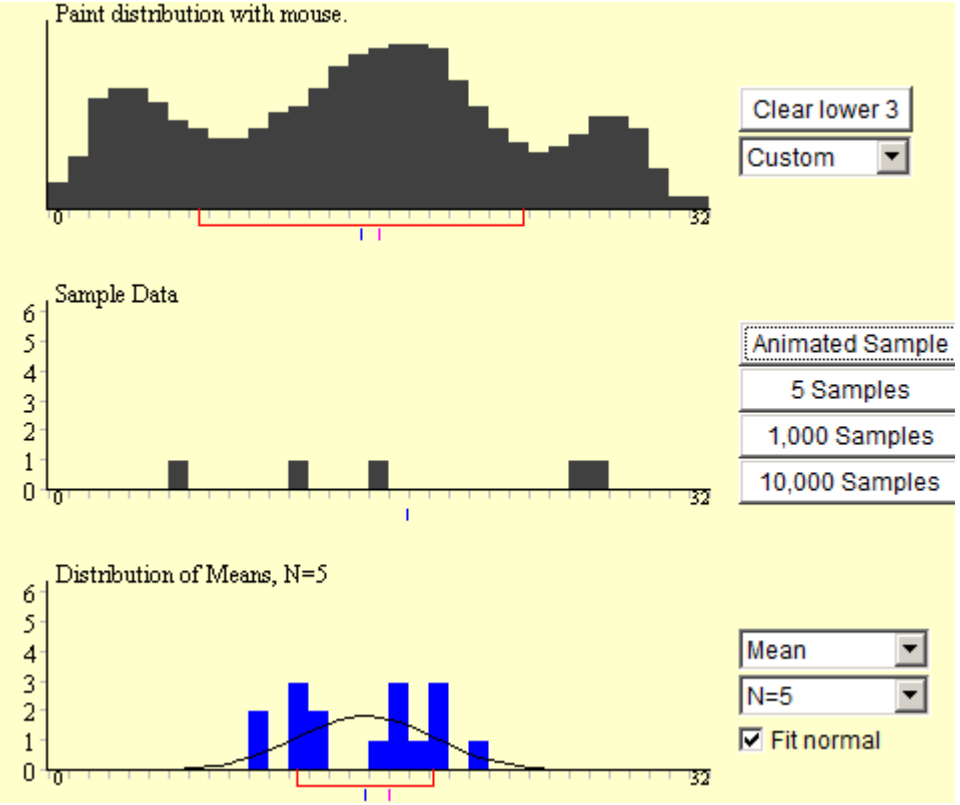

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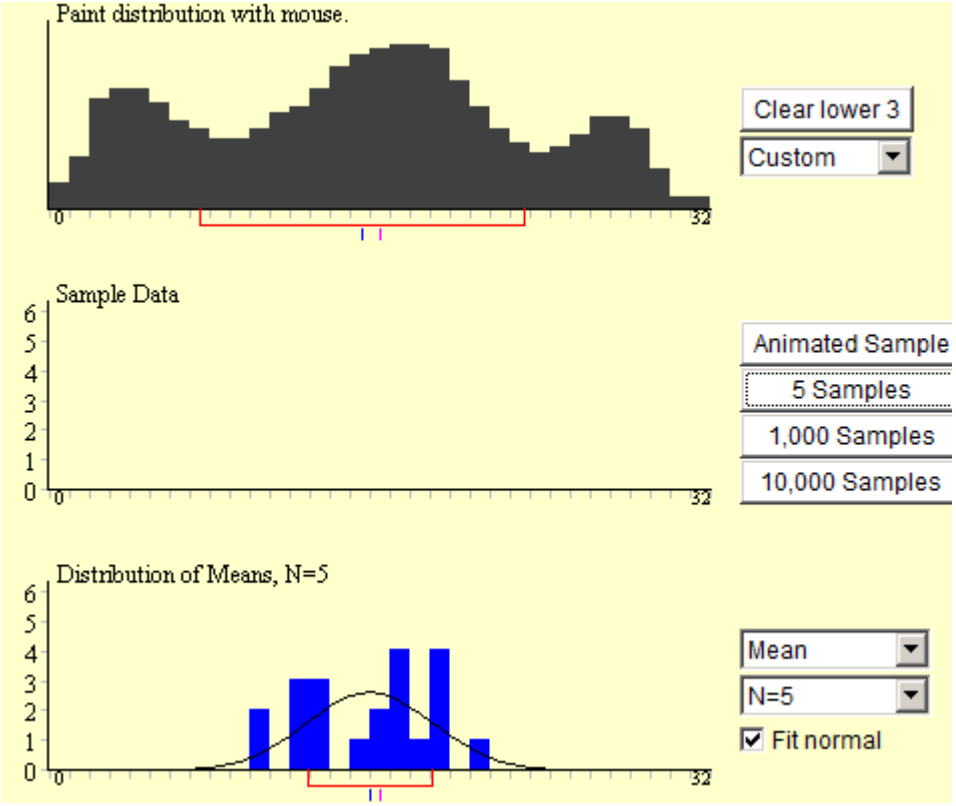
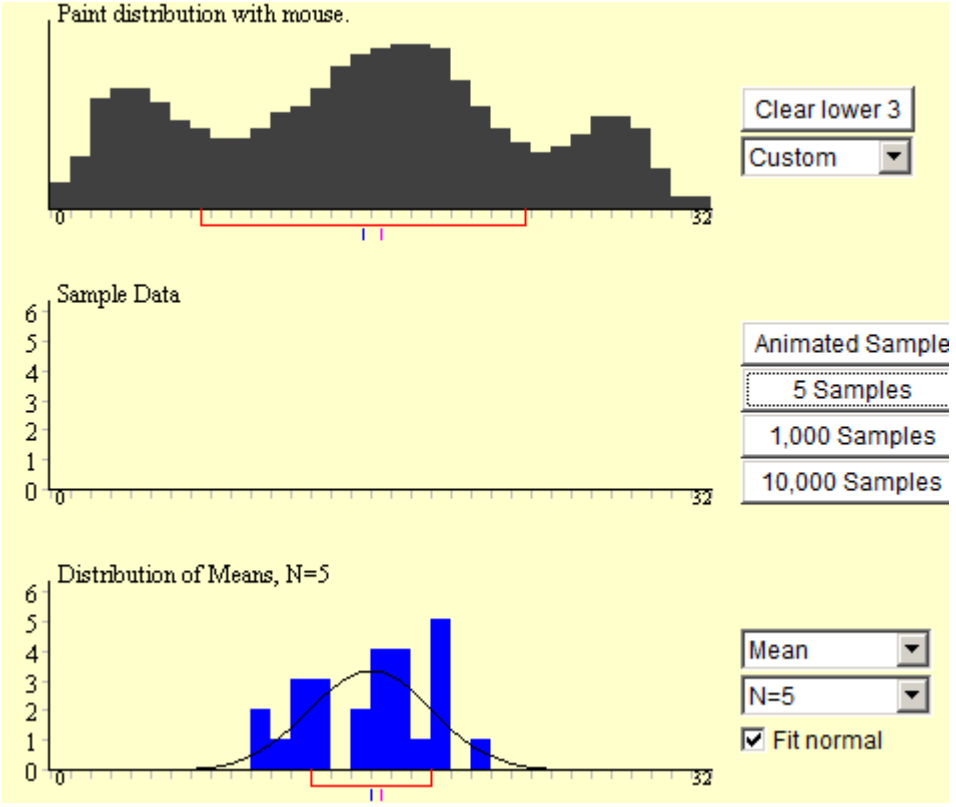


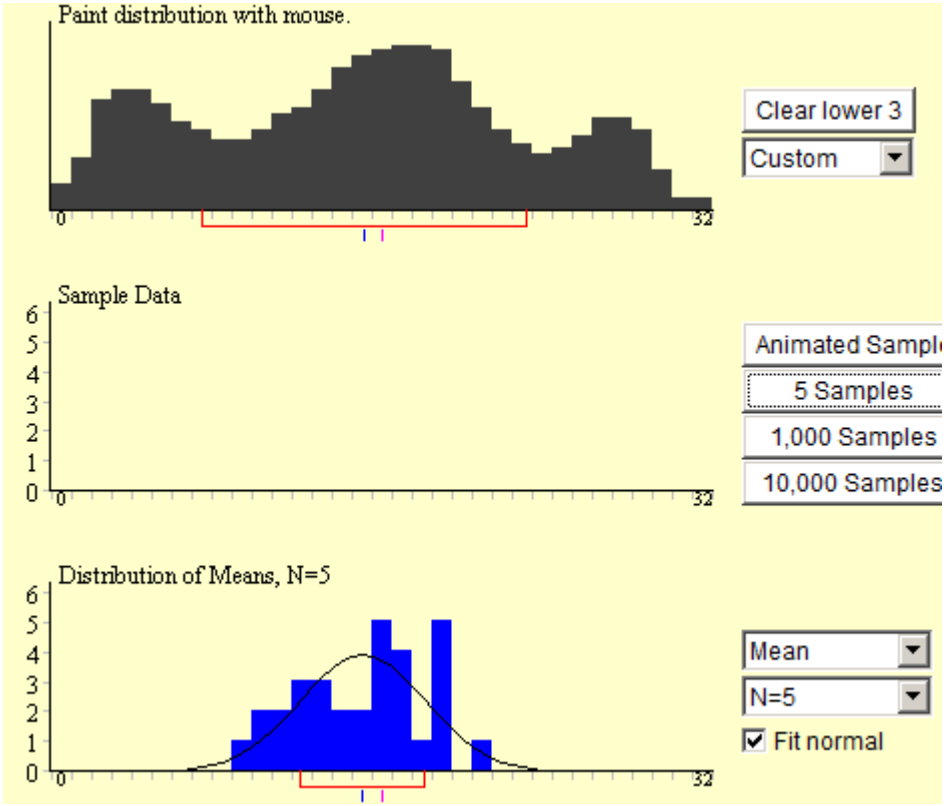
Now we are taking 5 samples and averaging each.

Standard Error in the mean value



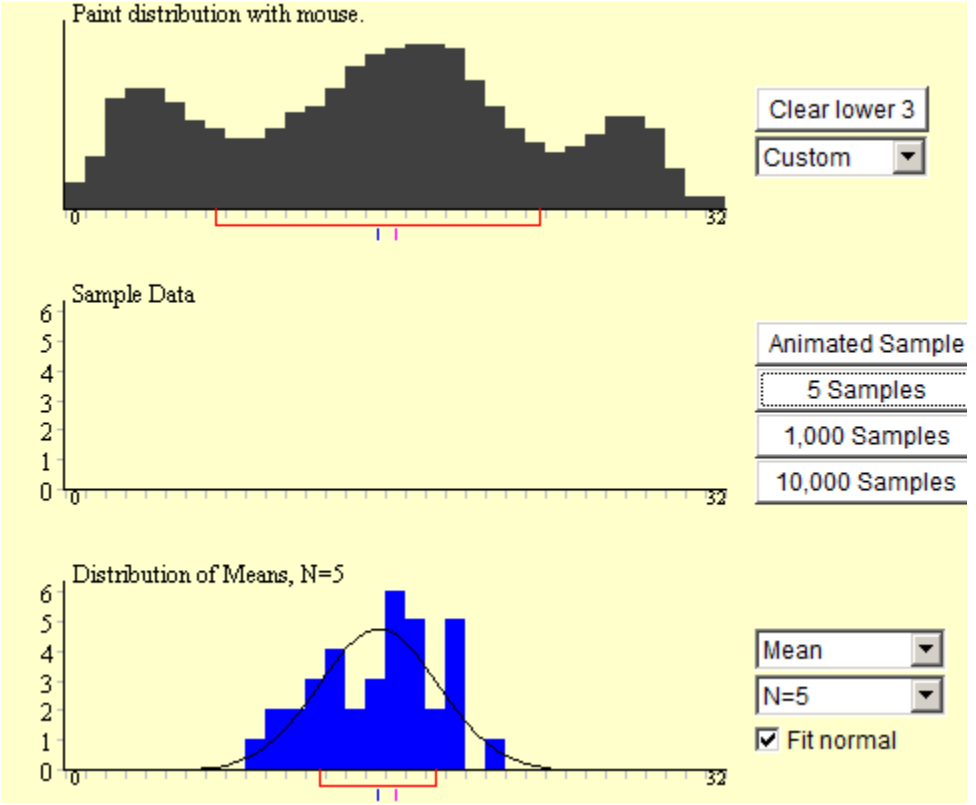
Now we are taking 5 samples and averaging each.

Standard Error in the mean value



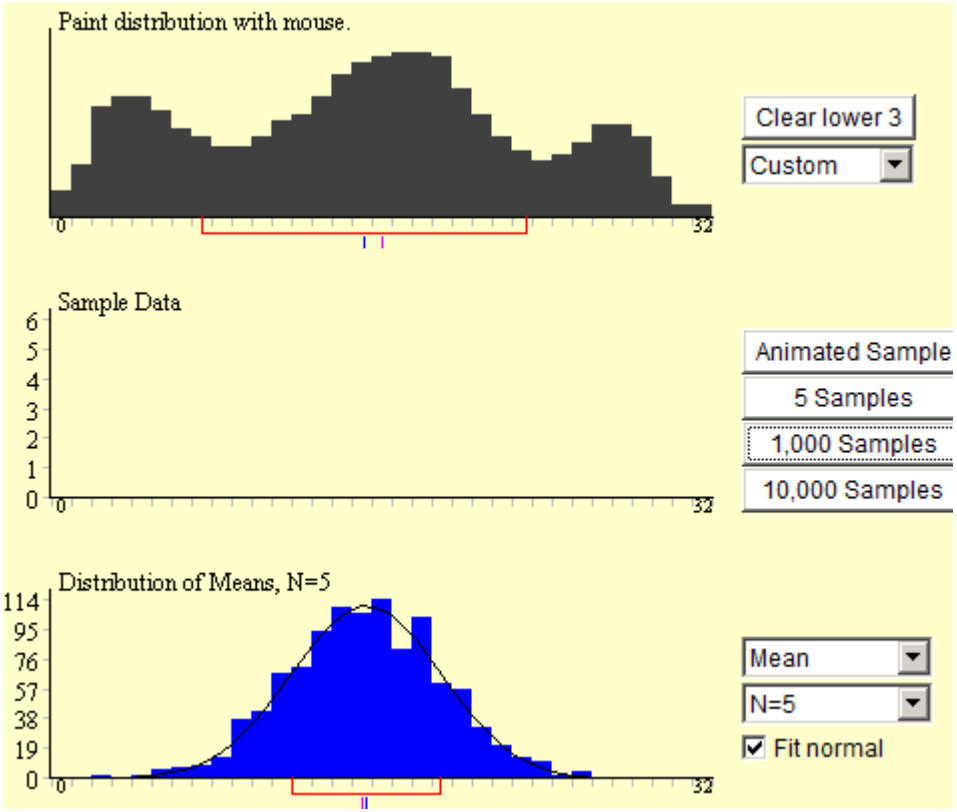
Now we are taking 5 samples and averaging each.

Standard Error in the mean value



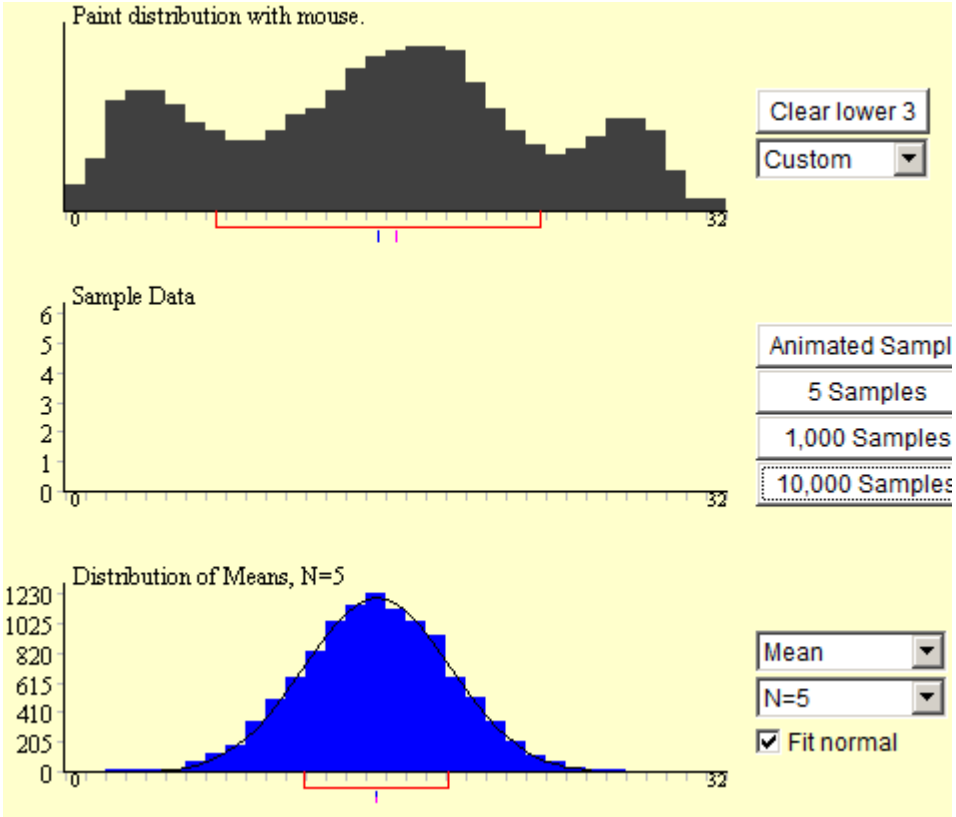
Now we are taking 5 samples and averaging each.

Standard Error in the mean value

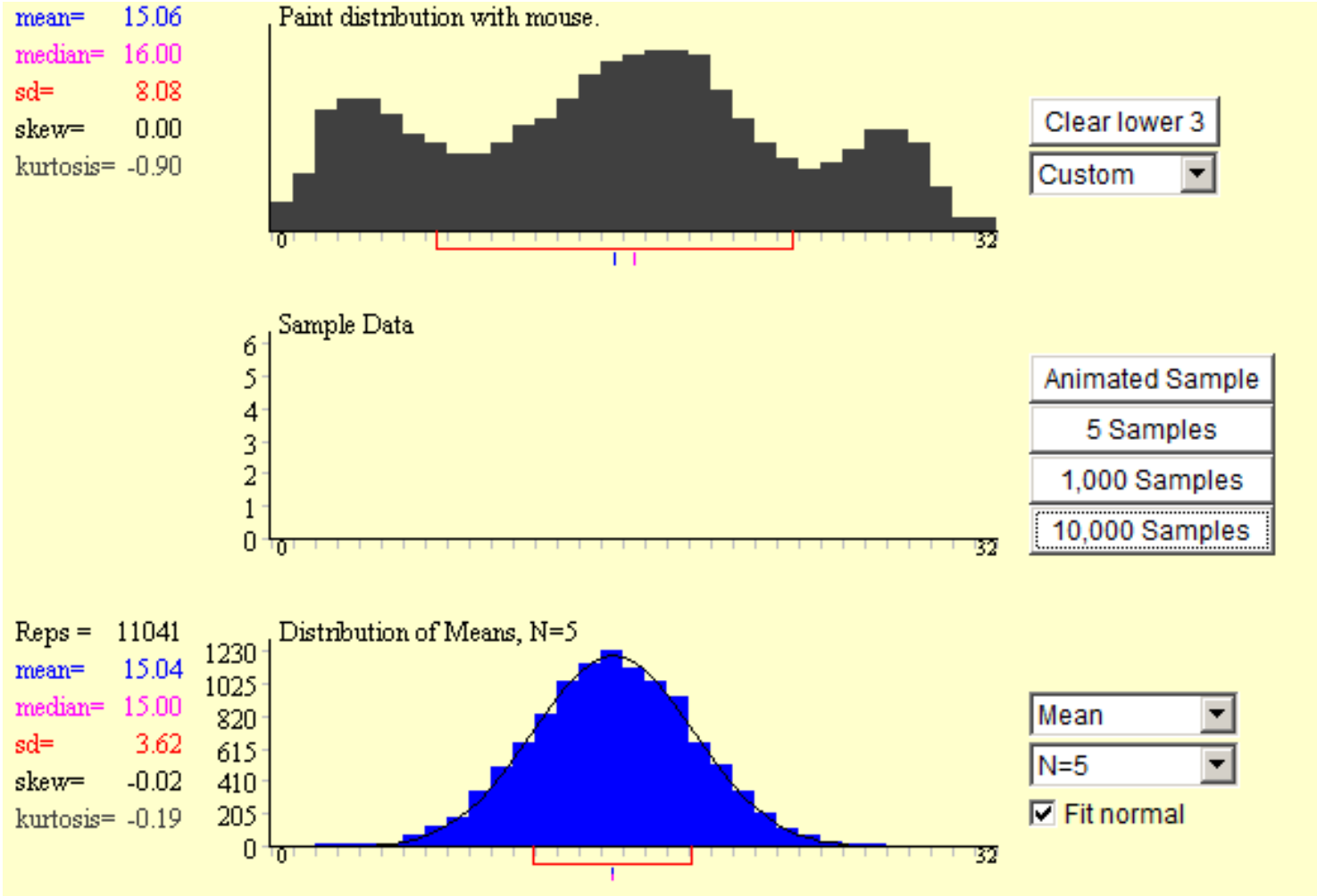


Now we are taking 1 000 samples and averaging each.

Standard Error in the mean value

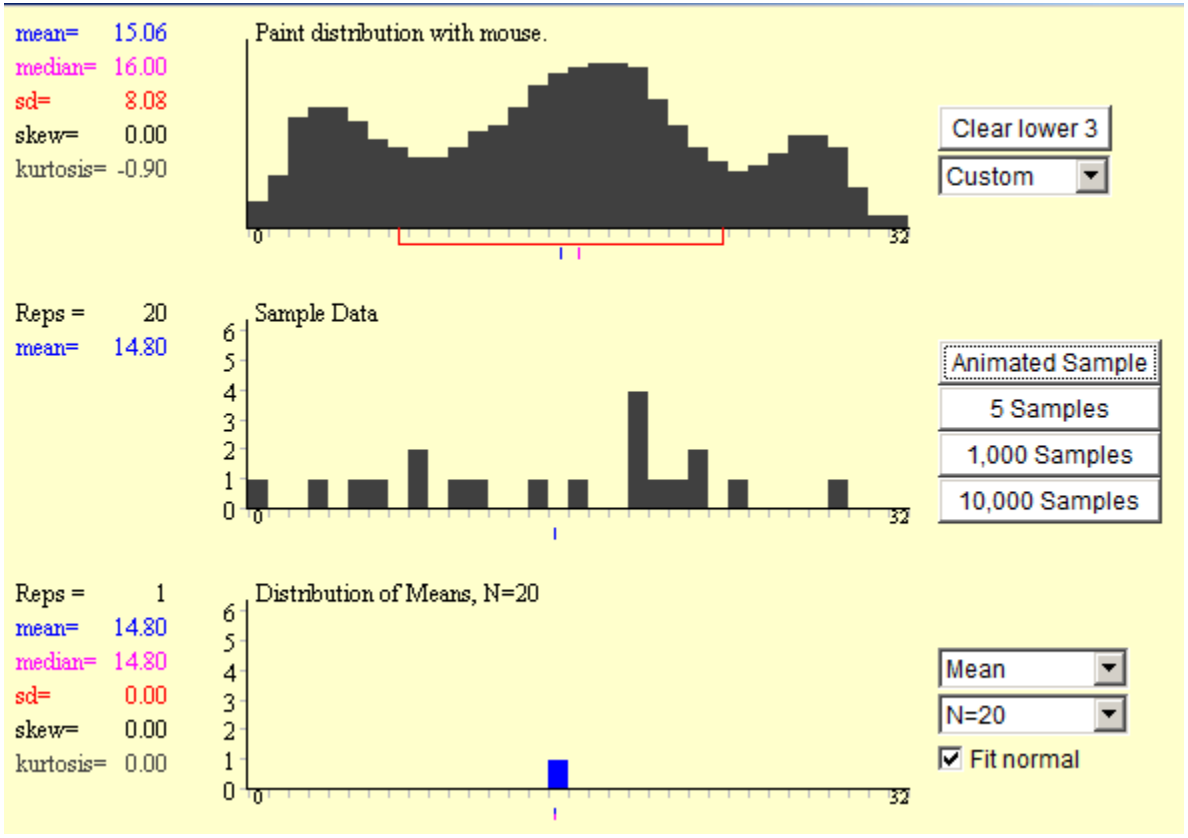


Now we are taking 10 000 samples and averaging each.


mean= 15.06
median= 16.00
sd= 8.08
skew= 0.00
kurtosis= -0.90
Paint distribution with mouse.
0
32
Clear lower 3
Custom
Sample Data
6
5
4
3
2
1
0
0
32
Animated Sample
5 Samples
1,000 Samples
10,000 Samples
Reps = 11041
mean= 15.04
median= 15.00
sd= 3.62
skew= -0.02
kurtosis= -0.19
Distribution of Means, N=5
1230
1025
820
615
410
205
0
0
32
Mean
N=5
Fit normal

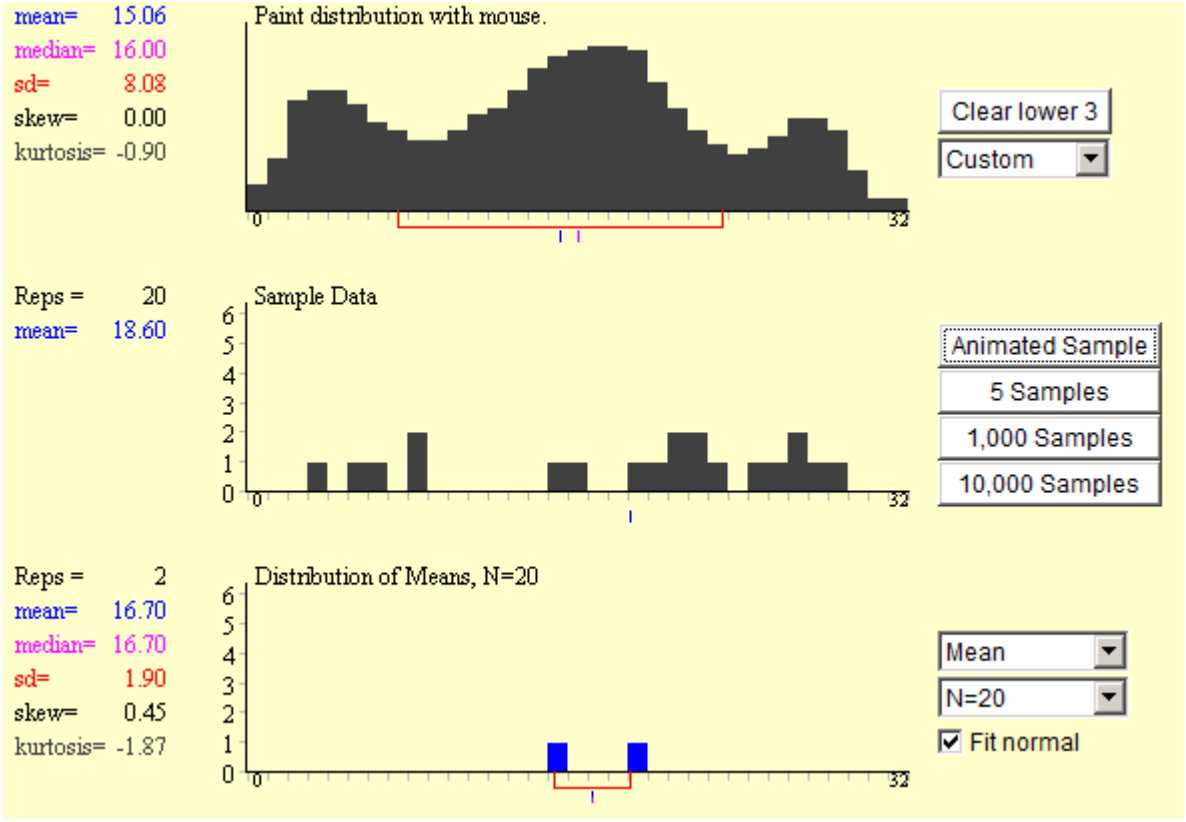
What if we choose N=20?

The super-duper N20 Student weighing machine



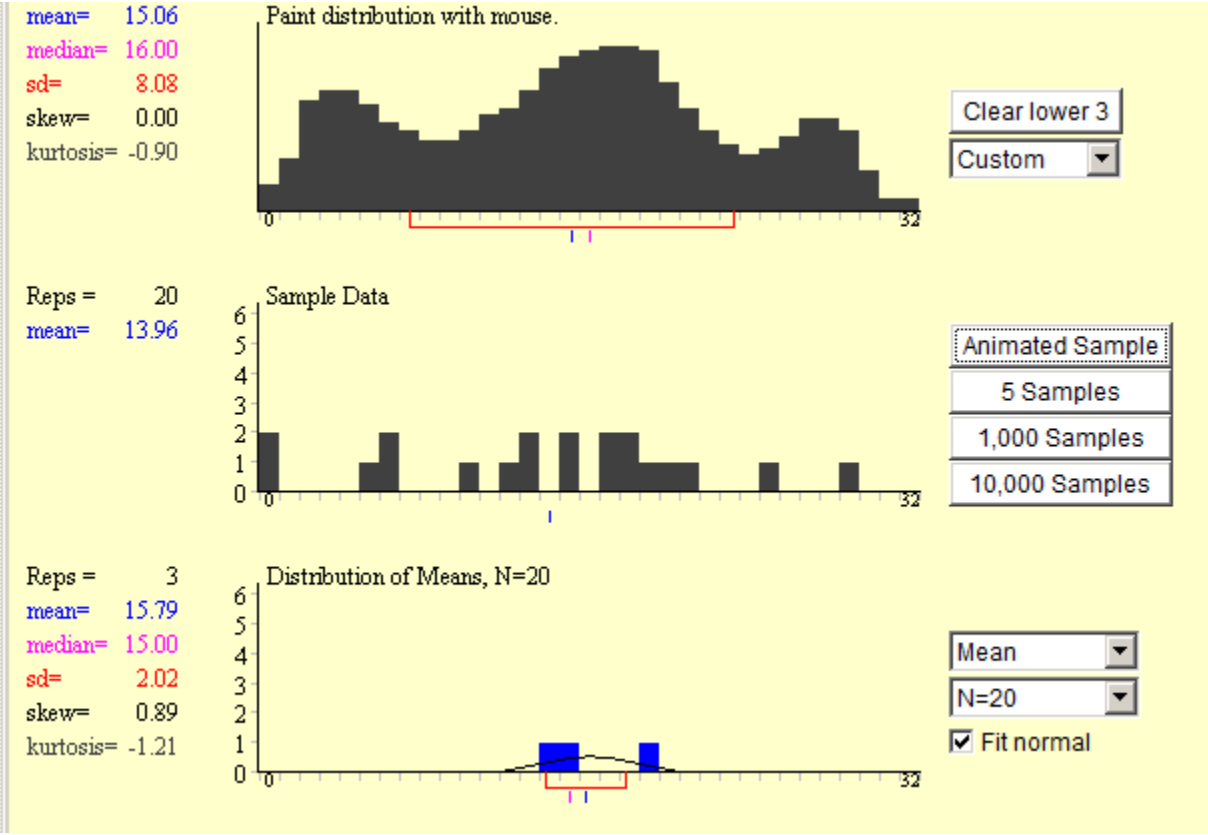
What if we choose N=20?

The super-duper N20 Student weighing machine



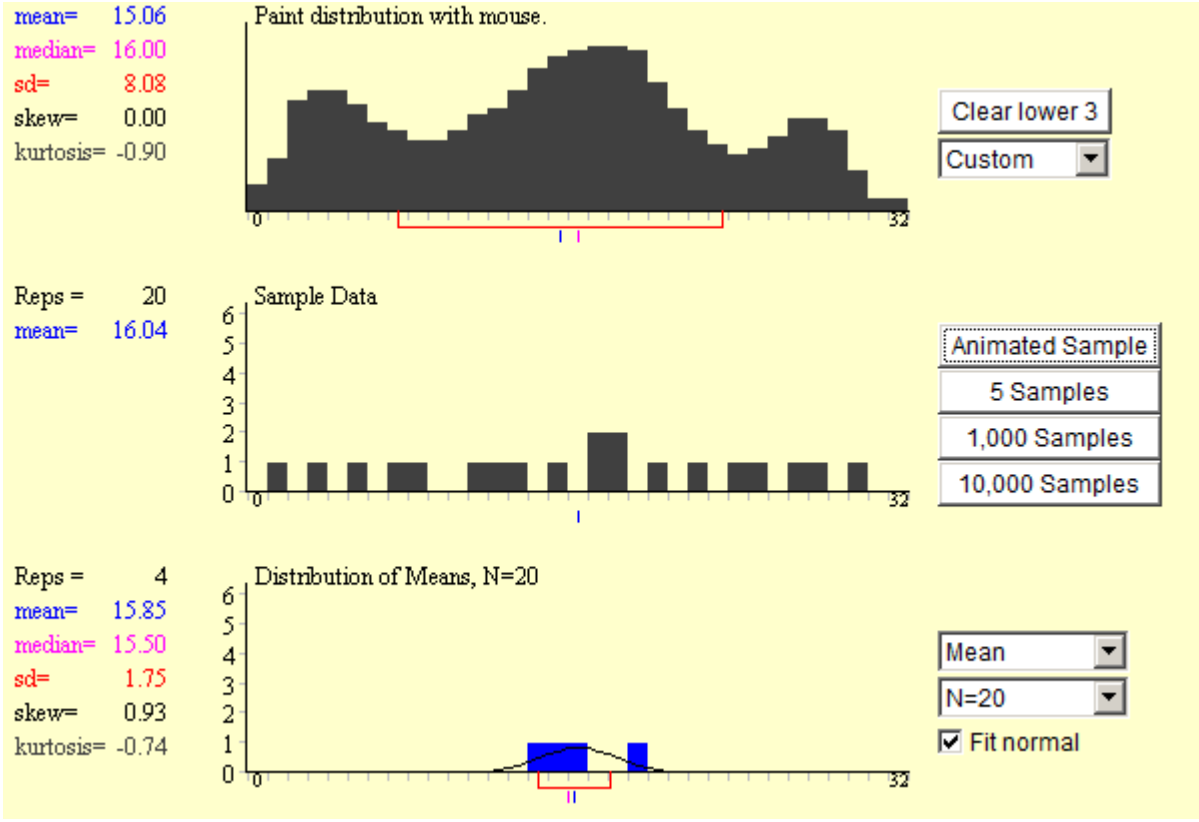
What if we choose N=20?

The super-duper N20 Student weighing machine



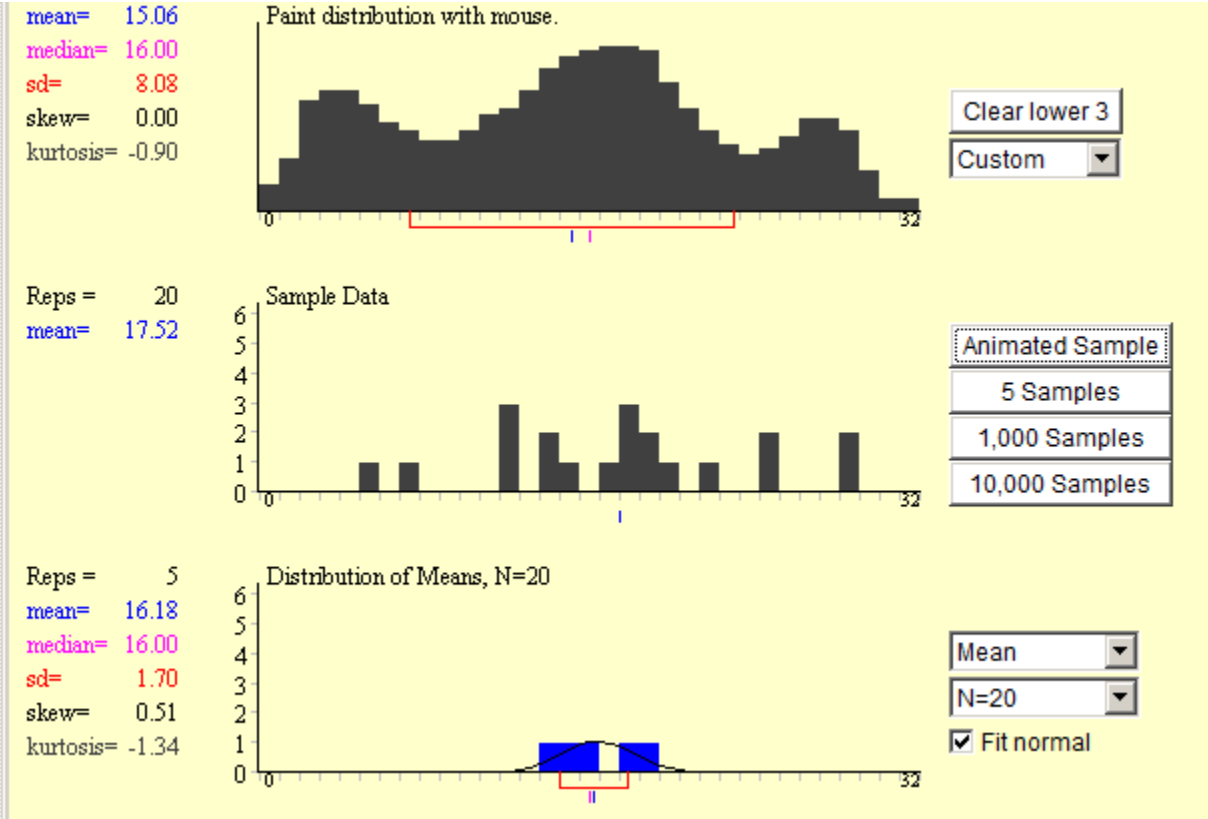
What if we choose N=20?

The super-duper N20 Student weighing machine



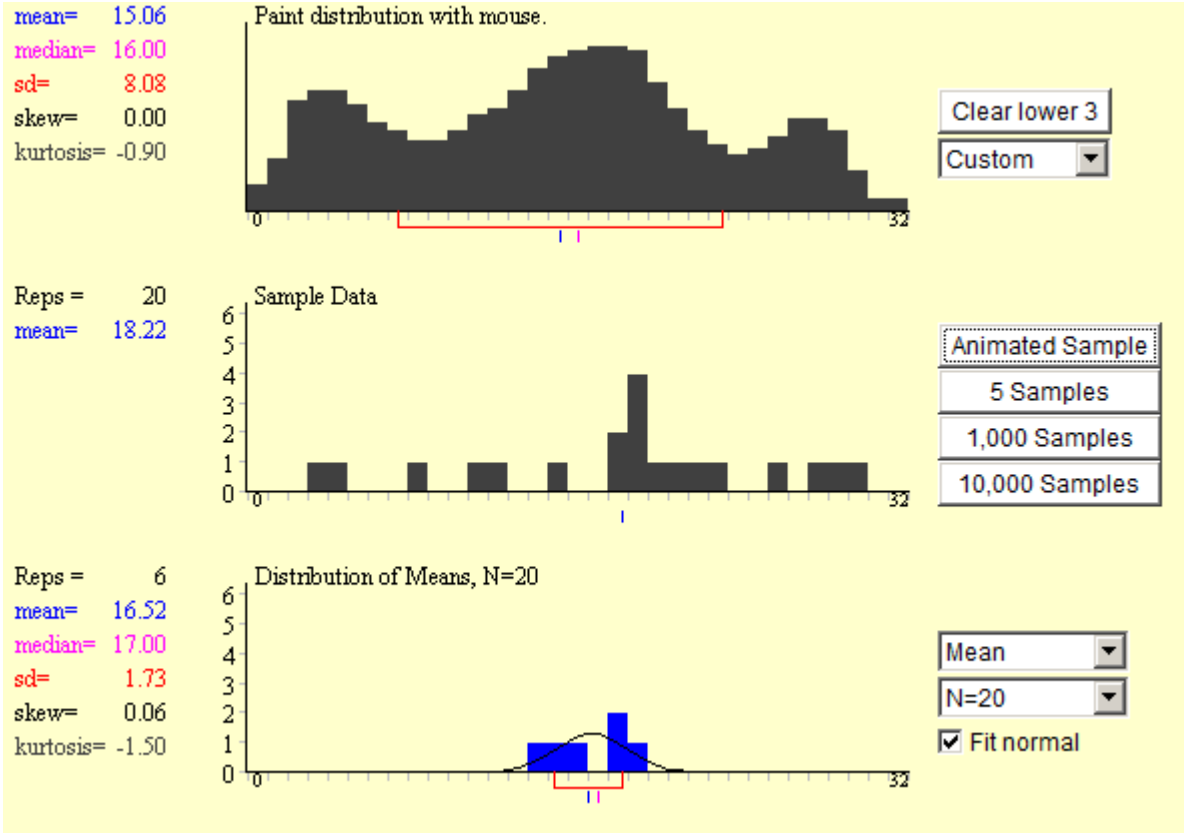
What if we choose N=20?

The super-duper N20 Student weighing machine



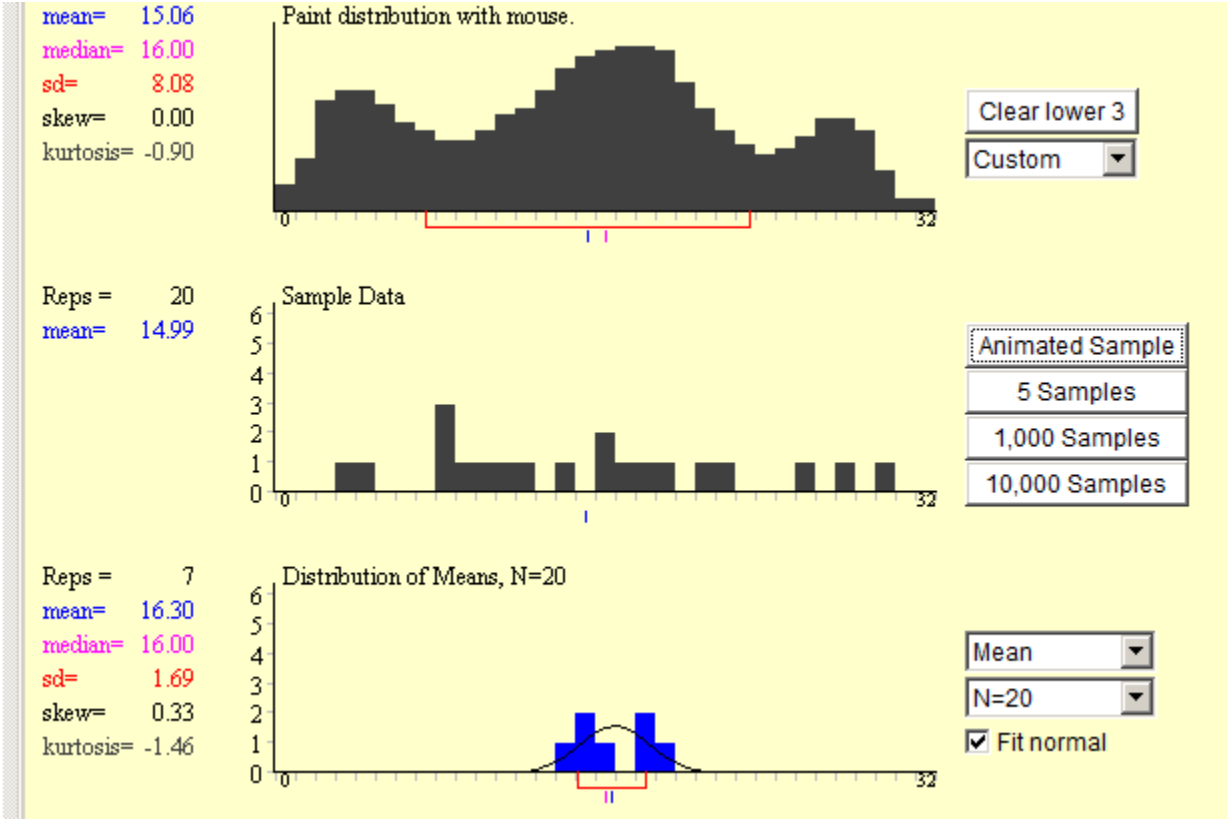
What if we choose N=20?

The super-duper N20 Student weighing machine



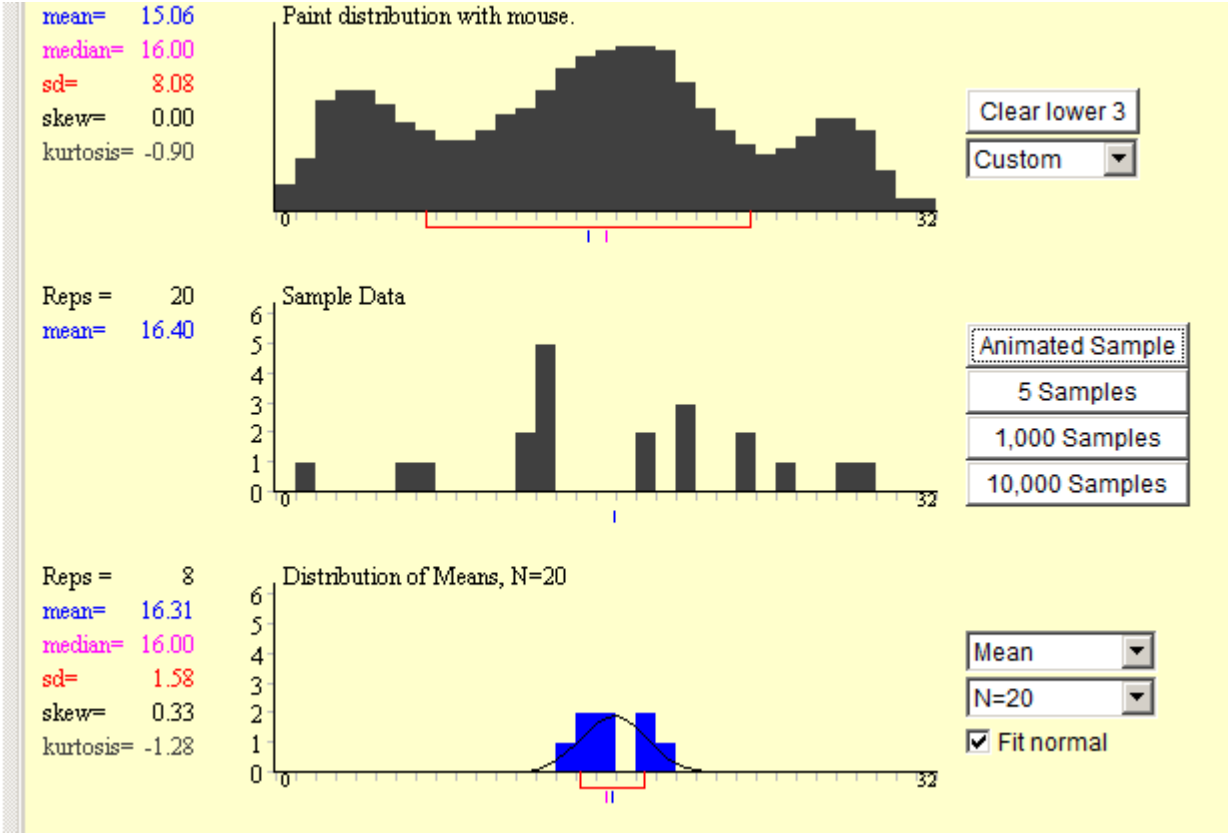
What if we choose N=20?

The super-duper N20 Student weighing machine



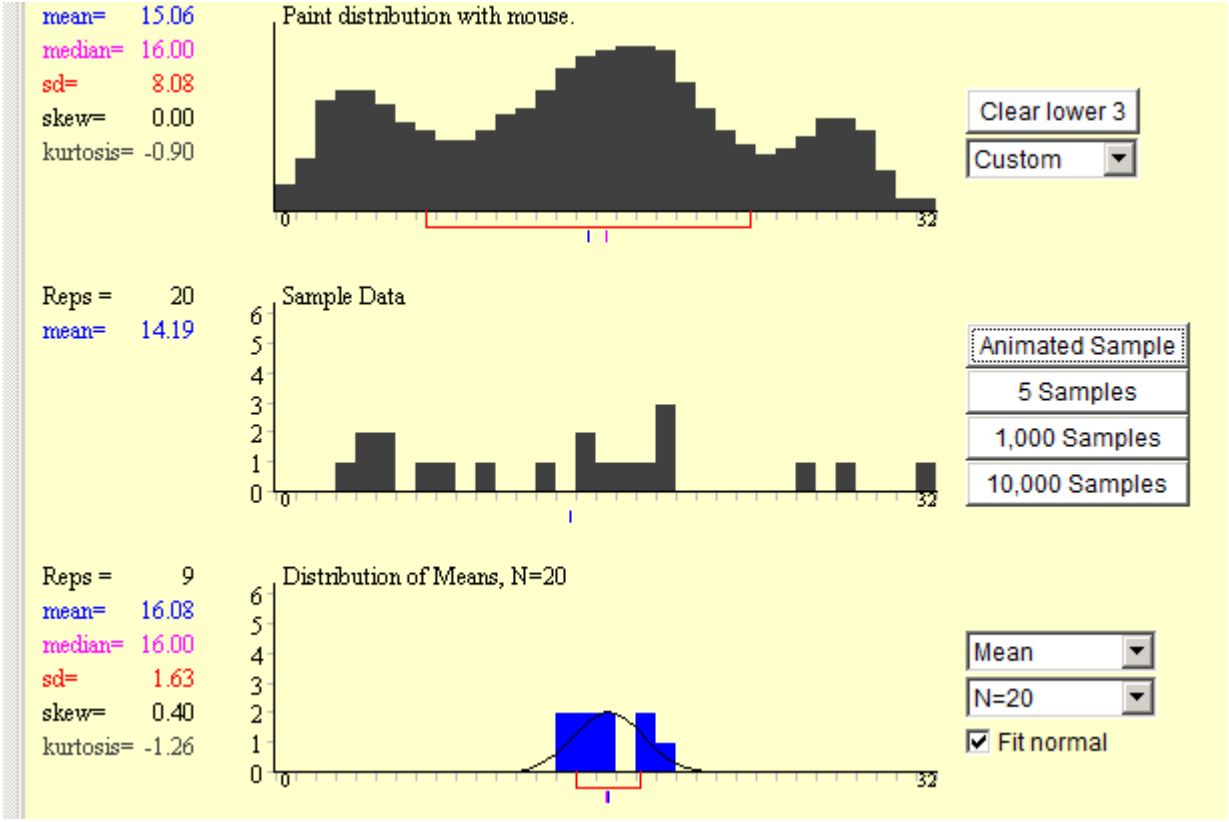
What if we choose N=20?

The super-duper N20 Student weighing machine



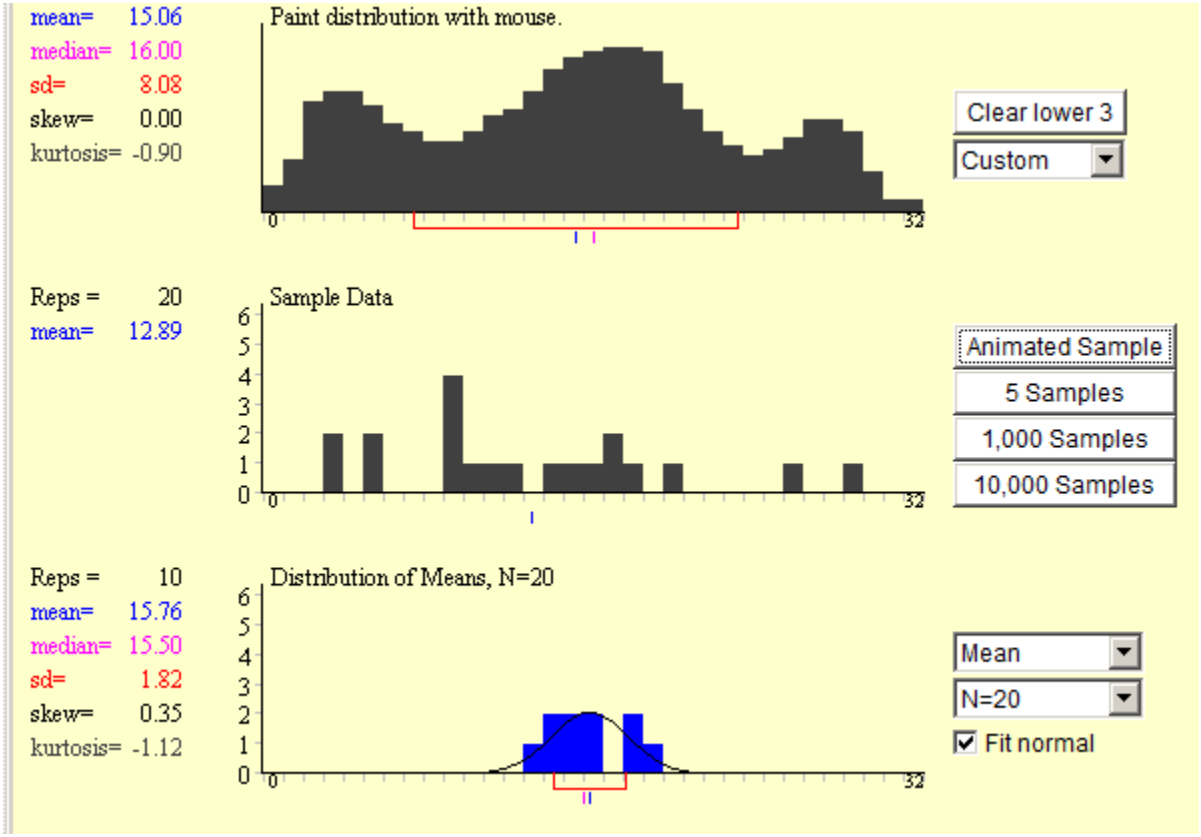
What if we choose N=20?

The super-duper N20 Student weighing machine



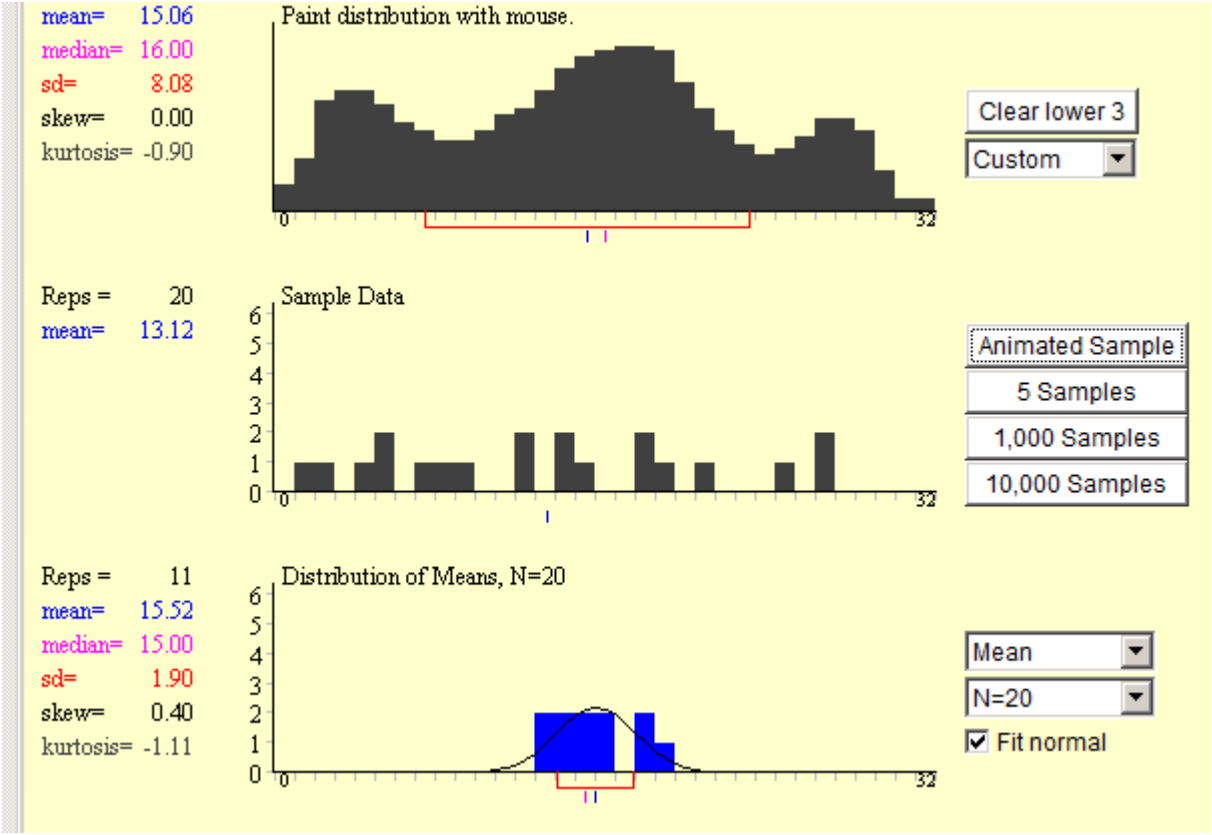
What if we choose N=20?

The super-duper N20 Student weighing machine



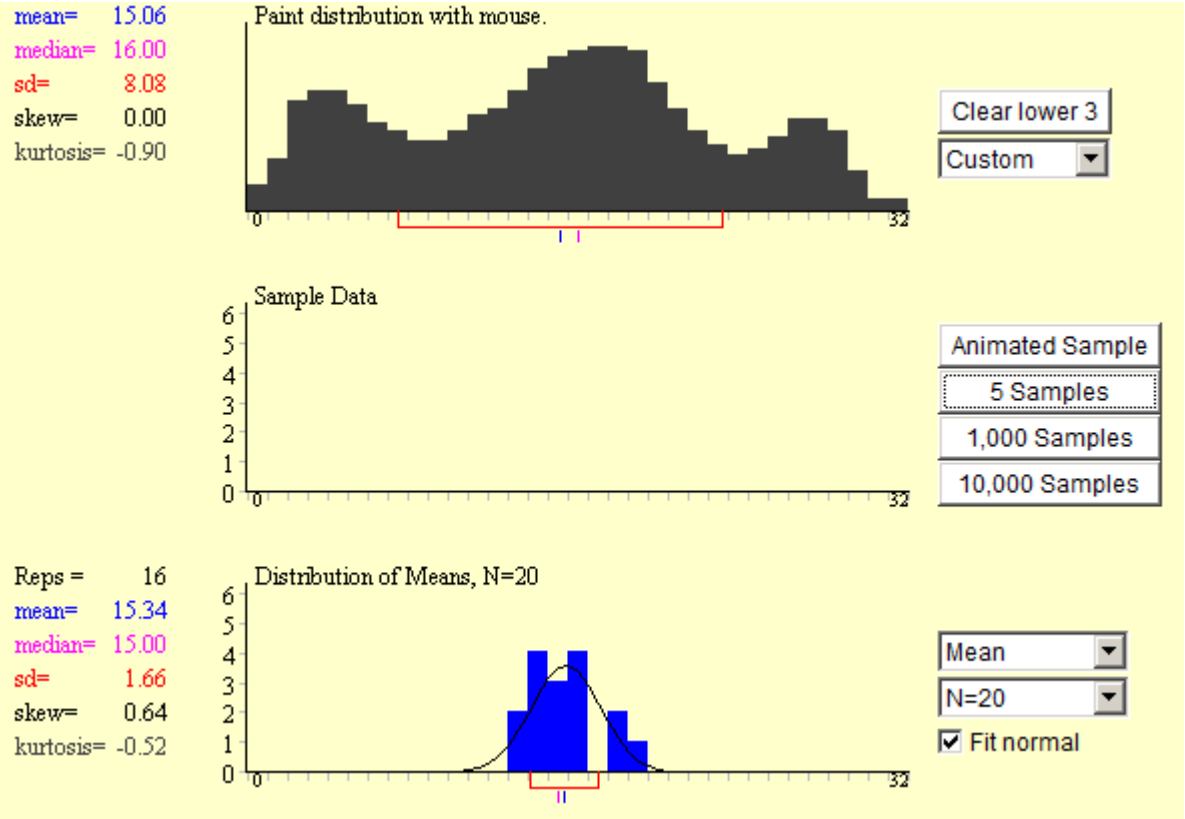
What if we choose N=20?

The super-duper N20 Student weighing machine



What if we choose N=20?

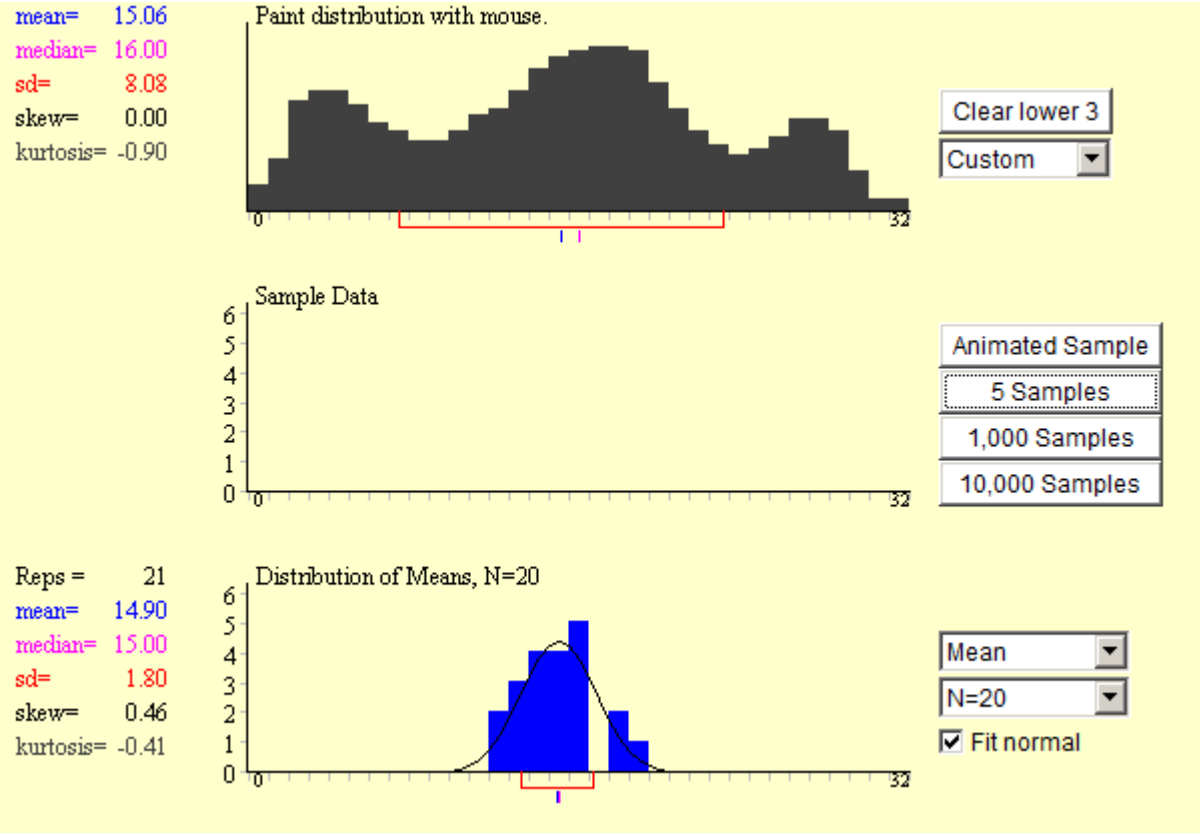
The super-duper N20 Student weighing machine



Now we step in 5 samples

What if we choose N=20?

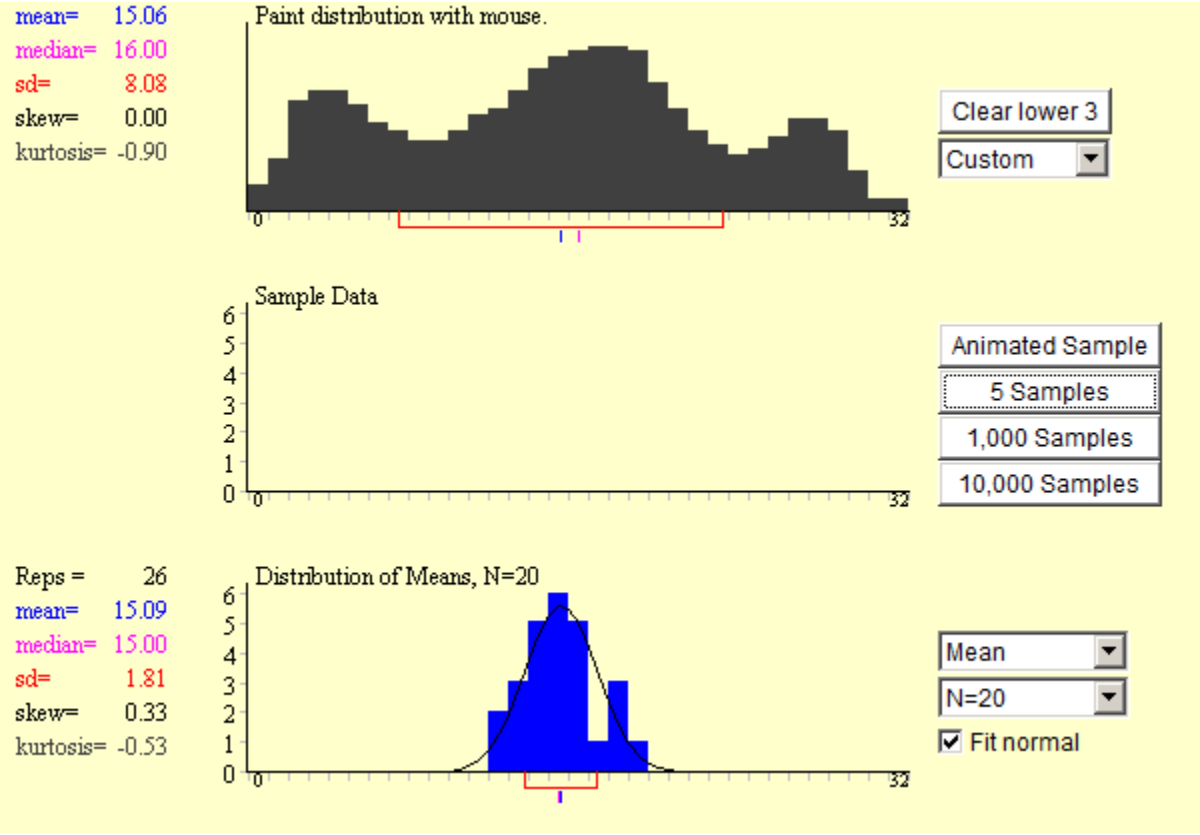
The super-duper N20 Student weighing machine



Now we step in 5 samples

What if we choose N=20?

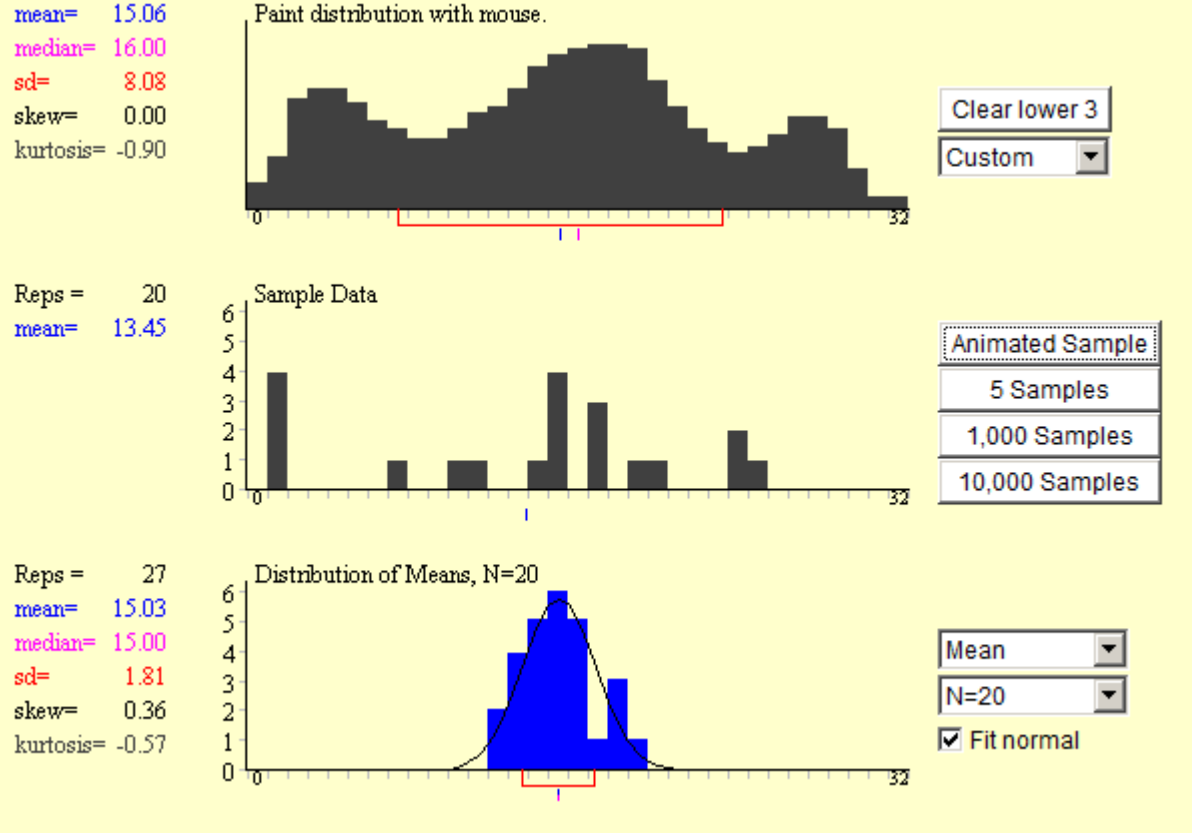
The super-duper N20 Student weighing machine



Now we step in 5 samples

What if we choose N=20?

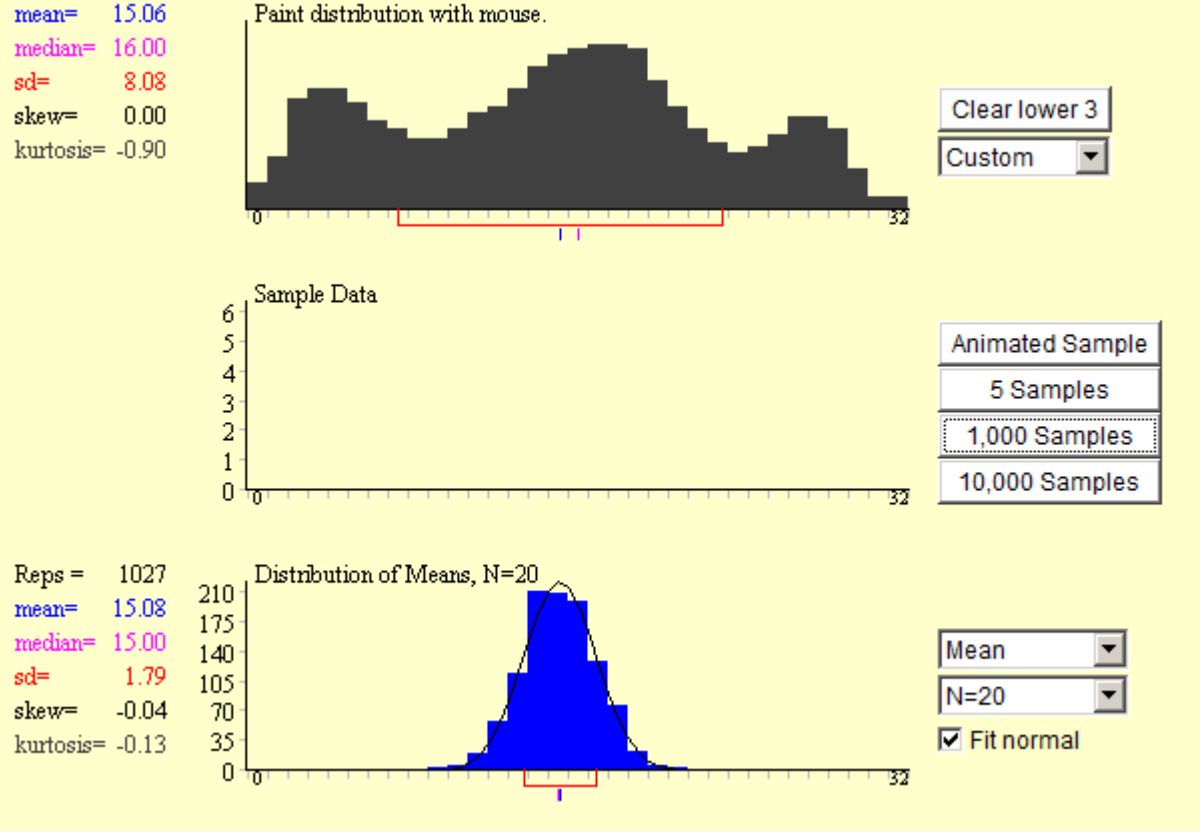
The super-duper N20 Student weighing machine



Now we step in 5 samples

What if we choose N=20?

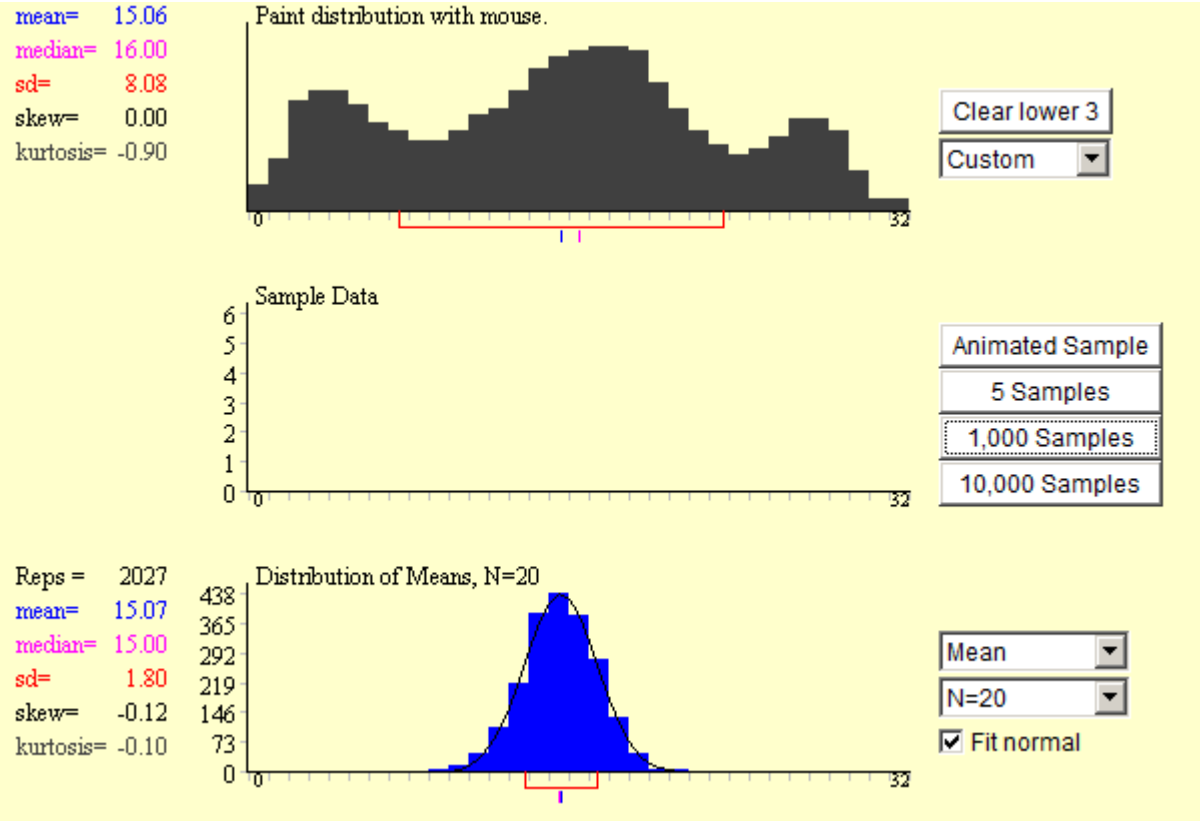
The super-duper N20 Student weighing machine



Now we step in 1 000 samples

What if we choose N=20?

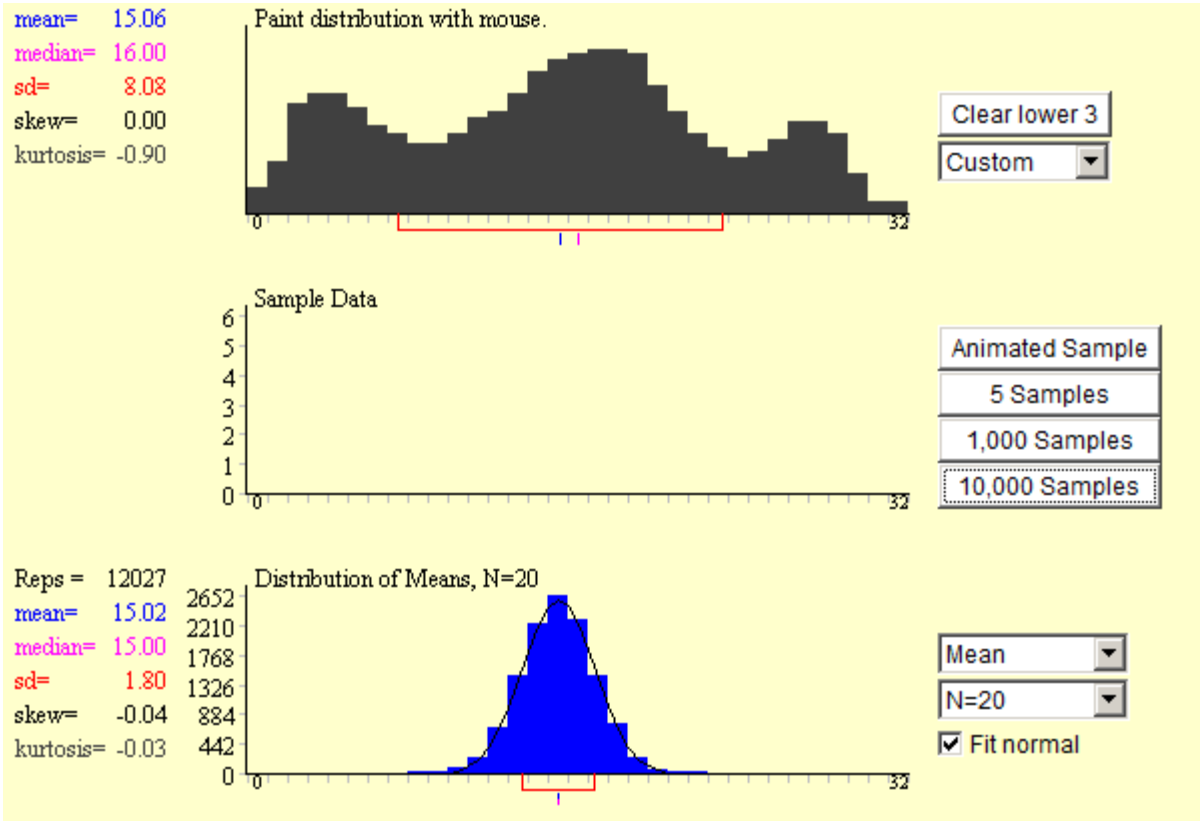
The super-duper N20 Student weighing machine



Now we step in 1 000 samples

What if we choose N=20?

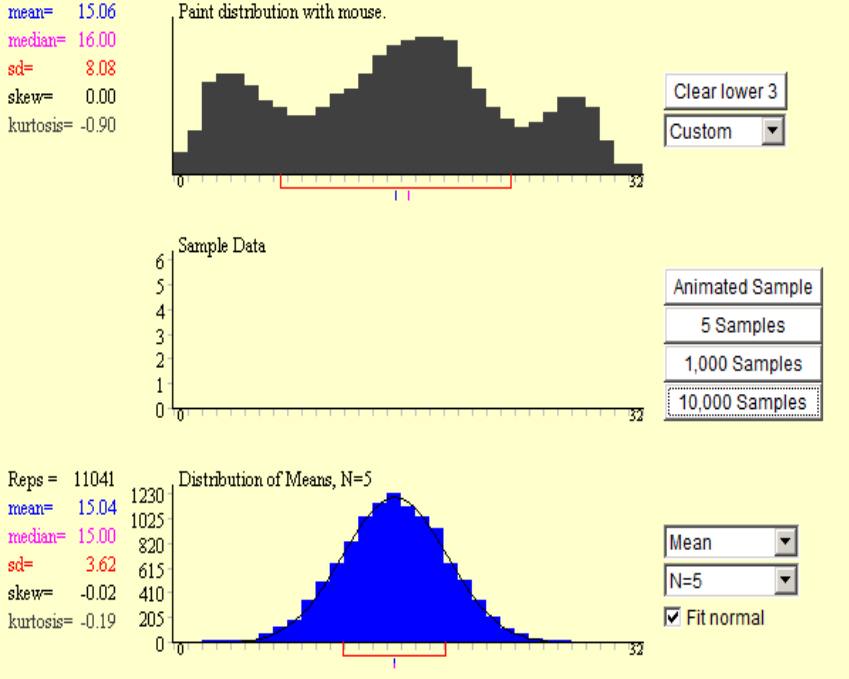
The super-duper N20 Student weighing machine

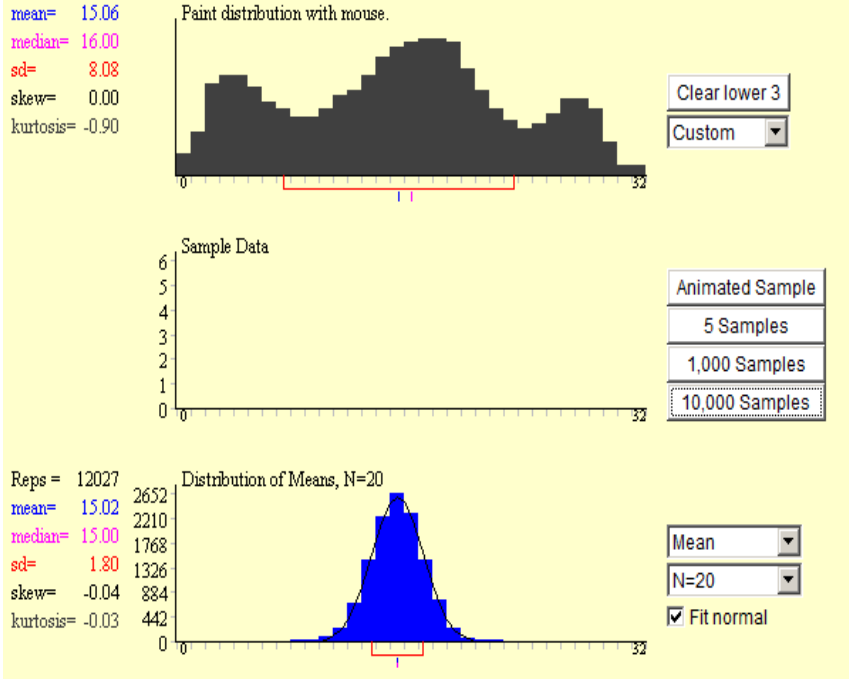


Now we step in 10 000 samples

The N5 Weighing Machine versus the N20 Weighing Machine

The difference between the machines is the width





More Precise (Narrower Distribution)

Averages of 5 samples taken from the student population.

Averages of 20 samples taken from the student population.

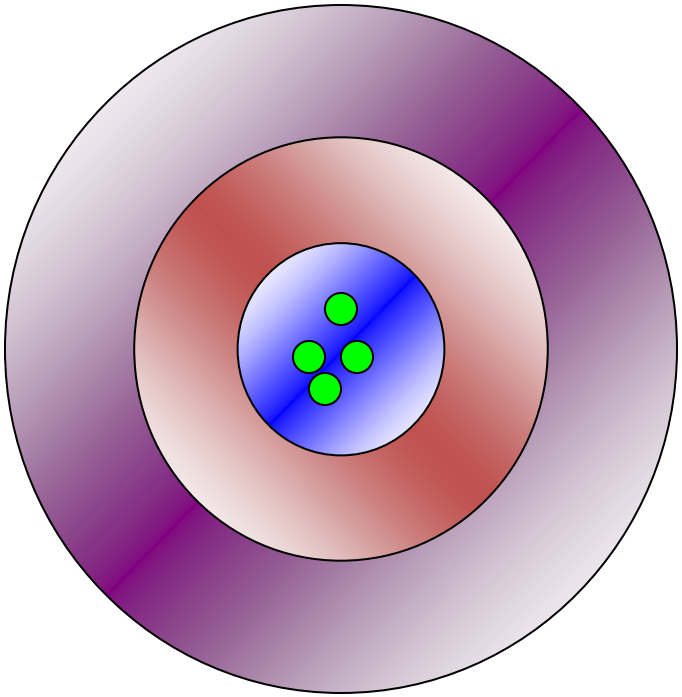
Which machine is better?
Which machine is more precise?
Which machine is more accurate?

What number (statistic) would you use to quantify the difference in these machines?

Precision and Accuracy

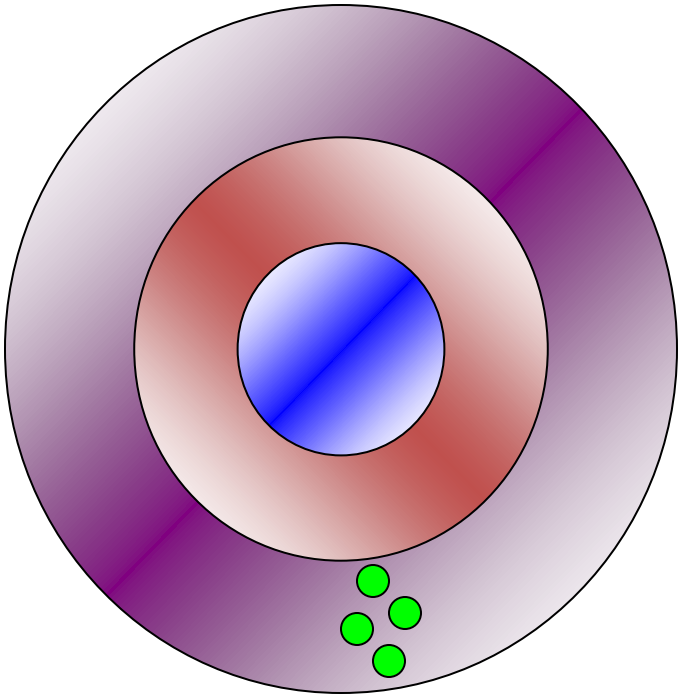
- High accuracy (low bias)
- High precision (low standard deviation)

N20 Machine



Precision and Accuracy

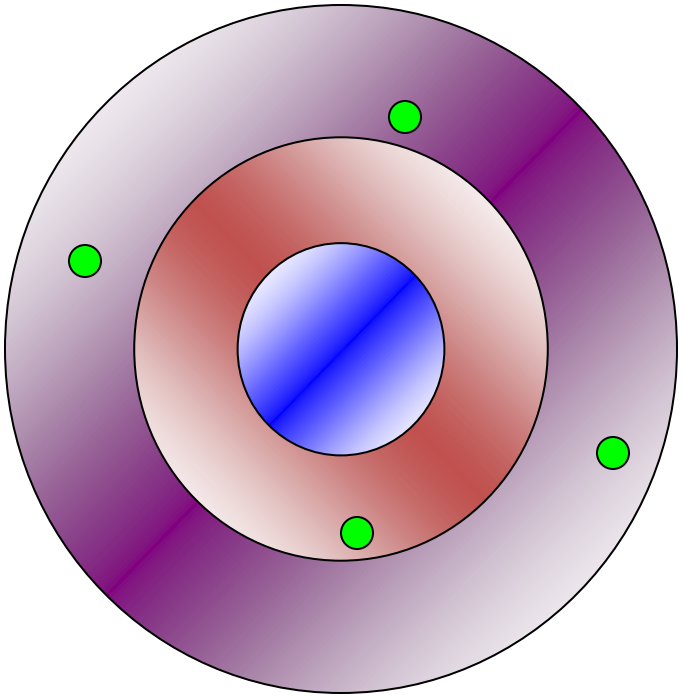
- Low accuracy (large bias)
- High precision (low standard deviation)



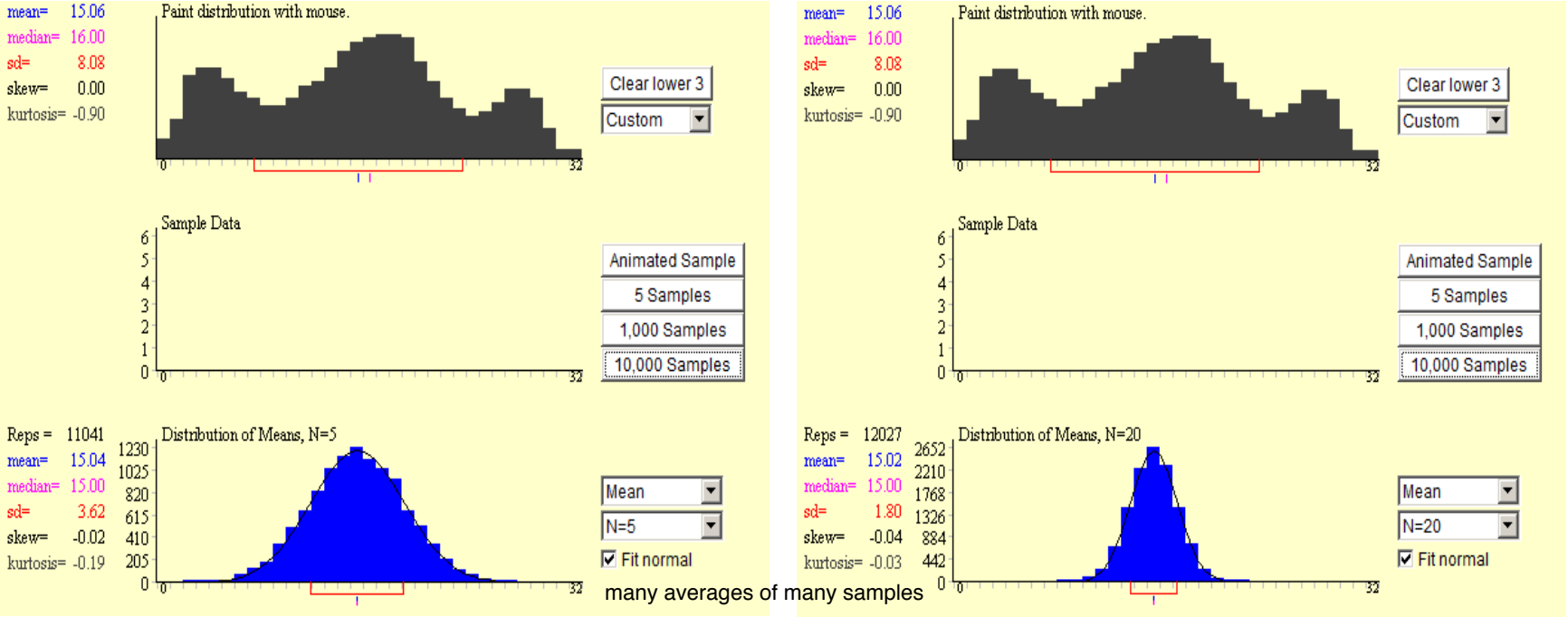
Precision and Accuracy

- High accuracy (low bias)
- Low precision (high standard deviation)

N5 Machine



The N5 Weighing Machine versus the N20 Weighing Machine



- The standard error is related to the width of the sampled distribution. The standard error is the standard deviation of the distribution of the means, i.e., the 'sd' in the lower plots. Standard error = error associated with measurement
- The lower plots will always be normal curves (Gaussian curves) regardless of the parent population: this is the Central Limit theorem.
- The standard error indicates how well you know the mean.

Standard Error for the mean of x →

standard deviation of population

$$S_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

sample size

3 Standard Deviations
- Population
- Sample
- Distribution of Means

You can do this at home:

- Go to: http://onlinestatbook.com/rvls/index.html
- Go to the ‘Simulations/Demonstrations’ link and then to ‘Central Limit Theorem’ and then to ‘Sampling Distribution Simulation’.

Sampling Distribution Simulation

Standard Error

- The standard deviation of the means is called the **standard error**
  - Describes the variation of the means about the estimated mean
  - We usually do not know the true standard deviation, σ, of the parent population, so
  - The standard error is **estimated** as follows

$$s_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \approx \frac{s}{\sqrt{n}}$$

Standard Error

- Thus, the standard error associated with the estimated population mean is

$$\underset{\text{population mean}}{\mu} = \underset{\text{sample mean}}{\overline{x}} \pm z_c s_{\overline{x}}$$

where

z_c = confidence level

e.g. $z_{95} = 1.96$ for 95% confidence

- At 95% confidence, the true mean, μ, lies within this $\pm$ interval.

So, what is the point of all of this?

- Almost all of our measurements are made with instruments that give us '*average values*'.
- If you take many measurements and plot a histogram of these values, then you will get a normal (Gaussian) distribution
- If we only do one N5, or one N20, measurement then we will have an estimate of the true mean, based on a single sample.
- The single N5, or N20, measurement distribution will also have a width, which we calculate as the standard deviation: 'S'.
- From the standard deviation, S, we calculate the standard error in the estimated mean:

$$S_{\bar{x}} = S / \sqrt{n}$$

- We can never be 100% confident that the mean of the sample is the 'true mean', but …
- We can give the sample mean value, which is our best estimate, along with a $\pm z_c S_{\bar{x}}$ range, which is a confidence interval
  - depending on the choice of z_c.

Common Confidence Values

$$\text{'true value'} = \text{measured mean value} \pm z_c \sigma_{\text{measured}}$$

where

z_c = confidence level **FIXED NUMBERS

$z_{90} = 1.645$ for 90% confidence

$z_{95} = 1.96$ for 95% confidence (or 19 times out of 20)

Typical, but only because it's easy to multiply by 2

$z_{99} = 2.58$ for 99% confidence

So, up to now, you simply put error bars on your measurements. Now the size of the error bar depends on how confident you are about the measurement.

Evolution of Reporting Numbers

What you see on your calculator: 13.923

High School

13.9 to 3 sig figs, because of the least significant number in your calculation

Year 1 First Half Term

13.9 ± 0.05, because of an assumed error based on sig figs

NOTE: ABOVE AND BELOW EXAMPLE ARE NOT RELATED

Year 1 Last Half Term

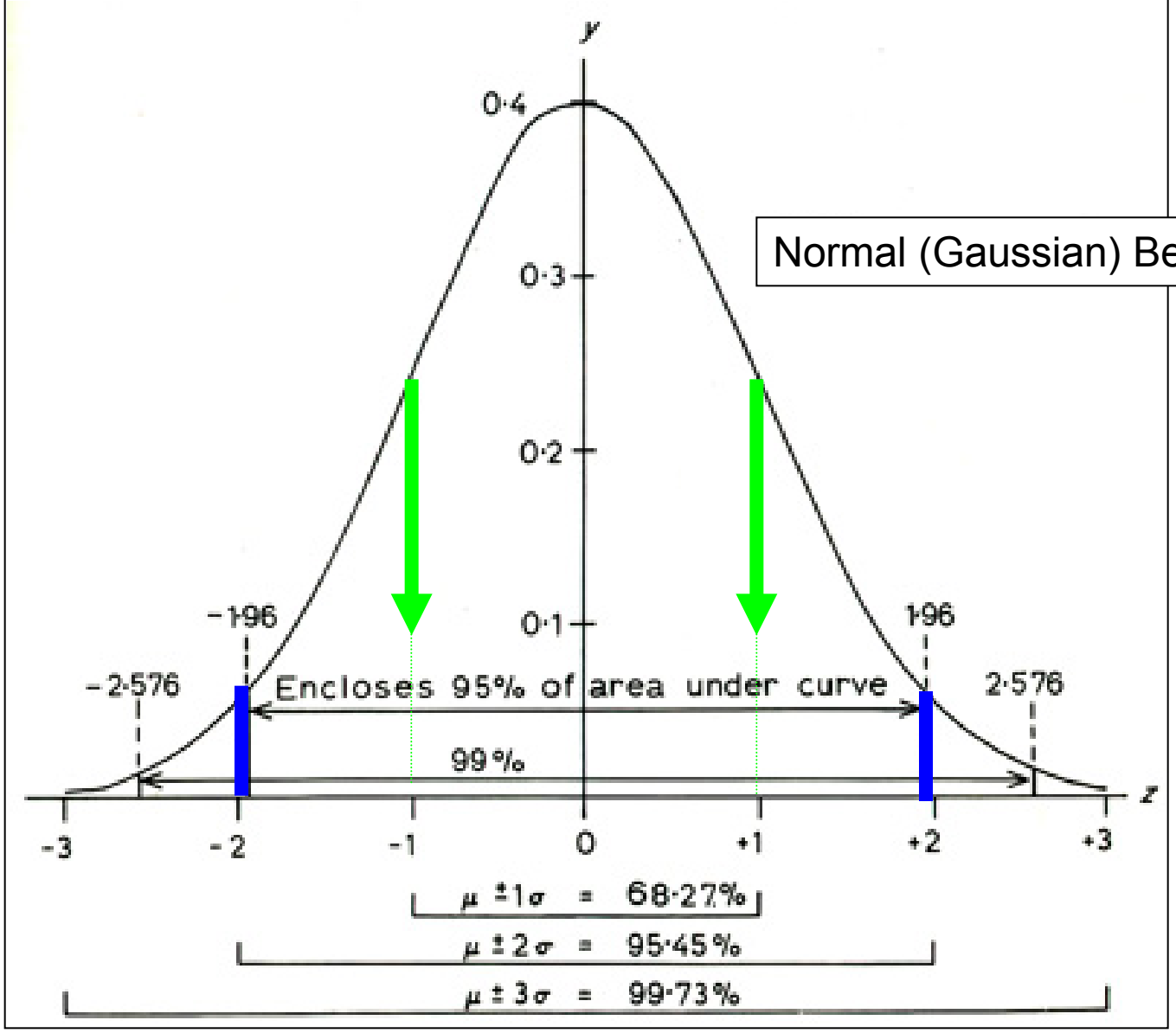
2 = 1.96 ROUNDED

13.9 ± 0.3, (2σ, 95% confidence)

Gaussian (normal) Distributions are everywhere, so let's look at them in some detail

Gaussian Distribution

- Also called **Normal** distribution
  - Named after Carl Fredrich Gauss (1777-1855)
- Common distribution in many engineering applications
- Symmetric about a central value

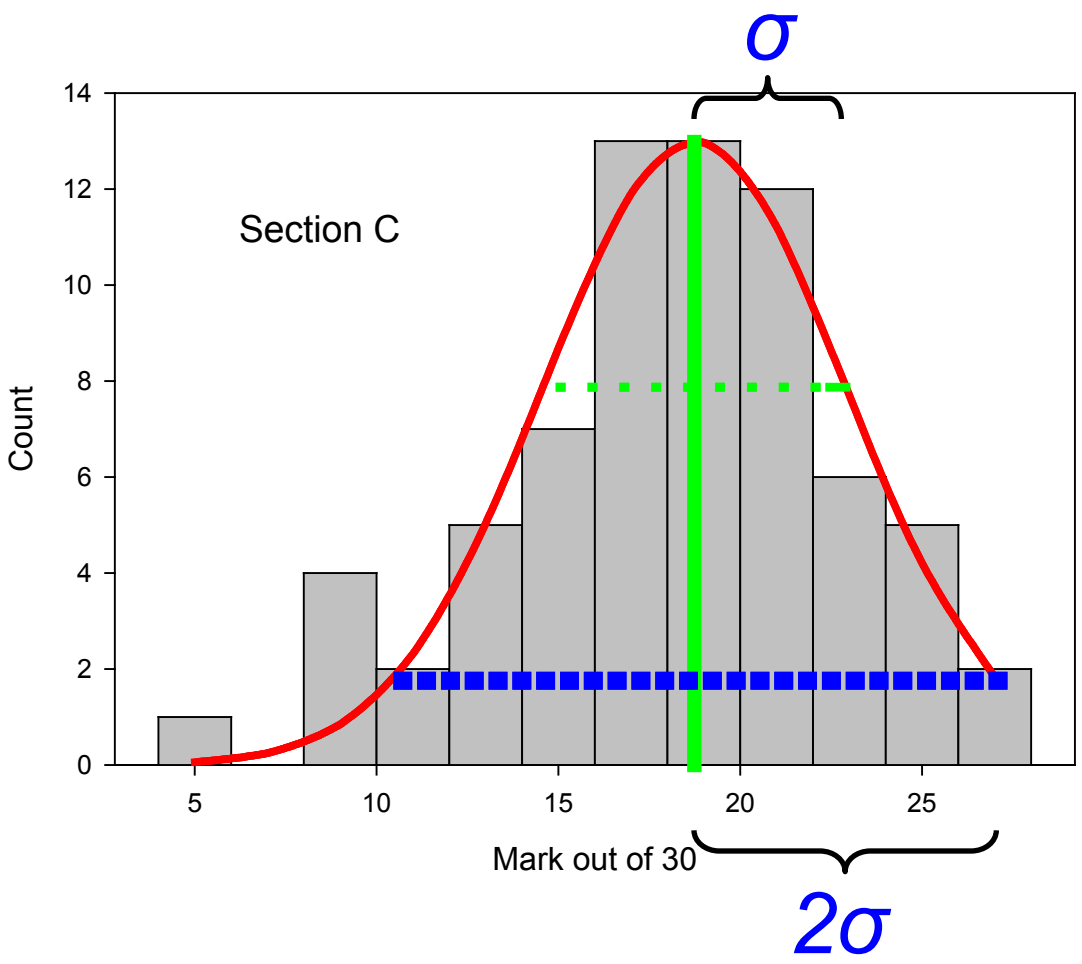


Compare these numbers with the z_c values:

$z_{95} = 1.96$ for 95% confidence (or 19 times out of 20)

$z_{99} = 2.58$ for 99% confidence

Normal (Gaussian) Distributions



- 68% of the students had marks in the range:

$$\text{mean} \pm \sigma$$

- 95% of the students had marks in the range:

$$\text{mean} \pm 1.96\sigma$$

How do we know that 1.96 σ corresponds to 95% of the area?

- We integrate the equation for the 'standard' Gaussian curve from -1.96 to +1.96 and we get 0.95
- Or, integrate from 0 to 1.96, and multiply by 2, because the Gaussian curve is symmetric about the mean.

Continuous Form of the Gaussian Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2}$$

$\sigma = \text{standard deviation}$

$\mu = \text{mean}$

Standard Normal Distribution

- To make the calculation easier, we create a special table the eliminates the need to perform a new integration every time
- Use a **standard** form, otherwise you need a table for every new mean and standard deviation
  - Apply a change of variable: $z = \dfrac{x - \mu}{\sigma}$

Population vs. Sample

$$z = \frac{x - \mu}{\sigma}$$

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{(x-\mu)^2}{2\sigma^2}\right)} \rightarrow f(z) = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}$$

$$z = \frac{x - \overline{x}}{s}$$

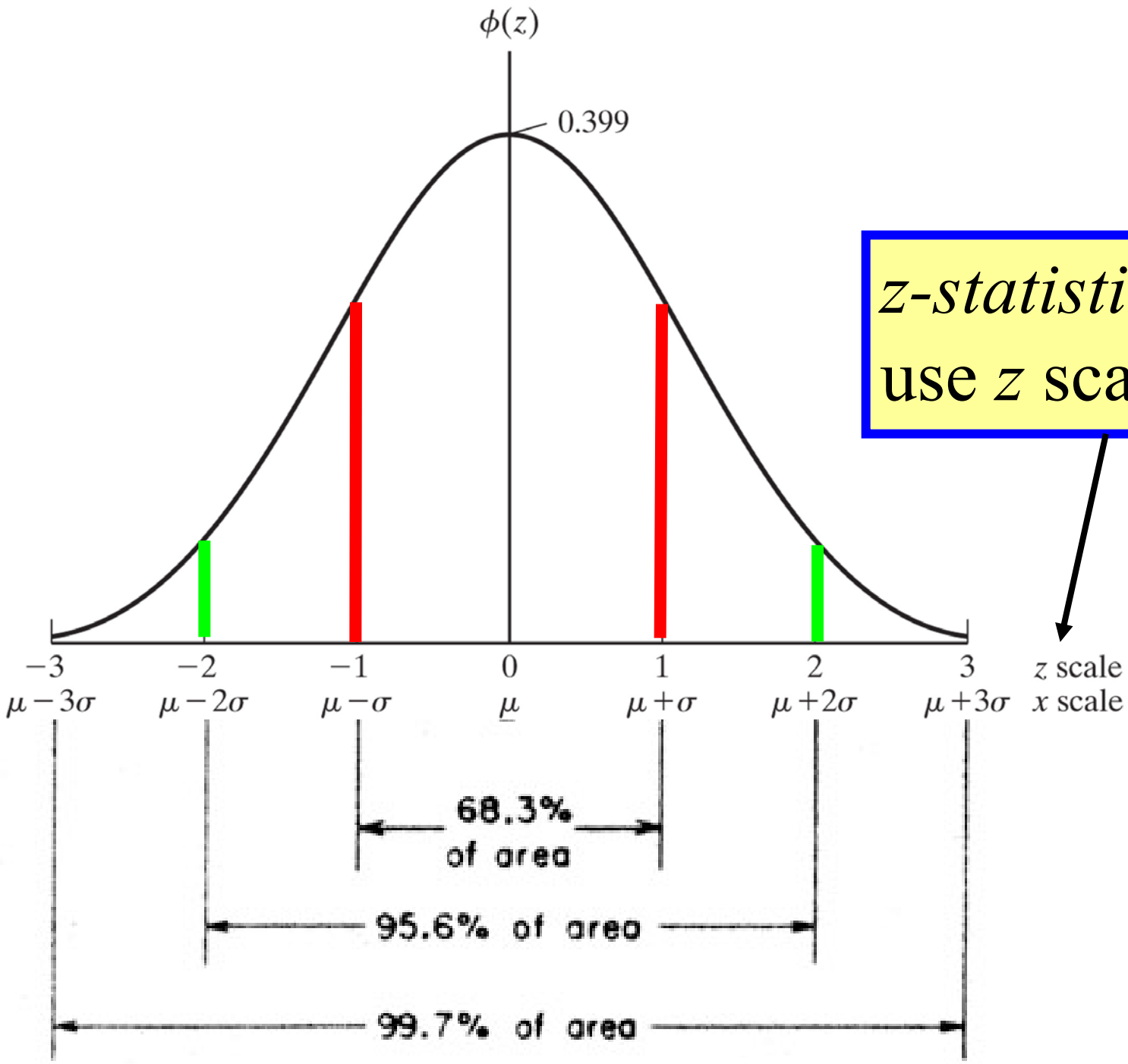
$$f(x) = \frac{1}{s\sqrt{2\pi}} e^{-\left(\frac{(x-\overline{x})^2}{2s^2}\right)} \rightarrow f(z) = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}$$

Standard Normal Distribution

- In the new variable z, the mean is at $z = 0$
- We also set the standard deviation to one (1)
- We get the standard normal distribution:

$$\phi(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2}$$

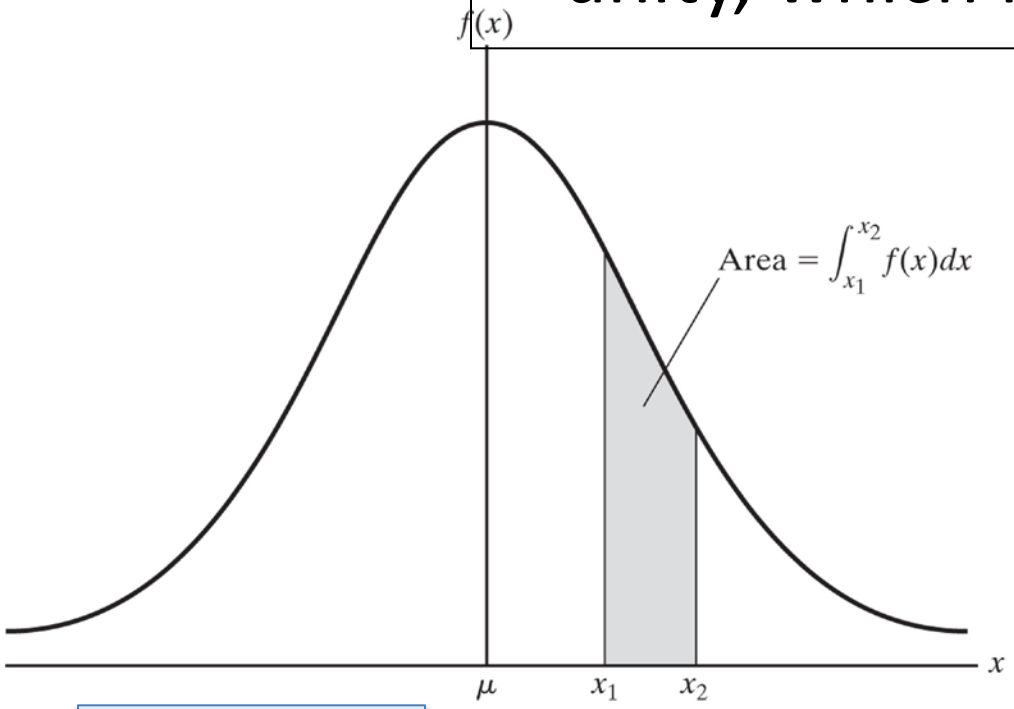
Called *z-statistics*



z-statistics:
use *z* scale

Standard Normal (Gaussian) Distribution

The total area under the standard normal distribution is unity, which means equal to 1.



Area under the curve is unity

z-Statistics (half-areas)

Table 9.4 Areas Under the Standard Normal Curve from 0 to *z*

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0754
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2258	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2996	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
3.1	.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
3.3	.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
3.4	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
3.5	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998

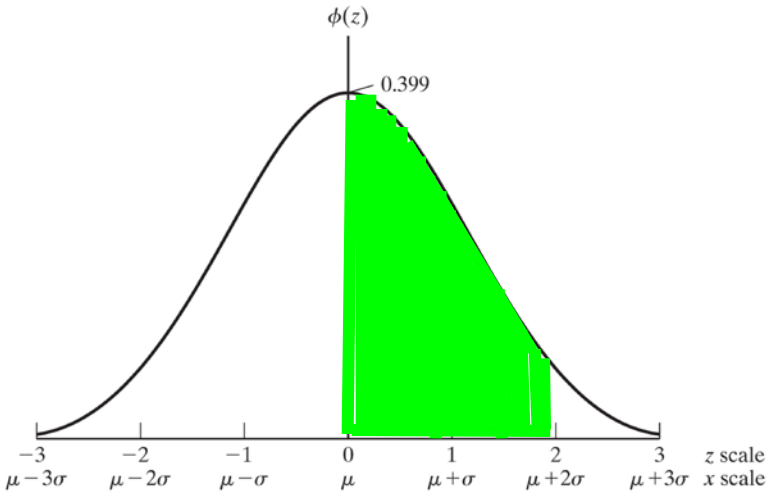
Source: *Introduction to Engineering Practice*, 3rd Ed., Hagen, 2008. Similar tables are in Chapter 10 of your textbook.

0.4750 is the area under the standard curve from zero, which is the mean, to z=1.96

1.9 + 0.06 = 1.96

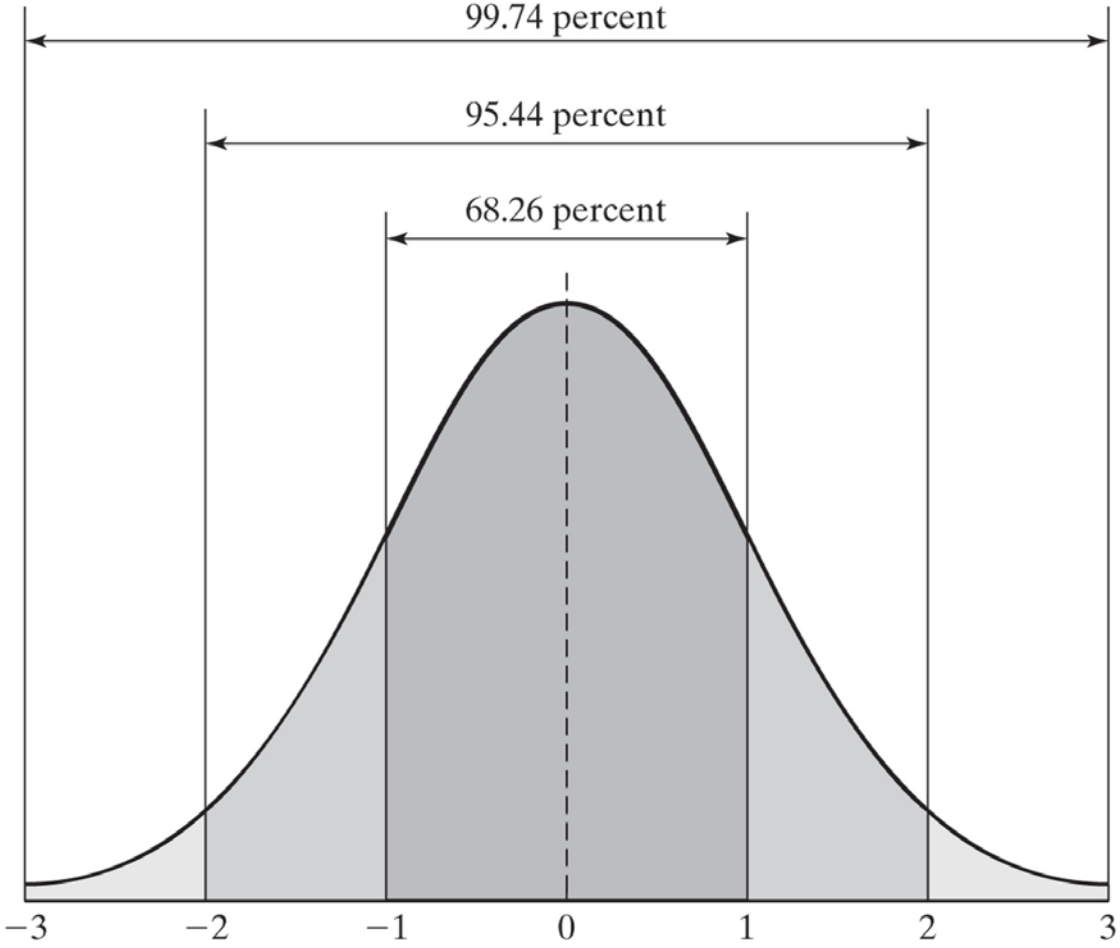
$$\int_0^{1.96} \frac{1}{\sqrt{2\pi}} e^{-\left(\frac{1}{2}\right)z^2} dz = 0.475$$

^ percent of curve (area) of HALF



0 → 1.96 (z-scale)

The Usual Values People Know



Most computer programs, like Excel for example, have functions that give you the areas, so tables are ‘old fashion’.

Random Number Generation

- We can use a computer to generate “pseudo-random” numbers
  - Not actually random, but have approximately random statistical properties
- Random numbers according to a **distribution** can be generated:
  - Normal (Gaussian)
  - Lognormal
  - Poisson
  - Binomial
  - Uniform
  - ChiSq , etc.

Estimating with Small Samples

Introduction to *t*-Statistics

Small Samples

- Small samples are those with $n < 30$ elements
- Our *z*-statistics are no longer accurate
- Must use *t*-statistics
  - The sample variance is weighted
  - Result is a different distribution from the normal distribution, but with a similar shape
  - Appropriate for small samples

Student t-Distribution

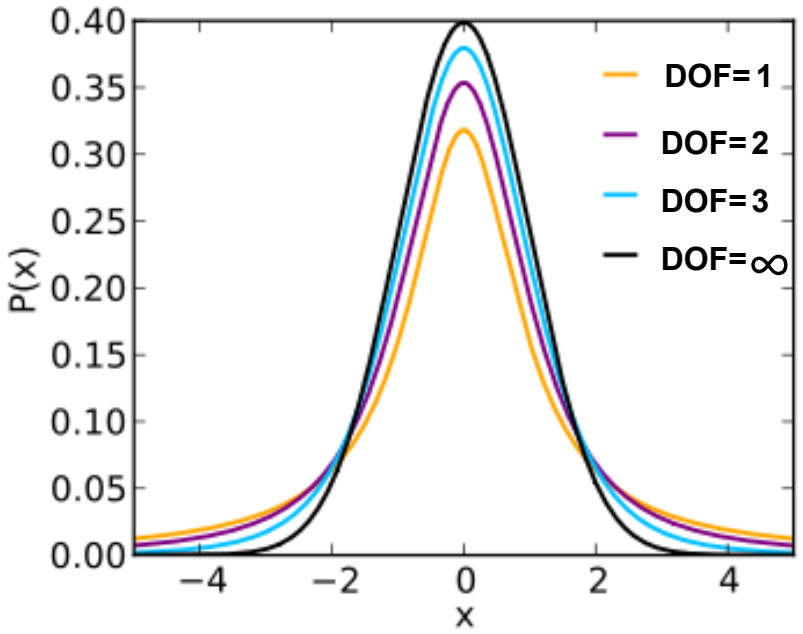
- The distribution for small samples is generally called the **student *t*-distribution**
  - Based on a weighting described by W. S. Gosset (1876-1937)
  - He was interested in beer (yes, beer)
  - He worked for a beer company (Guiness)

Student *t*-Distribution

- Because of variability in the ingredients of beer, samples that come from the same population are generally small
- Important for Quality Control
- Gosset's company did not allow him to publish, so he did so under the pseudonym "Student"

Student *t*-Distribution

- Gosset showed that small samples taken from an essentially normal population have a wider confidence interval than we would predict with z-statistics.
- For small samples, we must use t-statistics.
- The t-distribution is shorter and fatter than the normal distribution, but when DOF=∞ (i.e., for large *n*) the t-distribution becomes a normal (Gaussian) distribution



$$\text{DOF} = \nu = n - 1$$

= Degrees of Freedom

Lower amplitude, wider range (to maintain maximum area of 1)

Student *t*-Distribution

$$x = \overline{x} \pm t_{\nu,c} s_{\overline{x}}$$

where

$t_{\nu,c}$ = t-statistic for ν degrees of freedom

$\nu = n - 1 = \text{DOF} = \text{Degrees of Freedom}$

t-Statistics

υ	$t_{\upsilon,50}$	$t_{\upsilon,90}$	$t_{\upsilon,95}$	$t_{\upsilon,99}$
1	1.000	6.314	12.706	63.657
2	0.816	2.920	4.303	9.925
3	0.765	2.353	3.182	5.841
4	0.741	2.132	2.770	4.604
5	0.727	2.015	2.571	4.032
6	0.718	1.943	2.447	3.707
7	0.711	1.895	2.365	3.499
8	0.706	1.860	2.306	3.355
9	0.703	1.833	2.262	3.250
10	0.700	1.812	2.228	3.169
11	0.697	1.796	2.201	3.106
12	0.695	1.782	2.179	3.055
13	0.694	1.771	2.160	3.012
14	0.692	1.761	2.145	2.977
15	0.691	1.753	2.131	2.947
16	0.690	1.746	2.120	2.921
17	0.689	1.740	2.110	2.898
18	0.688	1.734	2.101	2.878
19	0.688	1.729	2.093	2.861
20	0.687	1.725	2.086	2.845
21	0.686	1.721	2.080	2.831
30	0.683	1.697	2.042	2.750
40	0.681	1.684	2.021	2.704
50	0.680	1.679	2.010	2.679
60	0.679	1.671	2.000	2.660
∞	0.674	1.645	1.960	2.576

note how when u = inf, normal gaussian curve

See the EXCEL functions:
TDIST & TINV

There are ‘calculators’ on the web. See, for example:

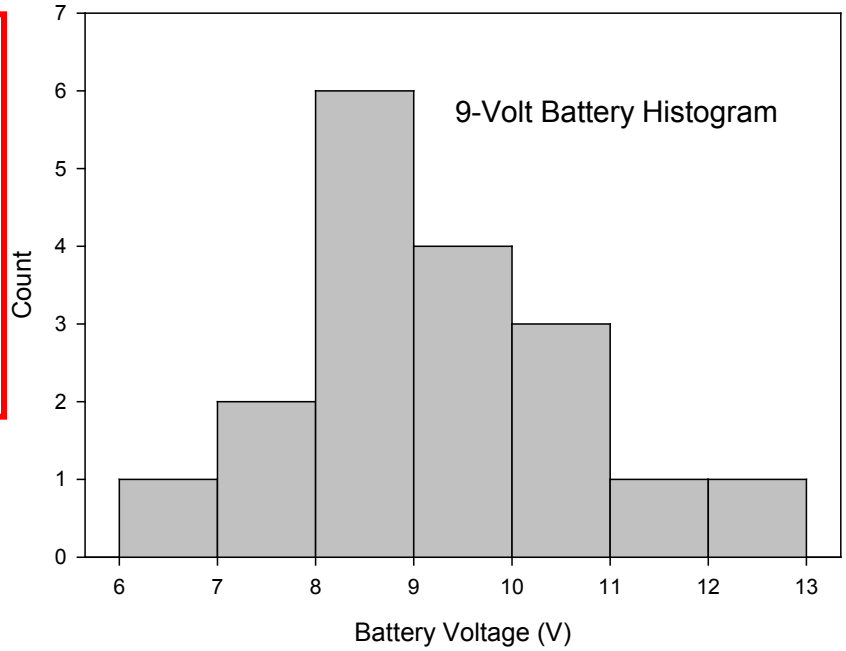
http://www.tutor-homework.com/statistics_tables/statistics_tables.html

Example

- Consider a sample of **eighteen** batteries from the entire population of batteries (each battery should be about 9 V)
- In order to establish the true mean of the voltages, you measure the voltage across each battery with a voltmeter
- Using the collected data, calculate:
  - Mean and standard deviation
  - 95% and 99% confidence interval estimates
  - Population mean with 90% confidence

Meas. #	Voltage (V)
1	6.51
2	8.45
3	11.76
4	8.36
5	9.35
6	9.23
7	7.85
8	8.59
9	9.05
10	8.08
11	10.59
12	9.87
13	8.04
14	8.38
15	10.01
16	12.84
17	10.48
18	7.27

$$\bar{x} = 9.1498$$



Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{n}(x_1 + x_2 + x_3 \ldots + x_n)$$

$$= \frac{1}{18}(6.51 + 8.45 + 11.76 \ldots + 7.27)$$

$$= 9.1498$$

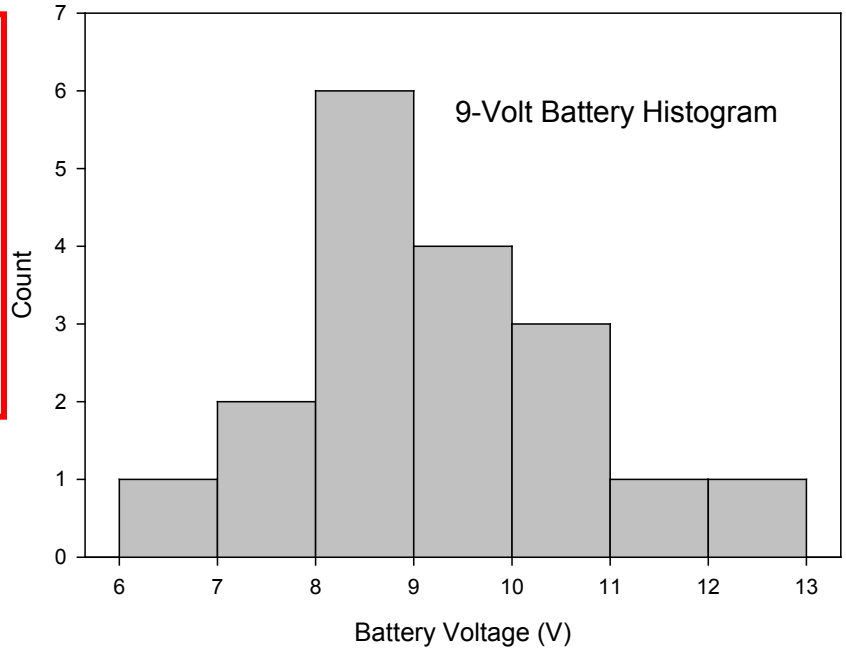
1. Histogram
2. Calculate Mean

➢ Do not round yet!

Meas. #	Voltage (V)
1	6.51
2	8.45
3	11.76
4	8.36
5	9.35
6	9.23
7	7.85
8	8.59
9	9.05
10	8.08
11	10.59
12	9.87
13	8.04
14	8.38
15	10.01
16	12.84
17	10.48
18	7.27

$$\bar{x} = 9.1498$$

$$s = 1.5776$$



$$s^2 = \frac{1}{n-1}\sum_{i}^{n}(x_i - \bar{x})^2$$

Sample Standard Variance

$$= \frac{1}{18-1}[(6.51-9.1498)^2 + (8.45-9.1498)^2 \ldots + (7.27-9.1498)^2]$$

$$= 2.4888$$

3. Sample standard variance
4. Standard deviation (sqrt(sv))

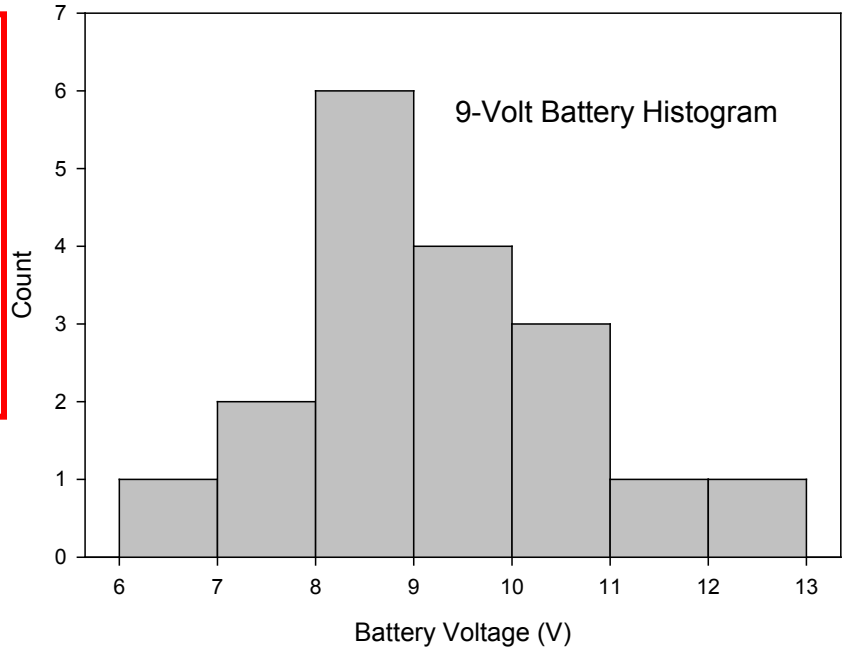
➢ Do not round yet!

Meas. #	Voltage (V)
1	6.51
2	8.45
3	11.76
4	8.36
5	9.35
6	9.23
7	7.85
8	8.59
9	9.05
10	8.08
11	10.59
12	9.87
13	8.04
14	8.38
15	10.01
16	12.84
17	10.48
18	7.27

$$\bar{x} = 9.1498$$

$$s = 1.5776$$

$$s_{\bar{x}} = 0.3718$$



Sample Standard Error

$$s_{\bar{x}} = \frac{s}{\sqrt{n}} = \frac{1.5776}{\sqrt{18}} = 0.3718$$

5. Sample standard error

➢ Do not round yet!

t-Statistics

υ	$t_{\upsilon,50}$	$t_{\upsilon,90}$	$t_{\upsilon,95}$	$t_{\upsilon,99}$
1	1.000	6.314	12.706	63.657
2	0.816	2.920	4.303	9.925
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17	0.689	1.740	2.110	2.898
18	0.688	1.734	2.101	2.878
19				
20				
21				
30				
40				
50				
60				
∞	0.674	1.645	1.960	2.576

$$x = \bar{x} \pm t_{17,95}\, s_{\bar{x}}$$

u = n - 1 = 18 - 1 = 17

where

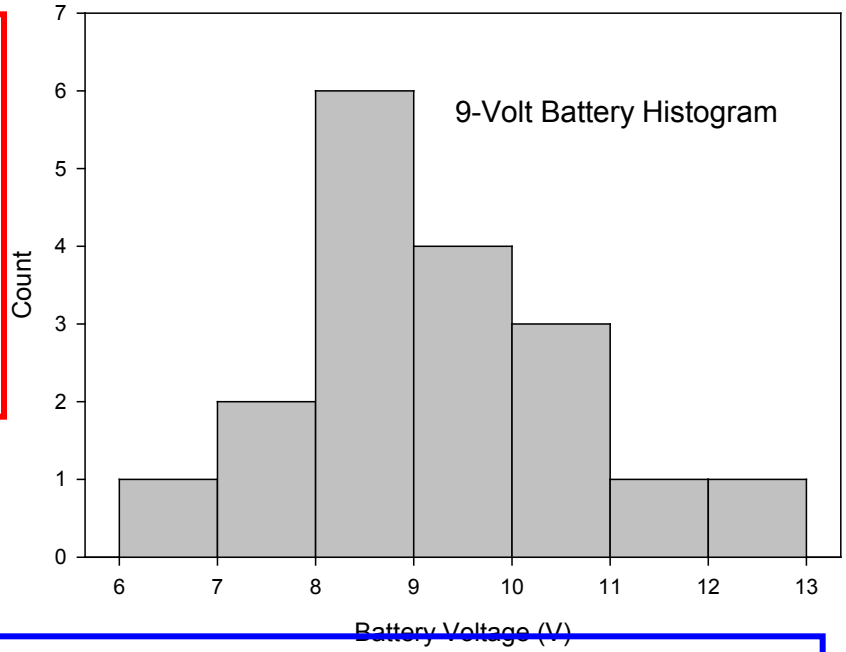
$t_{17,95}$ = 2.110 = Student's 95% confidence for 17 degrees of freedom

Meas. #	Voltage (V)
1	6.51
2	8.45
3	11.76
4	8.36
5	9.35
6	9.23
7	7.85
8	8.59
9	9.05
10	8.08
11	10.59
12	9.87
13	8.04
14	8.38
15	10.01
16	12.84
17	10.48
18	7.27

$$\bar{x} = 9.1498$$

$$s = 1.5776$$

$$s_{\bar{x}} = 0.3718$$



$$x = \bar{x} \pm t_{17,c}\, s_{\bar{x}}$$

$$x = 9.1498 \pm (2.110 \times 0.3718)$$

$$= 9.1498 \pm 0.7845$$

$$= 9.15 \pm 0.8$$

➤ 95% Confidence

$$x = 9.1498 \pm (2.898 \times 0.3718)$$

$$= 9.1498 \pm 1.076$$

$$= 9.1 \pm 1$$

➤ 99% Confidence

We were asked for 90% confidence estimate of the Population Mean

- What will be the difference in the calculations between what was just done, and what we are now being asked to do?

Previous estimates were also for the population mean

We use tv,90 instead for an estimate.

Comparison of *z-statistics* with *t-statistics*

- On the next slide, note that as the sample size nears 30, one can see how the results obtained using *t*-statistics get closer to those from *z*-statistics
- Using *z*-statistics overestimates confidence when the sample size is small:
    - the error bars are too small if you use z-statistics for samples of less than 30.

t-Statistics

υ	$t_{\upsilon,50}$	$t_{\upsilon,90}$	$t_{\upsilon,95}$	$t_{\upsilon,99}$
1	1.000	6.314	12.706	63.657
2	0.816	2.920	4.303	9.925
3	0.765	2.353	3.182	5.841
4	0.741	2.132	2.770	4.604
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6				
7				
8				
9				
10				
11				
12				
13	0.694	1.771	2.160	3.012
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16	0.690	1.746	2.120	2.921
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21	0.686	1.721	2.080	2.831
30	0.683	1.697	2.042	2.750
40	0.681	1.684	2.021	2.704
50	0.680	1.679	2.010	2.679
60	0.679	1.671	2.000	2.660
∞	0.674	1.645	1.960	2.576

$$x = \overline{x} \pm t_{17,95} s_{\overline{x}}$$

where

$t_{17,95} = 2.110$ = Student's confidence interval for 17 degrees of freedom

Compare this with $z_{95} = 1.96$, which is for 95% confidence for large samples

Estimating Proportional Mean Values

Tossing a Coin

- P(H) = P(T) = 0.5 (we know this is true for a 'fair coin') fair coin = balances on table on edge
- Try 100 tosses and find:
  - 58/100 are heads in one trial
  - 45/100 are heads in another trial
- We call these ratios **proportions**

Population Mean for Proportions

- Estimate the proportion p by sampling

$$\overline{p} \pm z_c \sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

average value of probability
(58/100 for first trial)

Below conditions must be true to use the above formula!

$$n\overline{p} > 5$$

$$n(1-\overline{p}) > 5$$

Must be satisfied to use this method

- Use z-statistics for $n > 30$ and *t-statistics* for smaller n

Proportion Example

- Suppose we take $n = 150$ coin flips
- 80 of the 150 are 'heads'
- Then $\bar{p} = 80/150$ is the sample proportion of heads
- $\bar{p} = 80/150 = 53\%$

  What error do we put on $\bar{p}$?

In other words: given that we are sampling, how well do we think we know the 'true' proportion of heads?

Example

- For our coin-flipping example, find the 90% confidence interval for the proportion p

$$n\bar{p} = 150 \times 80/150 = 80 > 5$$
$$n(1-\bar{p}) = 150 \times (1 - 80/150) = 70 > 5$$

Check

$$z_{90} = 1.645 \quad \text{(see next slide)}$$

$$\bar{p} \pm z_c \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 80/150 \pm 1.645 \sqrt{(80/150) \times (70/150)/150}$$

$$= 0.53 \pm 0.07$$

From this measurement, we cannot say the coin is unfair.

Table 9.4 Areas Under the Standard Normal Curve from 0 to z

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0754
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2258	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2996	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
3.1	.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
3.3	.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
3.4	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
3.5	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998	.4998

1.645 corresponds to a half area of 0.4500. This means that the total area under the curve from –z to +z is twice this number, which is 0.90. So, z_{90}=1.645

TO CALCULATE zc:
1. Take c, divide by 2.
2. Find closest value in table, and trace back to find z value!

Polling (e.g., in Politics)

- A poll is conducted with a sample size of $n = 200$ to test the support for candidate *A*
- The sample suggests that *A* will receive 32% of the votes
- Estimate the population proportion, with 95% confidence

Estimate what the population will choose, based on the sample of 32% of 200 = A

$$\bar{p} \pm z_c \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.32 \pm 1.960\sqrt{0.32 \times 0.68 / 200}$$

$$= 0.32 \pm 0.06$$

To lower the error, increase number in the sample

Confident to within six percentage points, 19 times out of 20

$$n\bar{p} = 200 \times 0.3 = 60 > 5$$
$$n(1-\bar{p}) = 200 \times 0.7 = 140 > 5$$

Check

Manufacturing

- In a manufacturing operation, 200 parts were examined and 8/200 were found to be defective
- Estimate the population proportion, with 95% confidence

$$\bar{p} \pm z_c \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.040 \pm 1.960 \sqrt{0.04 \times 0.96 / 200}$$

$$= 0.04 \pm 0.027 = 0.04 \pm 0.03$$

$$n\bar{p} = 200 \times 0.04 = 8 > 5$$
$$n(1-\bar{p}) = 200 \times 0.96 = 192 > 5$$

Check

- For every 100 parts made, between about 1 and 7 parts will be defective 95% of the time

ECOR 1010
Lecture 14

Correlation and Regression I

In the previous lectures:

- We looked at how repeated measurements of average values of a single variable gave rise to normal distributions
- The peak of the normal distribution we took as our 'best estimate' of the 'true' population mean.
- We then calculated a confidence interval around the best estimate: $\pm z_c s_{\bar{x}}$ (if n is large)
  - where the standard error is $s_{\bar{x}} = s / \sqrt{n}$
  - and s is the sample standard deviation, n the number in each measurement sample
  - and z_c is a number we can find in z-statistics tables that depends on the choice of confidence we wish to have.

If n is less than 30, it is the same idea, but we use t-statistics

In the previous lectures:

- We only measured one variable for each sample, (x_i)
  - we just measured the weight of students with the N5/N20 machines, nothing else, we did not at the same time measure hair length, or height, etc.
- When we measure only one variable we use univariate statistics.

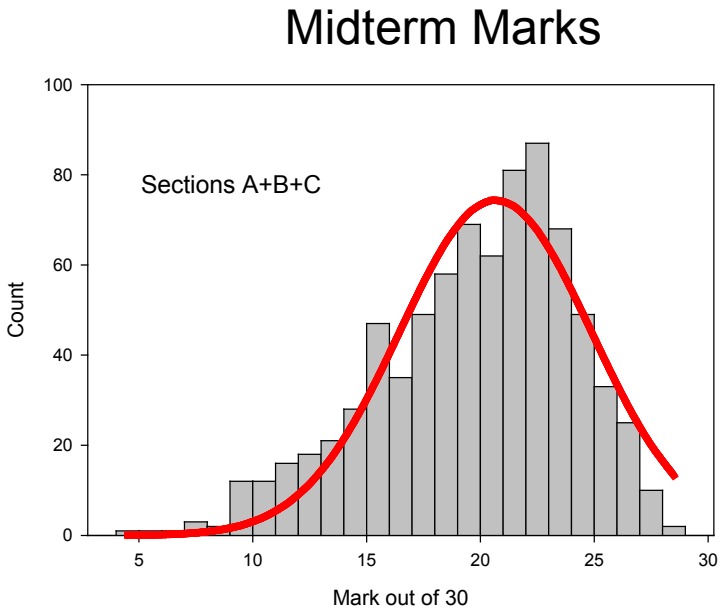
Bivariate relationships

- Now we look at the statistics we can use when two variables are measured
  - These are called bivariate statistics
- Bivariate observations come in pairs: (x_i, y_i)

- We want to know if there is a relationship between the variables x and y.
- We want to know if we can predict one from the other.

As an Example:

- We saw before that there was variability in the marks on the midterm
  - There was a spread in the marks
- You can imagine that there is also variability in class attendance
  - Not everyone comes to every class, and some miss more classes than others
- Can we relate marks on the exam to class attendance?

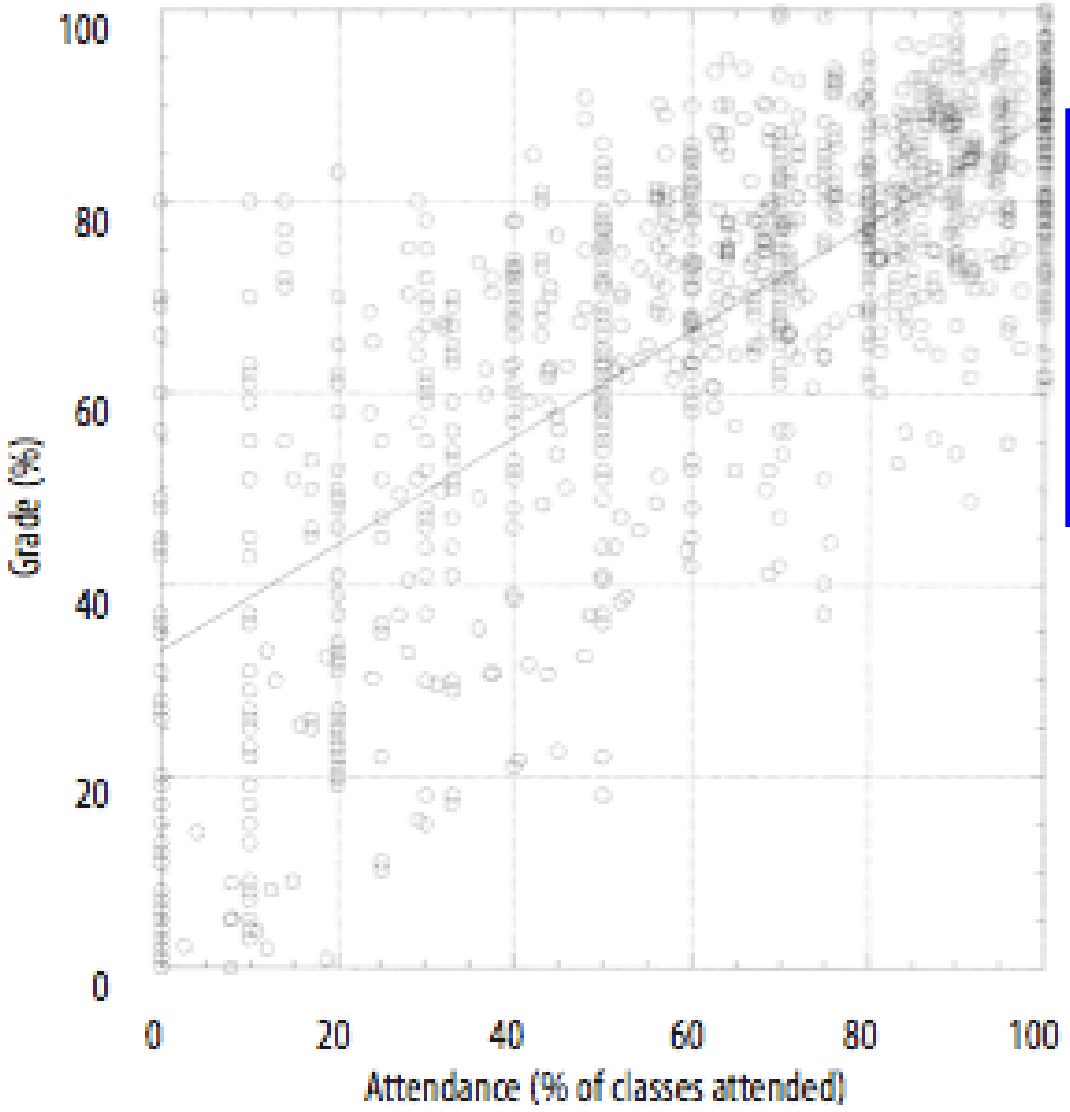


Of course, there are many reasons why people get the marks they do, but can we estimate the importance of attending class?

Showing Up: The Importance of Class Attendance for Academic Success in Introductory Science Courses

Randy Moore, Murray Jensen, Jay Hatch, Irene Duranczyk, Susan Staats, and Laura Koch
General College, University of Minnesota, Minneapolis, MN

The relation of class attendance and course grades in our Introductory Science classes. The size of this sample exceeded 1400. The equation for these data is $y = 33.1 + 0.55x$, and the correlation coefficient (r) = 0.78.



There is lots of variability (scatter), but, on average, we expect better marks for students who come to class more frequently.

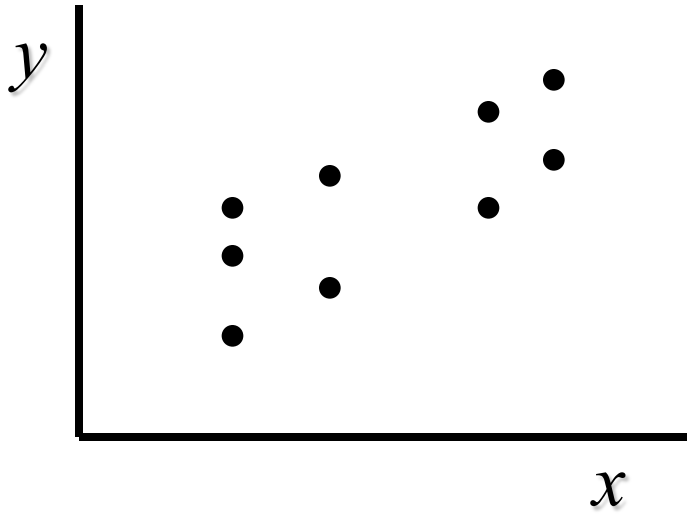
The words 'on average' are underlined in the box above because coming to more classes does not necessarily guarantee a higher mark for any individual – there are other things that we are not including in our analysis.

But, showing up explains 61% of the variability in the marks!

Bivariate relationships

- The distribution of bivariate measurements in a sample can be represented in a scatterplot (see below) with each point representing a pair of measurements (*x, y*) on some participant (i.e., the weight, and length of hair, of a student)
- There are 2 main questions that can be asked

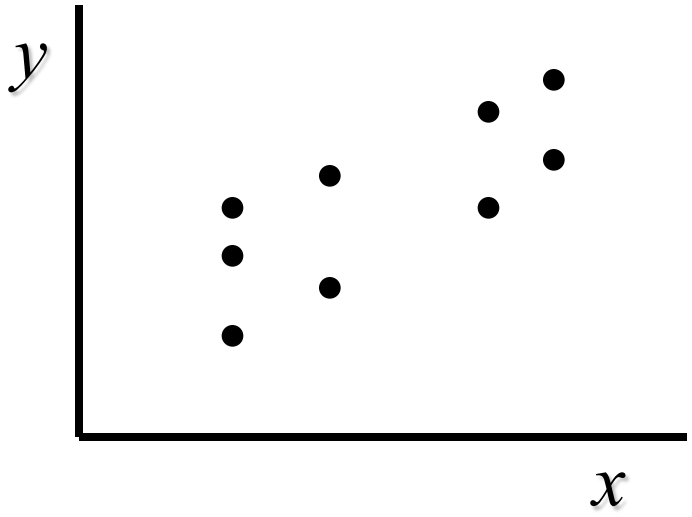
1) How strong is the relationship between the variables?
2) Can you predict the *y*'s from the *x*'s?



Bivariate relationships

- The answers to the first question are provided by the study of *correlation*
- The answers to the second question are provided by the study of *regression*

1) How strong is the relationship between the variables?
2) Can you predict the y's from the x's?



Linear Correlation

- Correlation is a measure of the **strength of a relationship**
  - How well does a “line of best fit” represent a trend in a data set?
  - How “correlated” are the two variables?

Linear Correlation

- How "good" is the assumption that a simple straight-line (i.e., linear) relationship exists between x and y?
- We can compute a correlation coefficient (r)

$$-1 \leq r \leq 1$$

  - This is a measure of how 'connected' x and y are in terms of the linear relationship assumption
  - Another way of saying it: r indicates how well a line of best fit correlates with the data

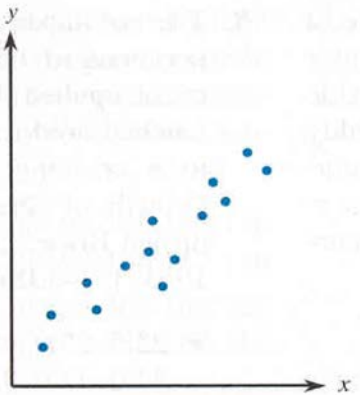
Some important values of the Correlation Coefficient: *r*

- When *r* is close to 1, it means that
  - *x* is large when *y* is large, and *x* is small when *y* is small
  - The plot of (*x, y*) is **tightly packed**
  - We say this is a 'Good' Positive Correlation
- When *r* is close to -1, it means that
  - *x* is large when *y* is small, and *x* is small when *y* is large
  - The plot of (*x, y*) is **tightly packed**
  - We say this is a 'Good' Negative Correlation
- If *r* is near zero
  - Little or no (linear) relationship exists between *x* and *y*

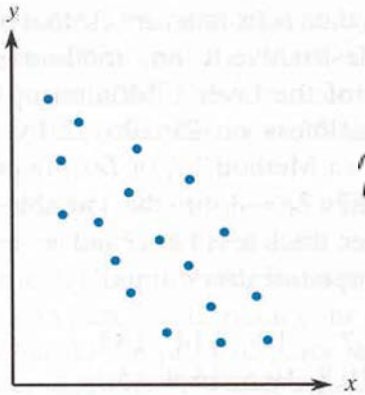
$$-1 \leq r \leq 1$$

Correlation Coefficient Examples

$r > 0$



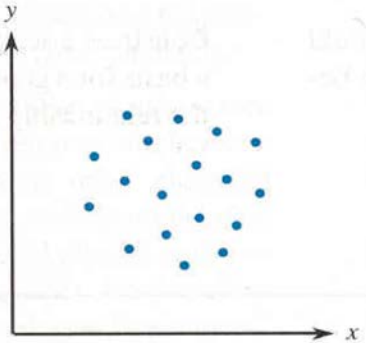
(a)



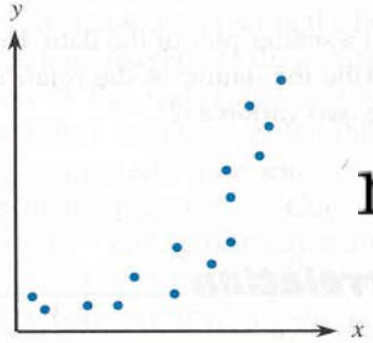
(b)

$r < 0$

$r \approx 0$



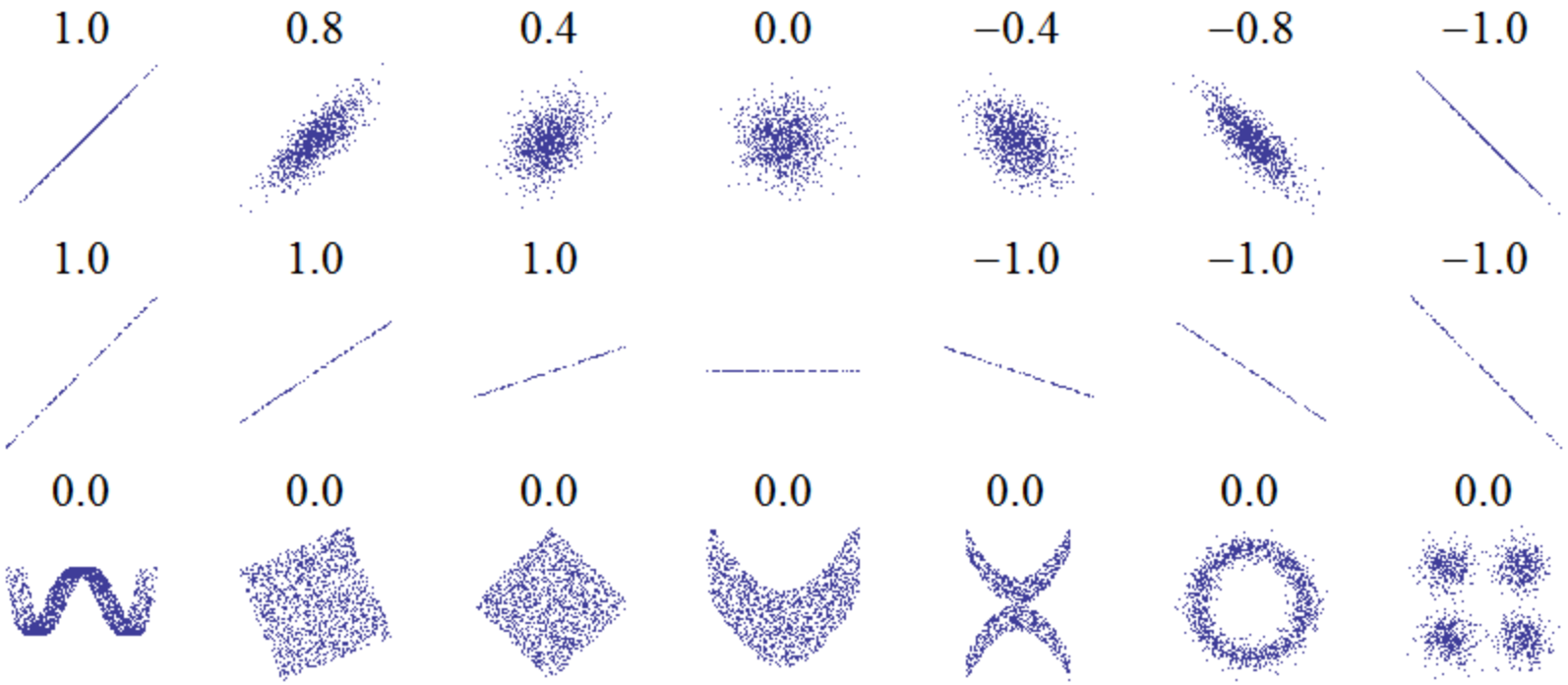
(c)



(d)

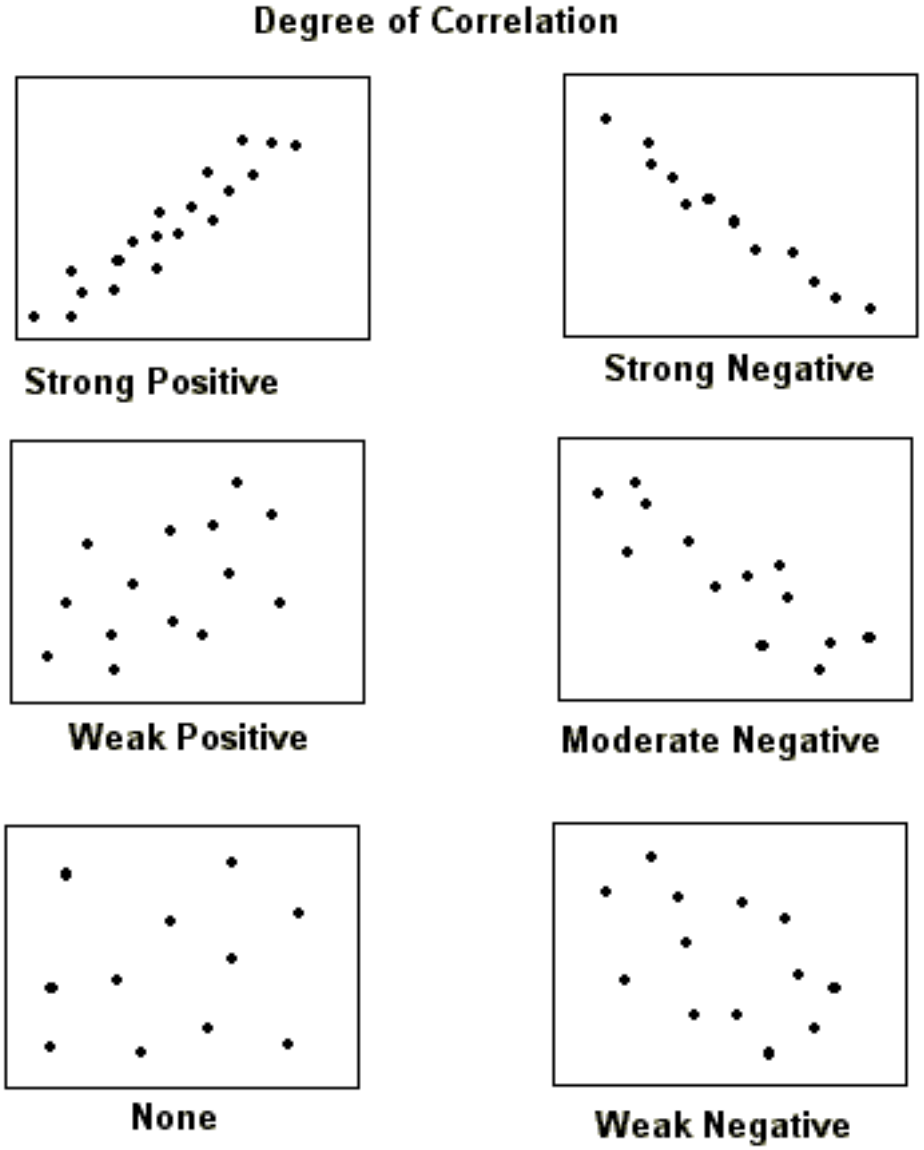
not linear

Correlation Coefficient Examples



Several sets of (*x*, *y*) points, with the Pearson correlation coefficient of *x* and *y* for each set. Note that the correlation reflects the noisiness and direction of a linear relationship (top row), but not the slope of that relationship (middle), nor many aspects of nonlinear relationships (bottom). N.B.: the figure in the center has a slope of 0 but in that case the correlation coefficient is undefined because the variance of *Y* is zero. (Wikipedia)

Correlation Coefficient Examples



Computing the Correlation Coefficient

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y}$$

NO UNITS !

n = number of data points

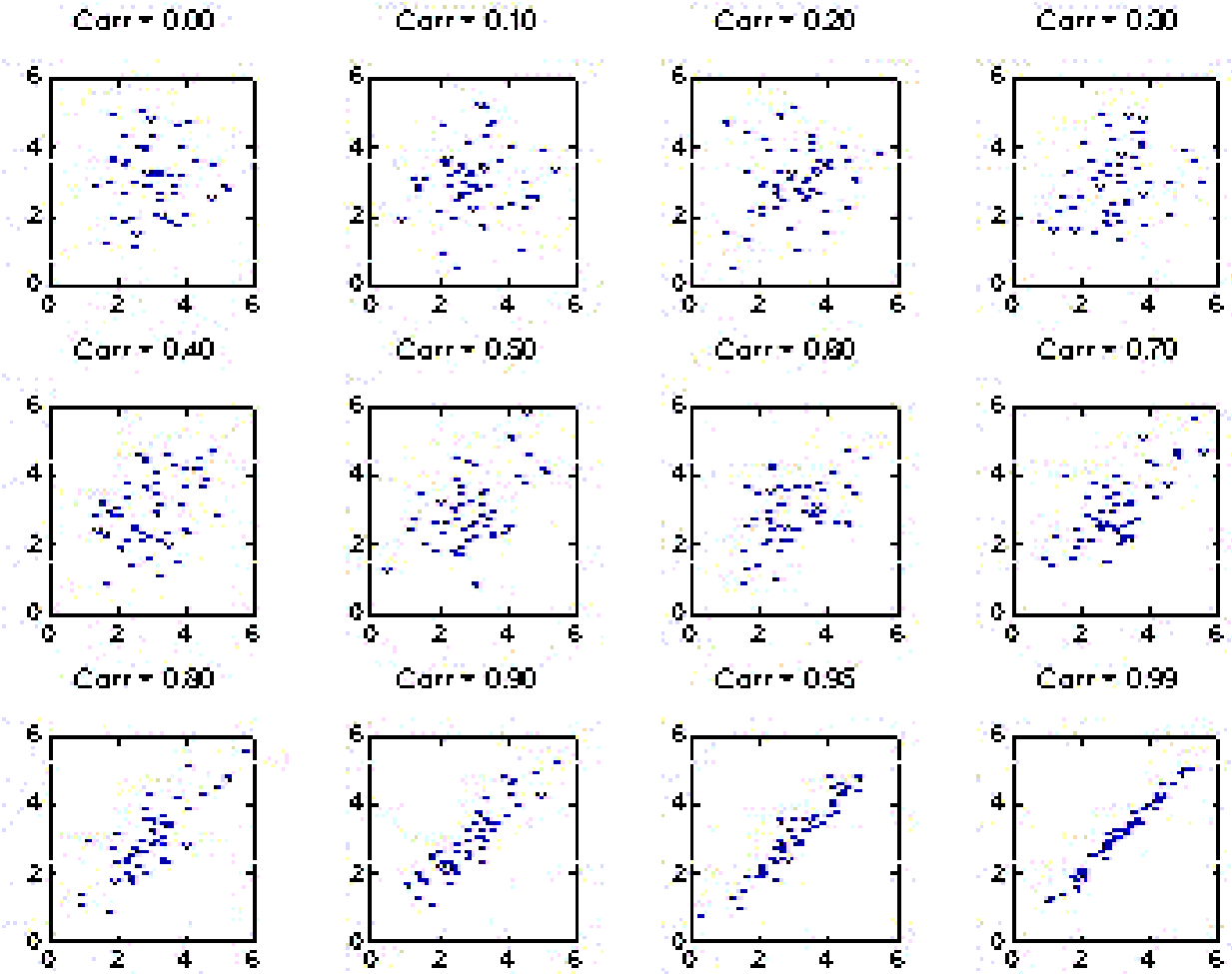
$\bar{x}$ = mean of x

$\bar{y}$ = mean of y

s_x = standard deviation of x

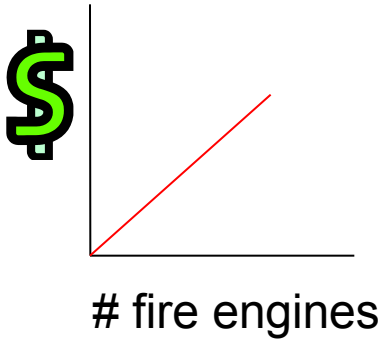
s_y = standard deviation of y

Correlation Coefficient Examples



Correlation and Causality

- Get data on all the fires in Ottawa for the last ten years.
- Correlate the number of fire engines at each fire and the damages in dollars at each fire.
- Note the significant correlation between number of fire engines and the amount of damage.
- Conclude that fire engines cause the damage.

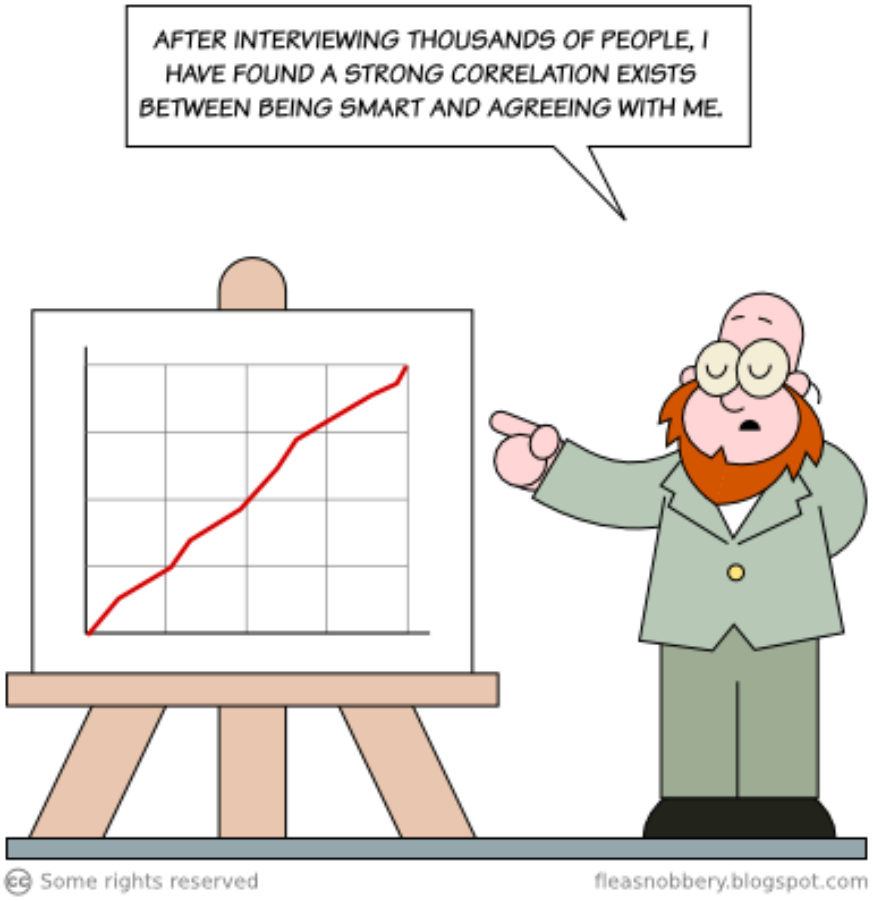


^^ The above is a wrong conclusion. Misuse of logic of correlation can create wrong conclusions

Correlation does not equate to Causality!

Correlation and Causality

- Just because two variables are correlated does not mean there is any connection between them



Regression

- The correlation coefficient expresses the strength of the relationship between *x* and *y* without worrying about units or directional relationships. It is the answer to the first question posed earlier: what is the strength of the relationship?
- However, if *x* and *y* are correlated, this implies that we can use information about *x* to *predict* the values of *y*
- If we want to *predict y* based on *x* we need more than r_{xy}…we need to perform a *regression*

Regression

Regression is a process by which a mathematical model is fitted to a set of data

- to **test** whether the model provides a reasonable description of the observations, and
- to give us confidence that **predictions** we make with the model will be good.

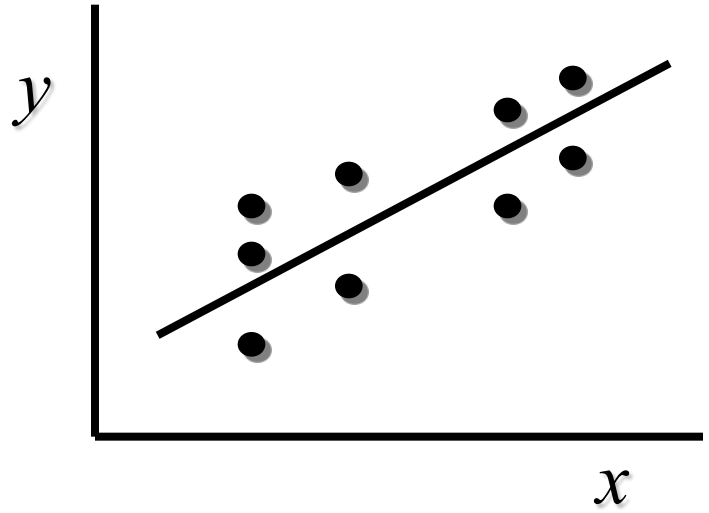
Father of Regression

- Sir Francis Galton (cousin of Charles Darwin) developed techniques for fingerprinting, weather forecasting, as well as regression and correlation
  - 1822-1911
- Developed regression by performing an experiment using five groups of sweet peas
  - Noticed that the average weight of sweet pea seedlings "regressed" towards the average of all of the peas, and not the parental group from which they came
  - Applied a similar technique to predict human heredity

→ "Regression to the Mean"

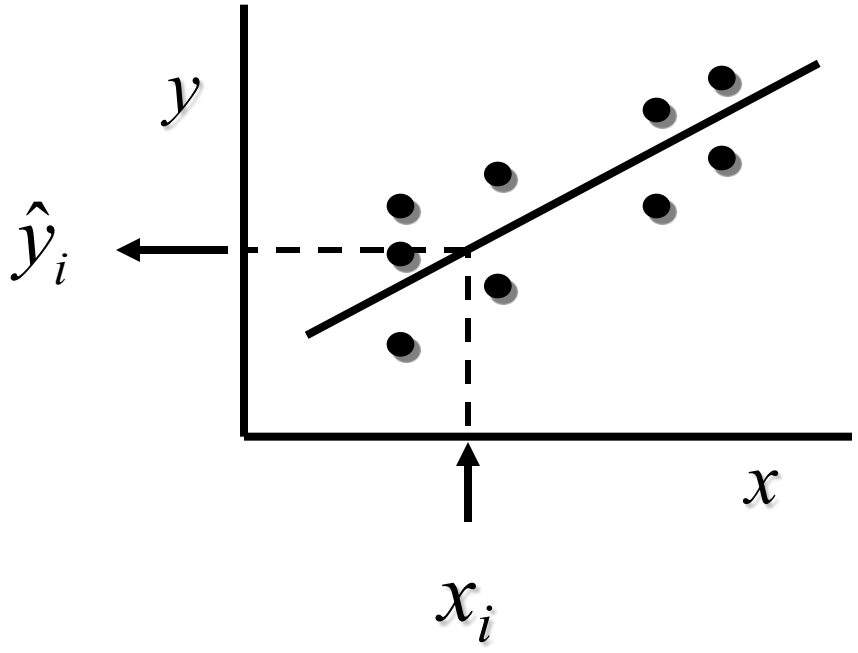
Regression

- Suppose we want to find the straight line relationship that best predicts the values of *y*, given *x*…this is called the *regression line*



Regression

- Once we figure out what the line should be, for any given x we can find a predicted y
- The predicted value is called $\hat{y}$



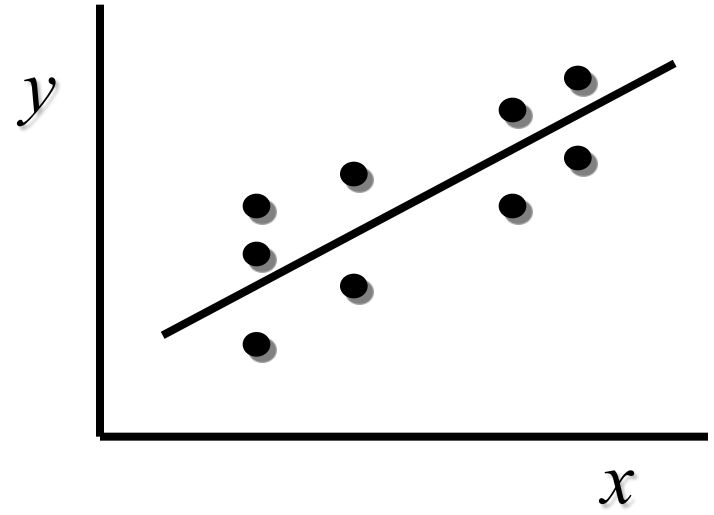
Regression

- The straight line is one we have made up to express the relationship between x and y that we see in the data
- The line has an equation

$$\hat{y} = mx + b$$

slope

intercept



- Find a “line of best fit”
  - Use a parameterized mathematical model

$$\hat{y} = mx + b$$

where

$\hat{y} =$ predicted dependent variable

$x =$ independent variable

$m =$ slope

$b =$ y intercept

Regression

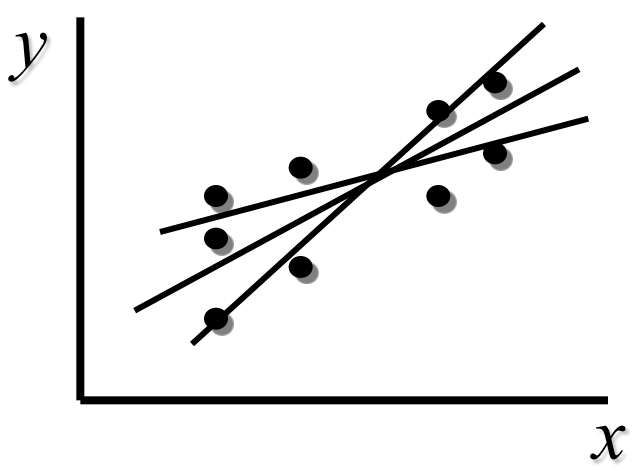
- The slope, *m*, and intercept, *b*, of the regression line each have their own interpretation

$$\hat{y} = mx + b$$

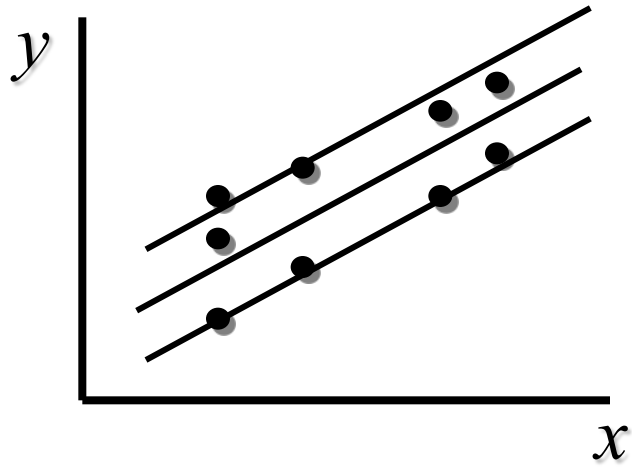
- *intercept*: b = value of $\hat{y}$ when $x = 0$
- *slope*: m = difference in $\hat{y}$ associated with a change of x by 1 unit

Regression

- Each different combination of *m* and *b* create a different regression line



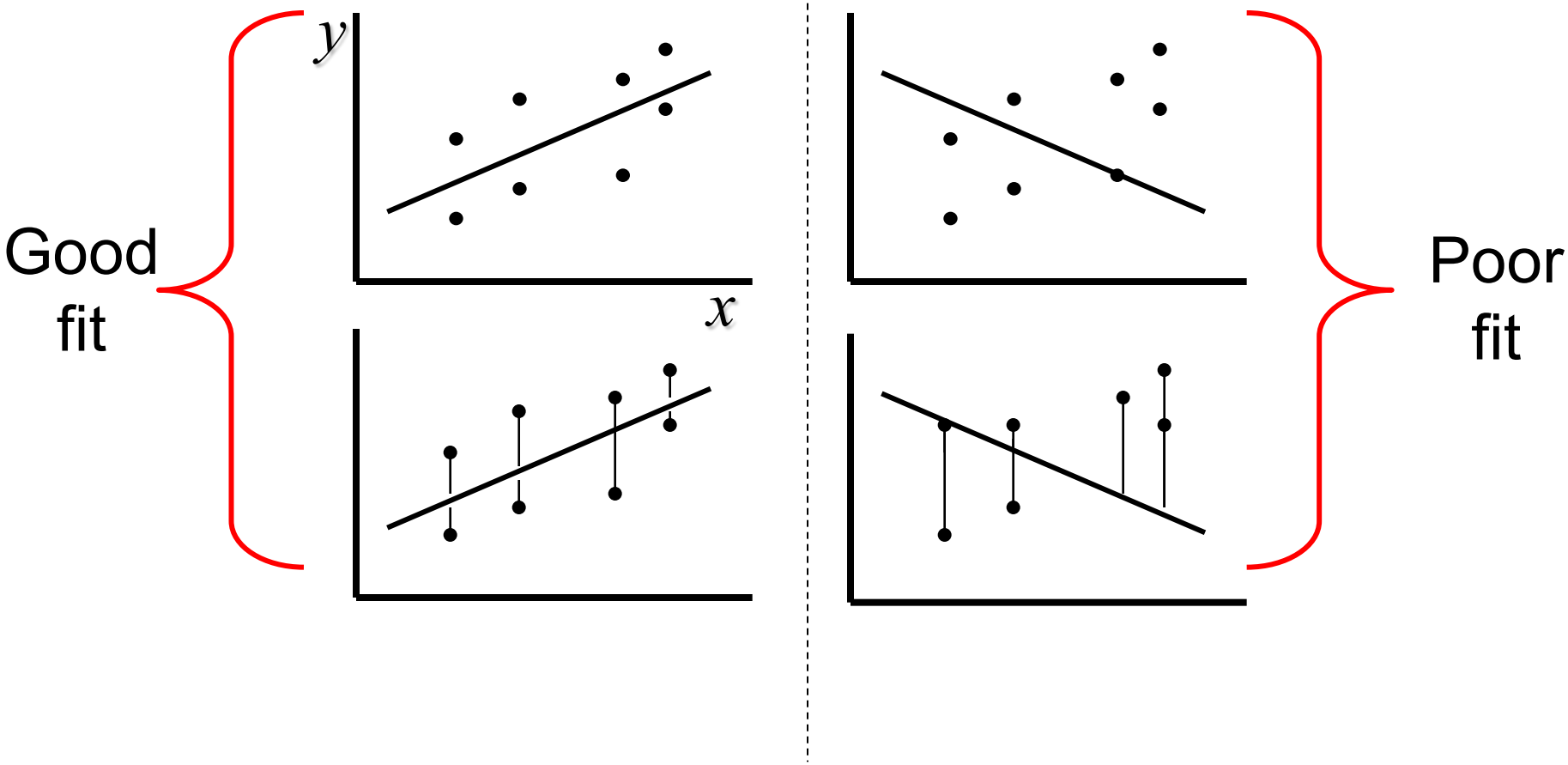
Different *m's*



Different *b's*

Regression

- The *best* regression line is the one that minimizes the *sum of squared deviations* of the data from the line



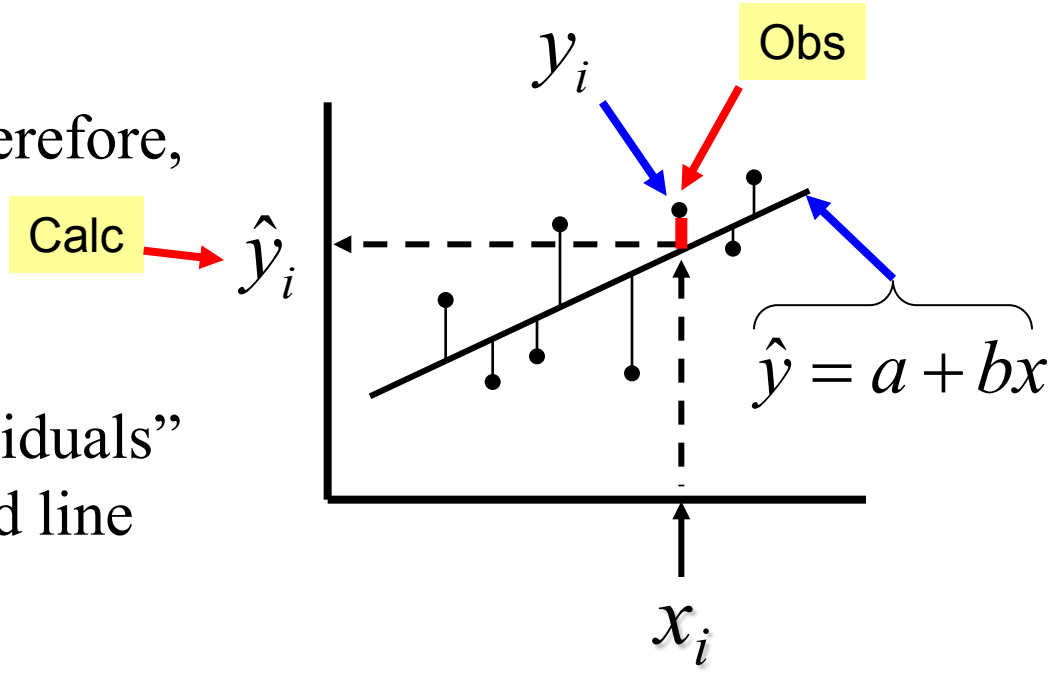
Regression

- For each datapoint connected with an observation x_i, the appropriate "deviation" is the deviation of the observed y_i from the value, $\hat{y}_i$, calculated from the regression equation

- The deviations are, therefore, given by

$$e_i = y_i - \hat{y}_i$$

and are called the "residuals" or "errors" of the fitted line for the data



Linear Regression

- The error, or **residual**, is the difference between the observed point, y, and the calculated point on the line, $\hat{y}$, at each x

$$e_i = y_i - \hat{y}_i$$ = Obs - Calc = Measured - Predicted

where

$\hat{y}_i$ = value of y predicted by the model

y_i = the i^{th} measured data point

What is the "Best Fit"?

- Consider the following **S**um of **S**quared **E**rrors

$$\mathrm{SSE} = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

Obs - Calc

- SSE is a measure of how well the model fits the data
- The parameters *m* and *b* of the best fitting line for a particular sample are determined by finding the line that *minimizes* SSE
- Called **least-squares fit/regression**

Regression

- Try some of the Java applets concerning regression at http://onlinestatbook.com/rvls/index.html

- The link called “Regression by Eye” shows how different regression lines have different associated SSE’s (In the applet instead of SSE, they use MSE, which stands for mean square error. This is the sum of the squared errors, SSE, divided by n-1.)

Least-squares Fit/Regression

(without proof)

For $\hat{y} = mx + b$,

The 'least-squares' slope

and intercept are given by:

m = dy/dx (SSE), which is below:

$$m = \underset{\text{sums are from i to n}}{\frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}}$$

x-bar and y-bar = mean of x, mean of y

and $b = \bar{y} - m\bar{x}$

n = number of data points

Eg. Fuel Consumption and Car Weight: Is there a relationship? Can we predict one from the other?

Model	Weight (hundreds of Lbf)	City Mileage (mpg)
Ford Festiva	18	31
Honda Civic	20	36
Toyota Matrix	27	30
Acura RSX	27	27
Mazda Protégé 5	27	29
Subaru Impreza WRX	31	24
Pontiac Firebird	32	21
BMW 330 Ci	33	21
Linxoln Copntinental	39	14
Chevrolet Suburban	51	11

Which is the dependent variable?

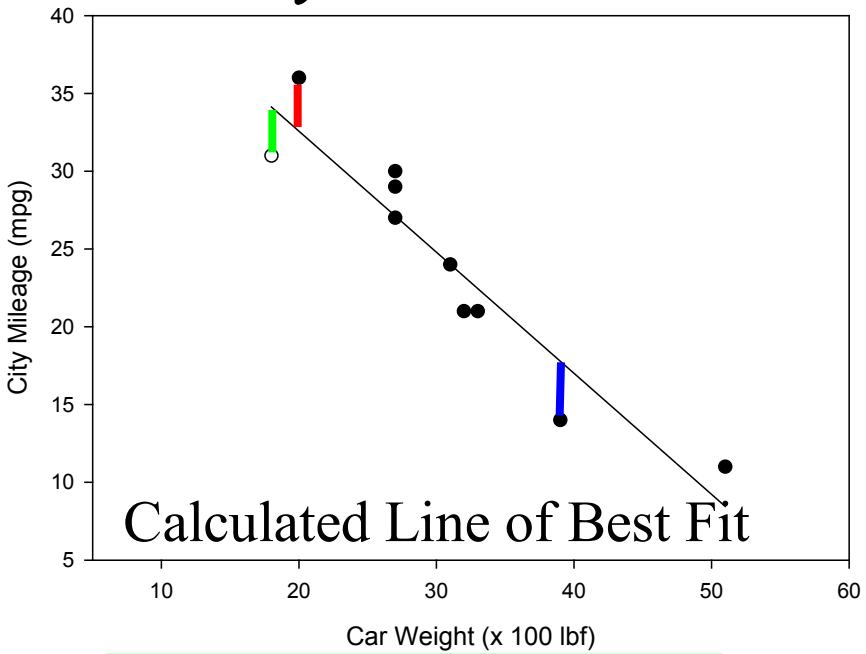
Which should be plotted on the y axis?

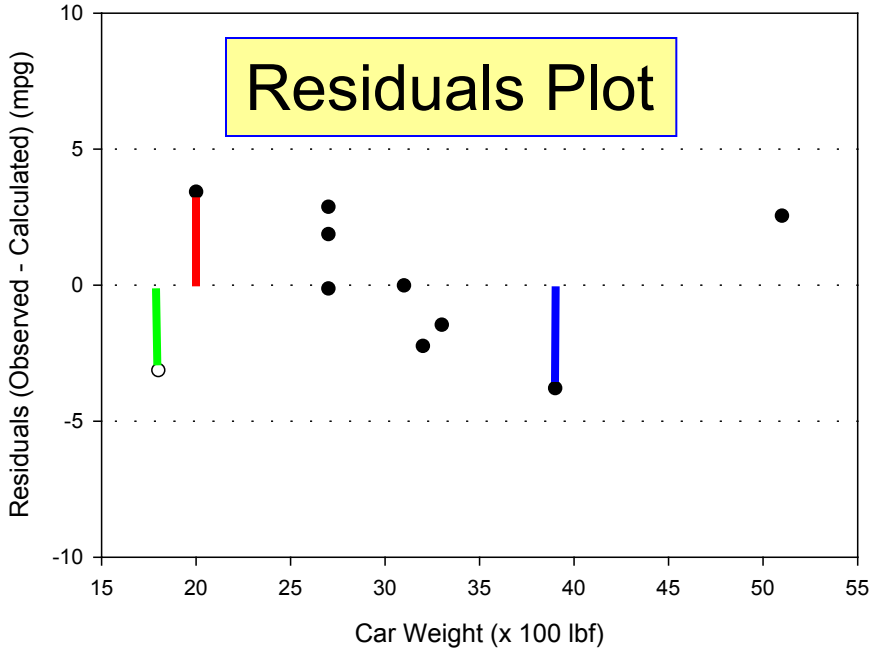
Line of Best Fit

Obs - Calc

$\hat{y} = mx + b$

$(y_i - \hat{y}_i)$





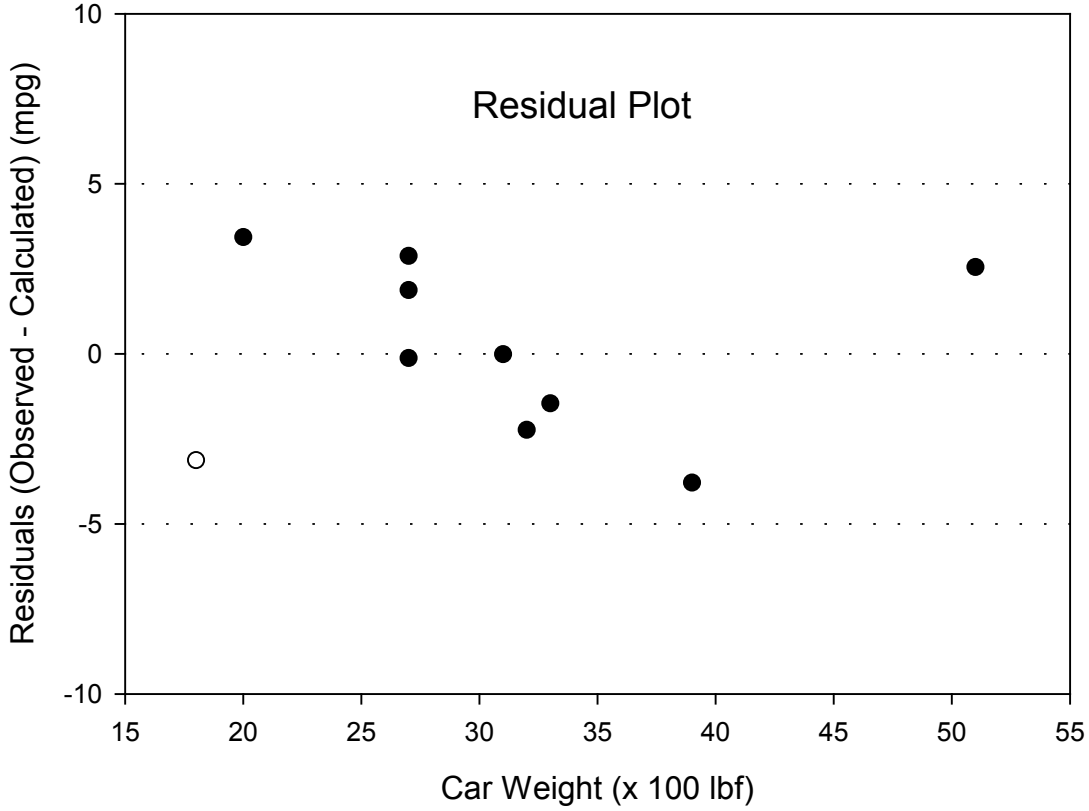
The line through the data is the "calculated data".

Residuals = Observed Values – Calculated Values

Least-Squares Regression minimizes SSE = $\sum (y - \hat{y})^2$

Obs - Calc

Residuals



The Residuals are equally (normally) distributed about 0, which is what we want to see.

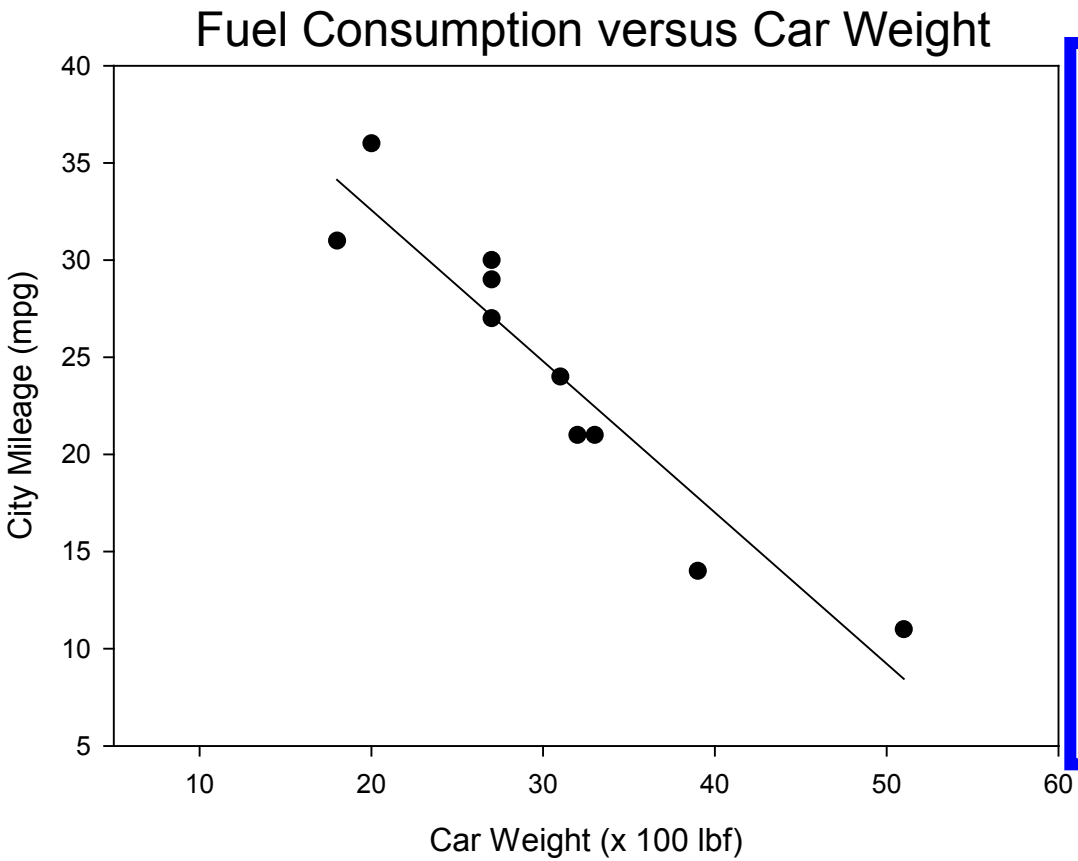
ECOR 1010
Lecture 15

Correlation and Regression II

Coefficient of Determination

- Often use r^2 to estimate the quality of a fit
  - Represents the proportion of the variation of the observed y data that can be explained by the model (discussed later)
  - Lies in the range [0,1]
  - Close to 1 means the assumed function (i.e., straight line in this example) is a good fit to the observed data

Coefficient of Determination



- The cars in the sample have Mileage values that vary from 11 to 36: this is the variability in the y-values.
- 89% of the variability in the y data can be explained by the straight-line relationship (why we can say this is explained on the next slides)

$$\hat{y} = -(0.8 \pm 0.1)x + (48 \pm 3) \quad [\text{mpg}]$$

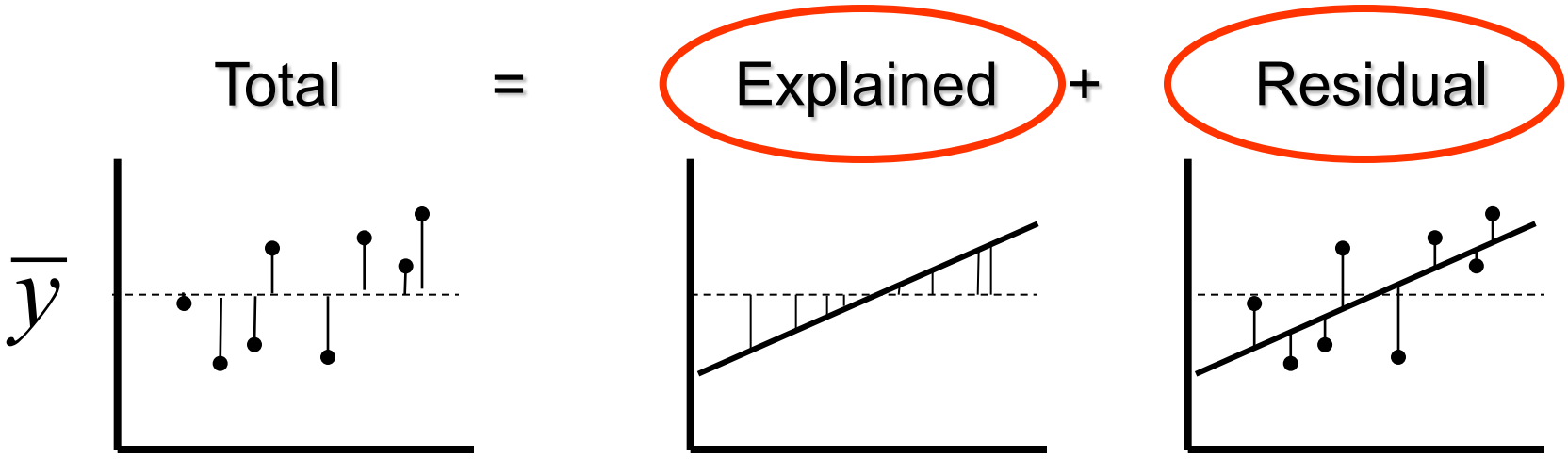
$$r^2 = 0.89$$

Relationship of the 'Coefficient of Determination' to Explained Variation

- Only part of the variation in a measurement (data point) can be explained by regression.
- There are two sources of variation:
  - Variation explained by the regression model
  - Variation not explained by the regression model
- Total variation = Explained + Unexplained

Accuracy of Prediction

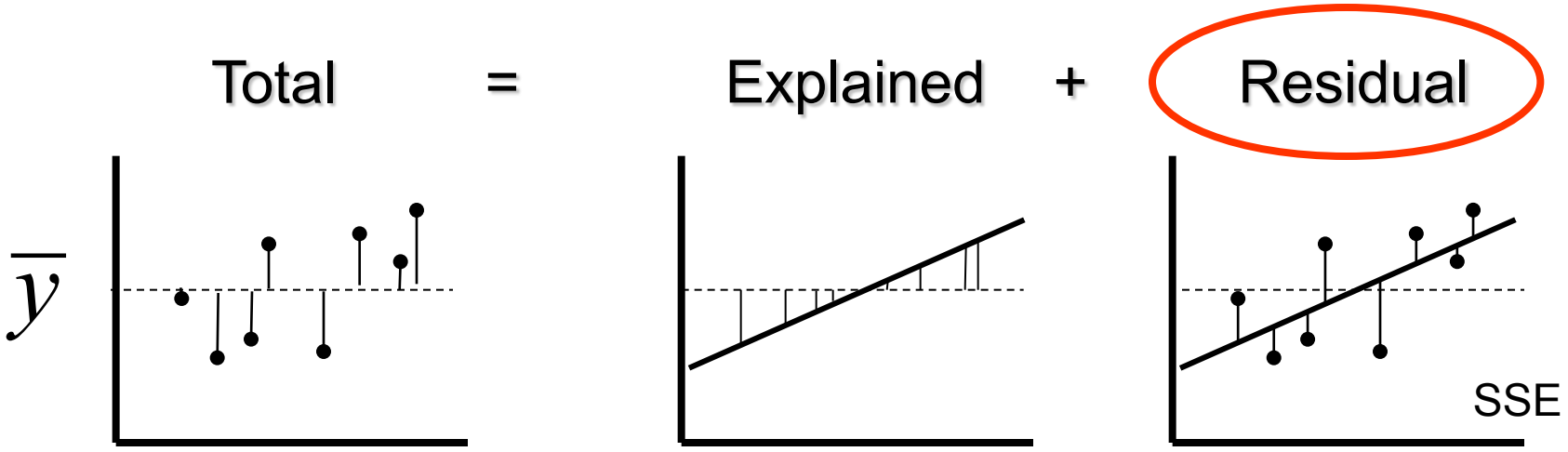
- Here is what is going on… there are 2 components of variation that together make up the total variation in *y*



Variation is measured relative to the mean value of all of the y measurements: $\overline{y}$

Accuracy of Prediction

- You have seen the "residual" variation before, it is the variation left over after fitting the regression line to the data



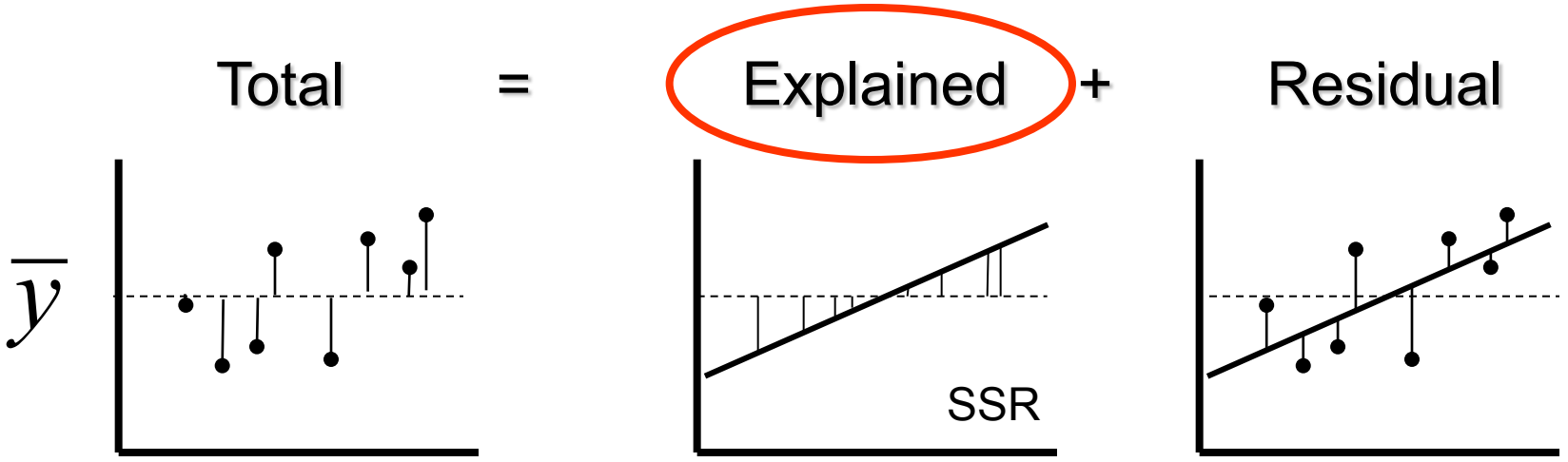
- Residual variation is quantified by the SSE and is minimized in a regression

SSE = sum of squared errors (residuals), or what is left over (resides) that has not been explained after you factor out the linear part.

$$\sum (y - \hat{y})^2$$

Accuracy of Prediction

- "Explained" variation is the variation in y values that is explained by the regression line



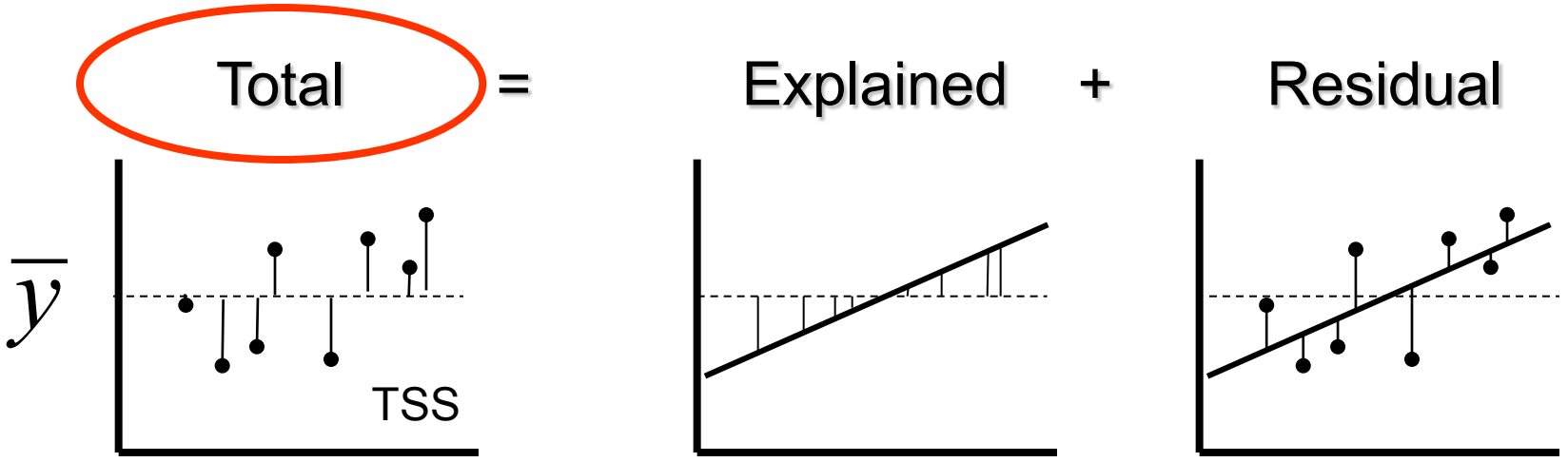
- Explained variation is quantified by SSR

SSR = sum of squares of the deviations from the regression line to the mean of all the y`s.

$$\sum (\hat{y} - \overline{y})^2$$

Accuracy of Prediction

- "Total" variation is the overall variation in y values without regard to any information about the *x* values



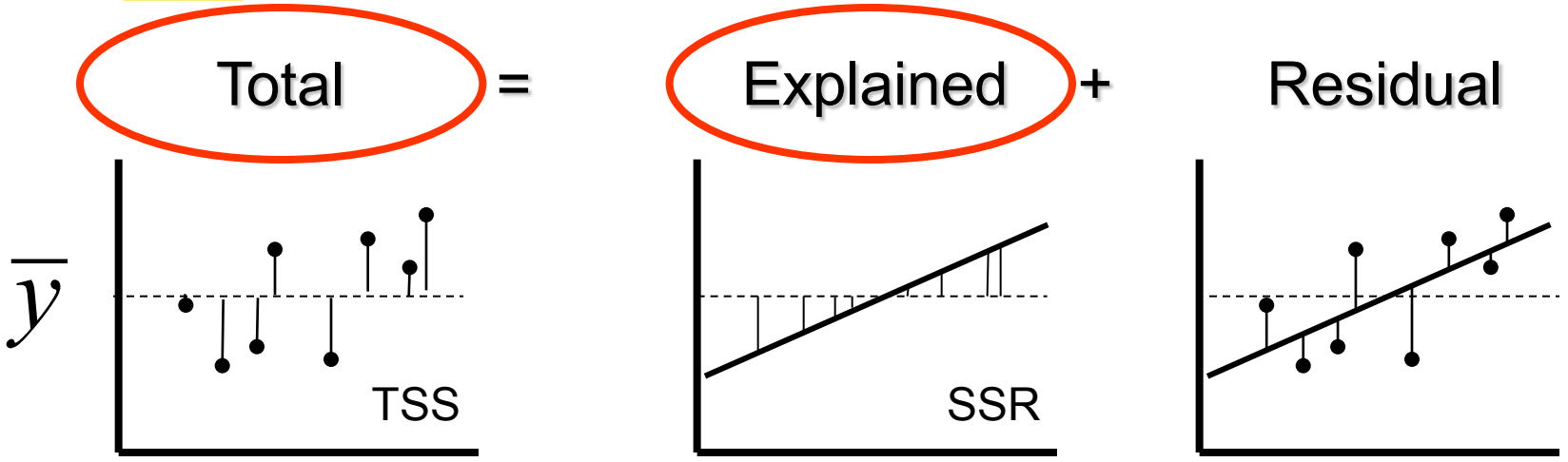
- The total variation is quantified by TSS

TSS = total sum of squares from the mean of all of the y data

$$\sum (y - \overline{y})^2$$

Accuracy of Prediction

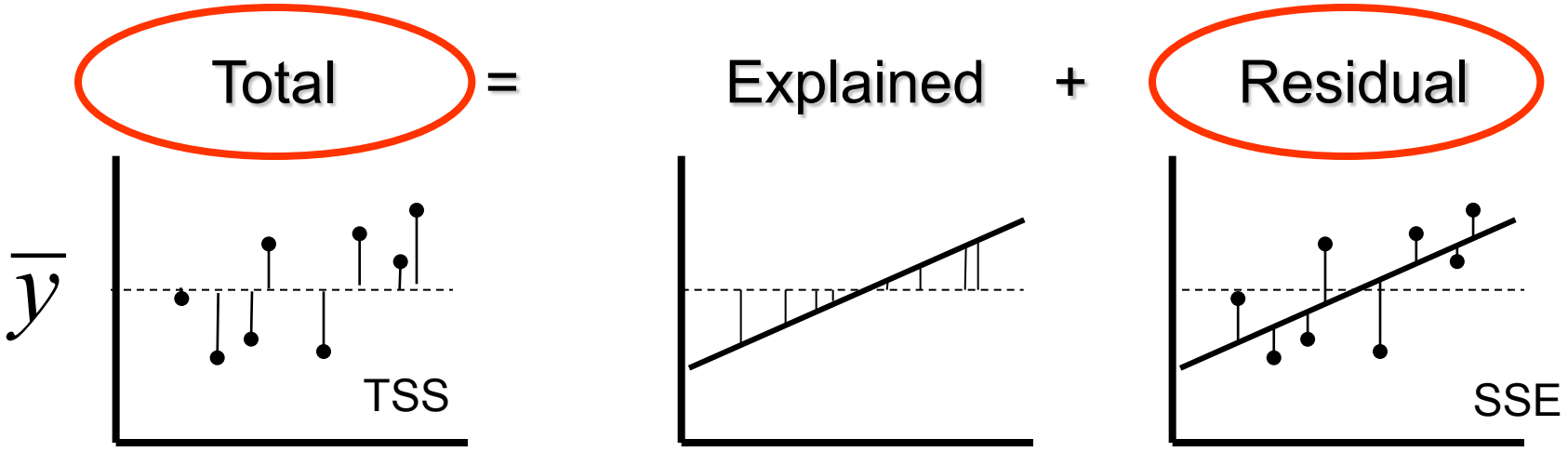
- So the *ratio* of explained variation to total variation characterizes how well the regression describes the data



- Explained variation $\frac{SSR}{TSS}$

Accuracy of Prediction

- Likewise, we get the *proportion of unexplained variation* by dividing SSE by TSS



- Unexplained variation = $\frac{\text{SSE}}{\text{TSS}}$

Relationship to Variation

$$\underbrace{\sum (y-\bar{y})^2}_{\text{TSS}} = \underbrace{\sum (\hat{y}-\bar{y})^2}_{\text{SSR}} + \underbrace{\sum (y-\hat{y})^2}_{\text{SSE}}$$

- TSS = SSR + SSE
- TSS = total sum of squares
- SSR = sum of squares from regression
- SSE = sum of squared errors (residuals), or what is left over (the residue) after you factor out the part explained by the assumed model.
  - In this case, the assumed model is a straight line.

Accuracy of Prediction

- It should not be surprising that the proportion of explained variation plus the proportion of unexplained variation equals 1
- So the proportions of explained and unexplained variation work together to account for all the variation in *y*…
- You can see this in the simulation, available at the RVLS website:

http://onlinestatbook.com/rvls/index.html

- called the "Components of *r* demonstration"…go there and try it out

Accuracy of Prediction

- The *accuracy of prediction* for a regression is quantified by the proportion of explained variation

$$\frac{SSR}{TSS}$$

- Think of this as the proportion the total variation in y values that is explained by the variation in the x values…the explanation is due to the correlation between x and y

Accuracy of Prediction

- There is one last amazing result concerning the proportion of variation explained by a regression…

$$r^2 = \frac{\text{explained variation}}{\text{total variation}} = \frac{\text{SSR}}{\text{TSS}}$$

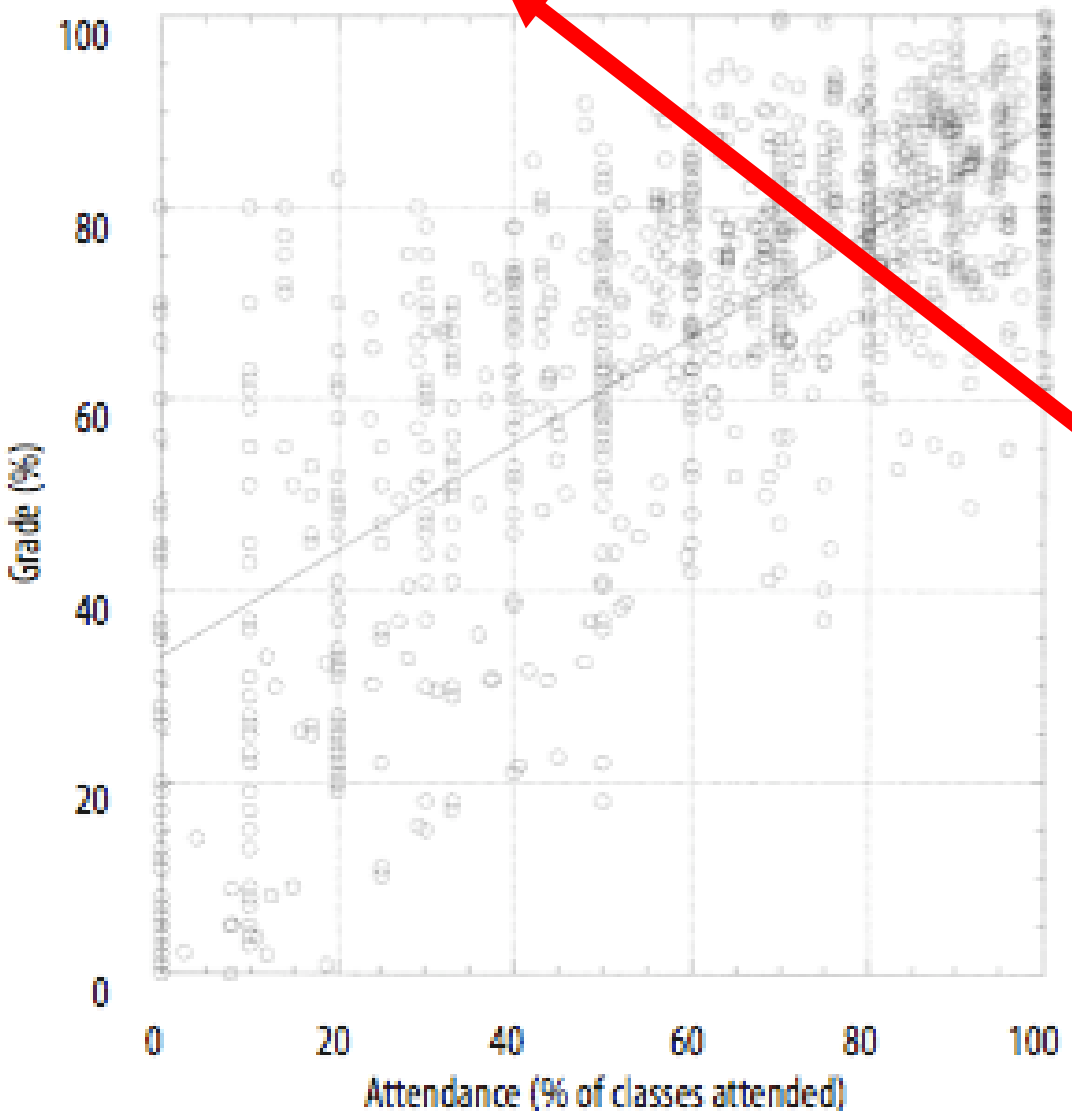
- In other words, the proportion of explained variation for the straight-line fit equals the square of the linear correlation coefficient!
- This ties together correlation and regression

r^2 is called the Coefficient of Determination

Showing Up: The Importance of Class Attendance for Academic Success in Introductory Science Courses

Randy Moore, Murray Jensen, Jay Hatch, Irene Duranczyk, Susan Staats, and Laura Koch
General College, University of Minnesota, Minneapolis, MN

The relation of class attendance and course grades in our Introductory Science classes. The size of this sample exceeded 1400. The equation for these data is $y = 33.1 + 0.55x$, and the correlation coefficient (r) = 0.78.



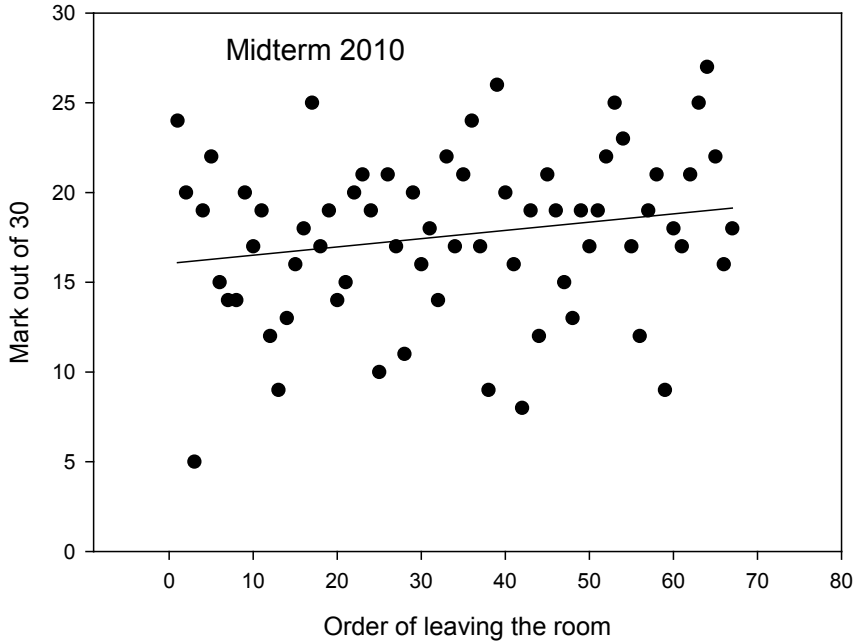
The proportion of the total variation in marks explained by the linear relationship with class attendance is $r^2=(0.78)^2$ or 61%.

shows that attendance is 61% of the problem (as it is 61% related to the grade)

Closer to home:

- Marks for the midterm versus the order that students left the room.

$$r^2 = 0.0375$$



- Roughly 4% of the variability in the marks can be explained by the order students left the room.
- An Aside: On average, students who stayed till the end of the exam got 3 more marks than those who left early.

Linear Least Squares Regressions/Fits

- The technique we have used so far is called "Linear Least Squares".
- You might think that the word "Linear" refers to the fact that the equation of the straight line is linear in x.
- This is not the reason.
- The "Linear" refers to the fact that the equation is linear in the determinable parameters m and b.

$$\hat{y} = mx + b$$

Linear means raised to the power one.

Linear Least Squares Regressions/Fits

- The following equations are linear in the parameters to be determined (m's and b's):

$$\hat{y} = mx + b$$

$$\hat{y} = m_1 x + m_2 x^2 + m_3 x^3 + b$$

$$\hat{y} = m_e e^x + m_s \sin x + b$$

Can use linear least squares

- These following equations are examples where the parameters are <u>not</u> linearly related to the dependent variable:

Cannot use linear least squares

$$\hat{y} = m^x + \log b$$

$$\hat{y} = 3e^{-mx} + 15 \sin bx$$

Linear means raised to the power one.

Correlation Coefficient and the Coefficient of Determination for Linear Least Squares

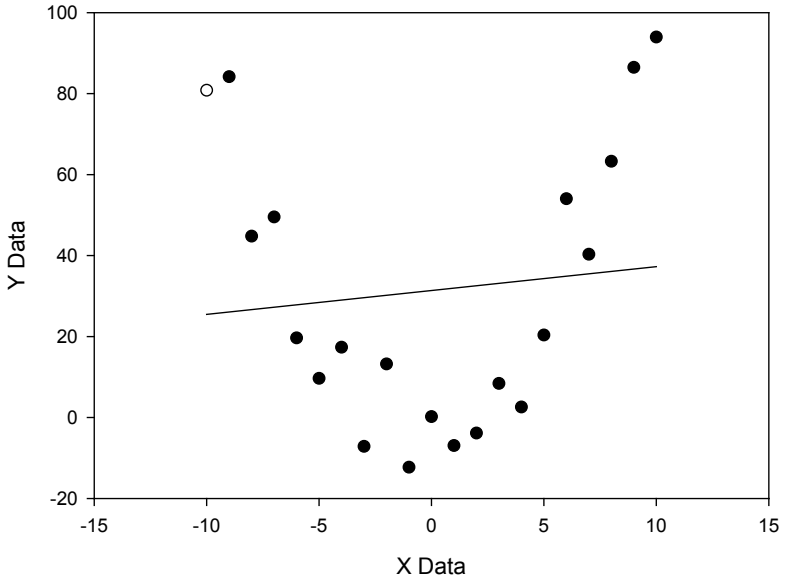
r^2 only for straight lines

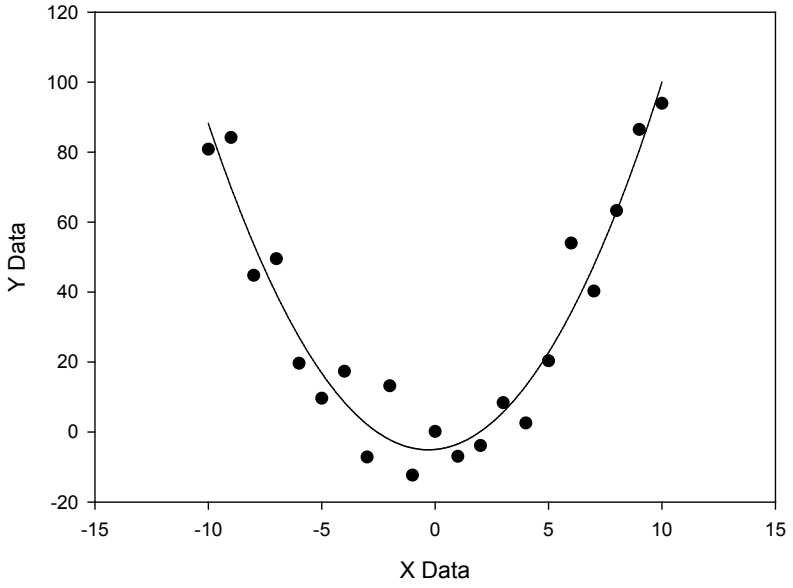
- In the top plot $r = 0.11$, which means $r^2 = 0.012$, which means 1% of the variability in the data can be attributed to a linear relationship between x and y.
- In the bottom plot the data are fitted to

$$\hat{y} = b_0 + b_1 x + b_2 x^2$$

- The Coefficient of Determination for the fit was $r^2 = 0.929$ SSR/TSS
- Or, 92.9% of the variability in the y-data can be attributed to the fitted relationship between x and y.

$$y = x^2 + \text{noise}$$

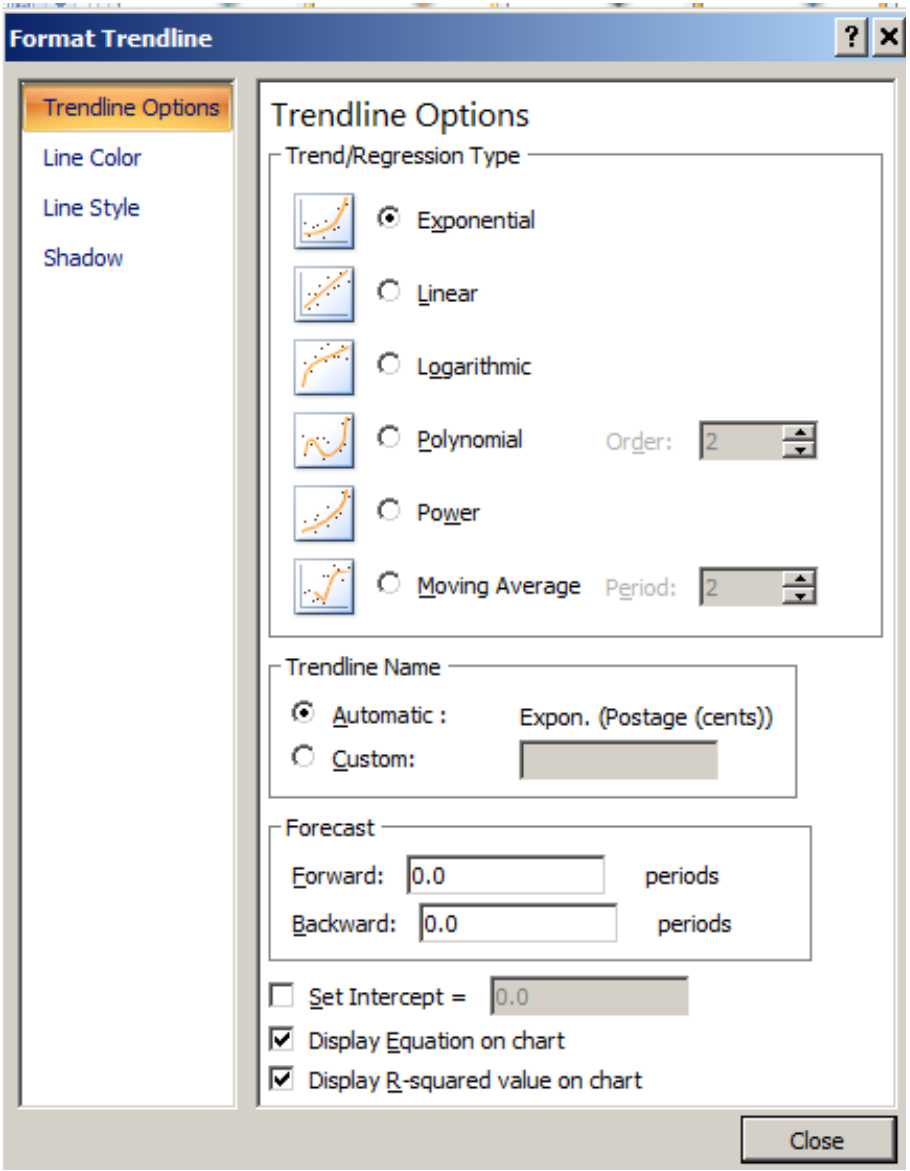




Trend Lines

- Excel and most other plotting programs have a ‘trend line’ option.
- When the trend line is a non-linear function, like an exponential for example, the program `manipulates` the data so that linear least squares can be done (See page 612 in the 6th ed of the text book: Introduction to Engineering).
- This is okay for a trend line that is used only as a guide for the eye.
- But, it is absolutely not okay for serious data analysis.

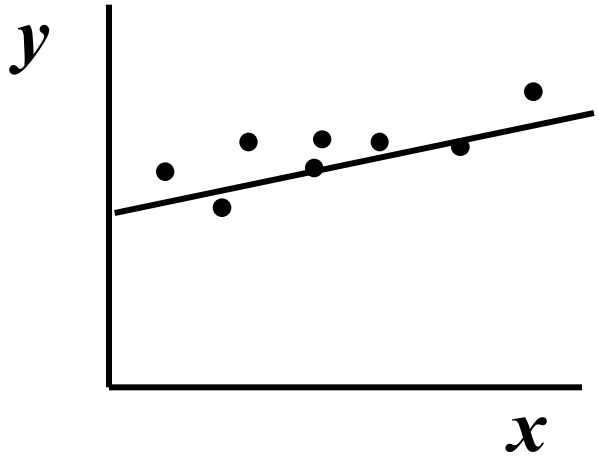
Trend Lines



Be careful with ‘trend lines’; they should not be used for anything other than producing a guide for the eye, unless you know that the underlying assumptions of least-squares regressions are satisfied by your data!!!!!

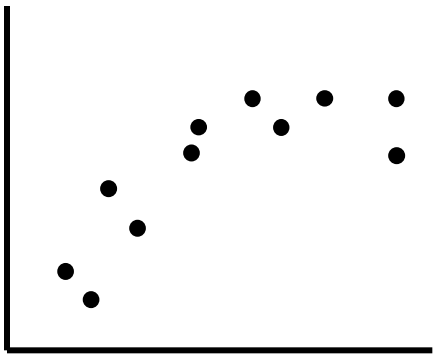
Assumptions

- Regression lines and tests of regression or correlation don't do you much good if the basic assumptions of linear regression are not met
- The first assumption for regression to a straight line is that the relation between *x* and *y* can be described by a straight line

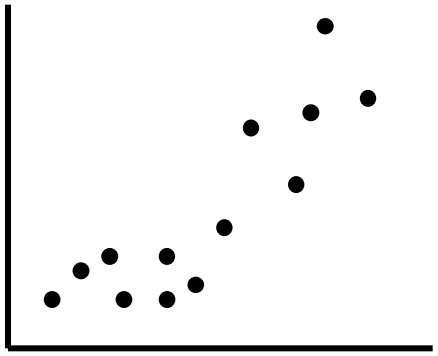


Assumptions

- If this assumption is not met the regression will still produce values for the slope and intercept, but these will not be interpretable
- Floor and ceiling effects often cause nonlinear relationships

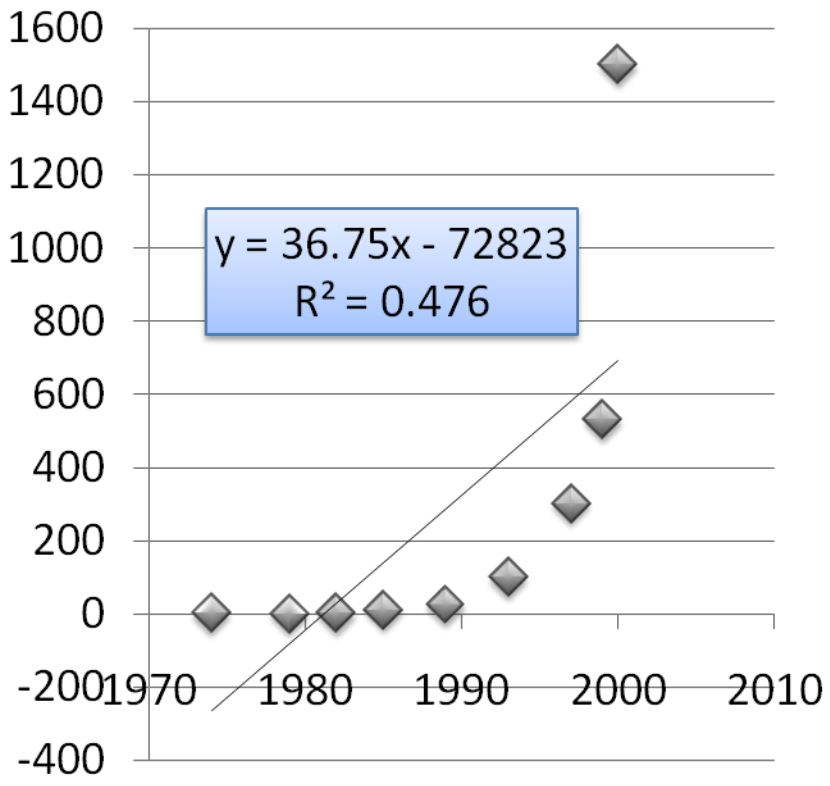


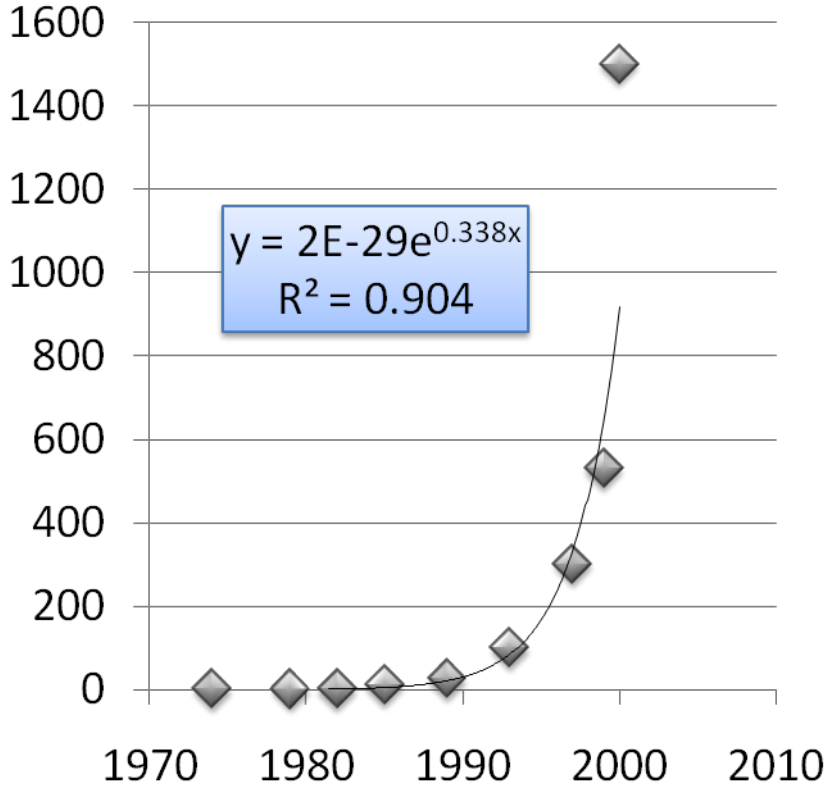
ceiling effect



floor effect

Linear and Exponential Trend Lines





How Excel Creates Trend Lines
log data
fit data to straight line
re-convert back to exponential

Trend lines are useful as guides for the eye: they provide a line showing the `stated` trend in the data, but they cannot be relied upon for serious analysis.

EXCEL:
lny -= lna _ mx
y = b + Mx

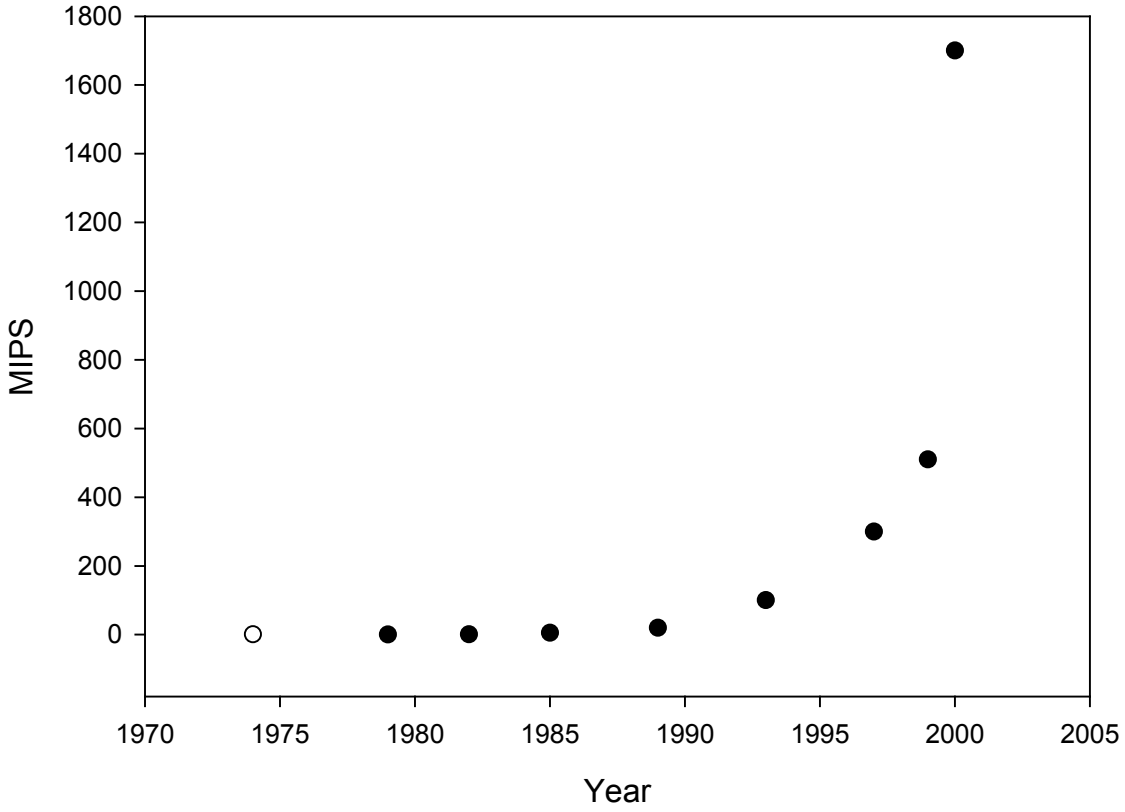
MIPS for Selected Intel Processors

Name	Year	MIPS
8080	1974	0.64
8088	1979	0.33
80286	1982	1
80386	1985	5
80486	1989	20
Pentium	1993	100
Pentium II	1997	300
Pentium III	1999	510
Pentium IV	2000	1700

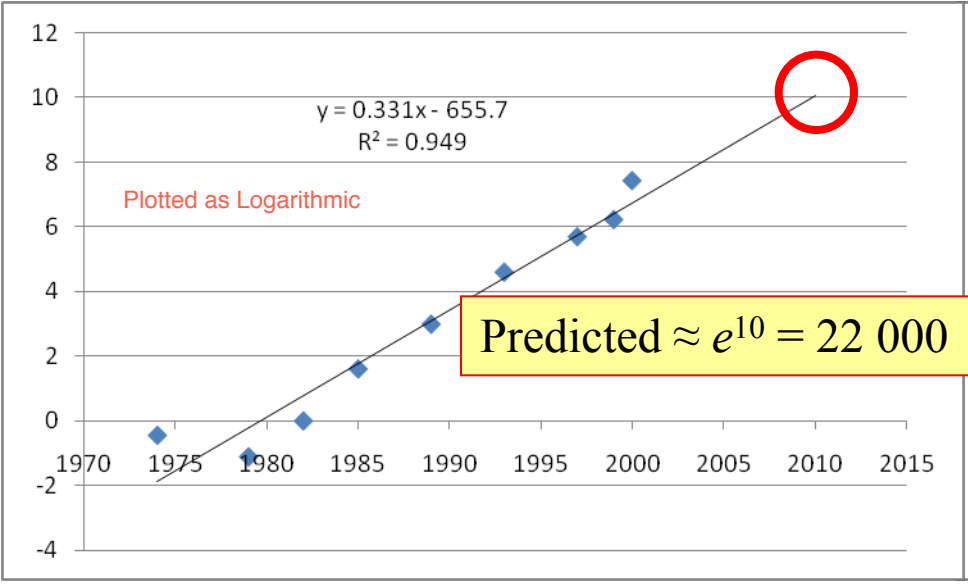
Task: Predict the speed (in MIPS) in 2010

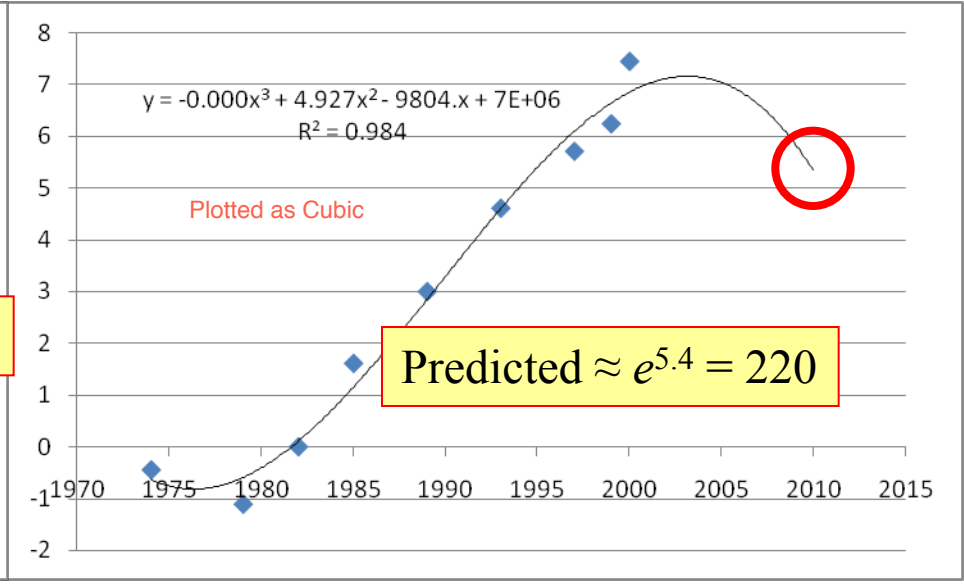
MIPS: Millions of Instructions Per Second

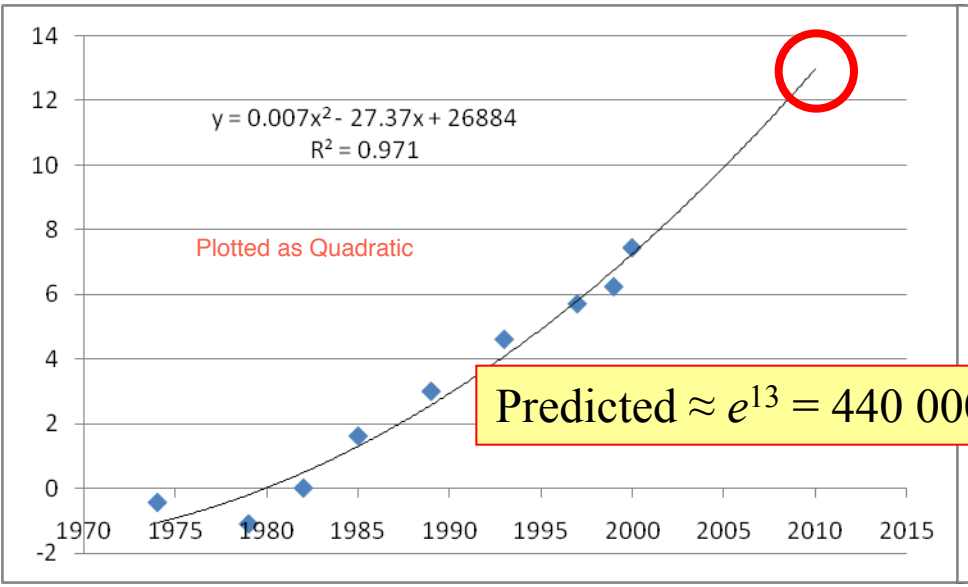
MIPS increases with time

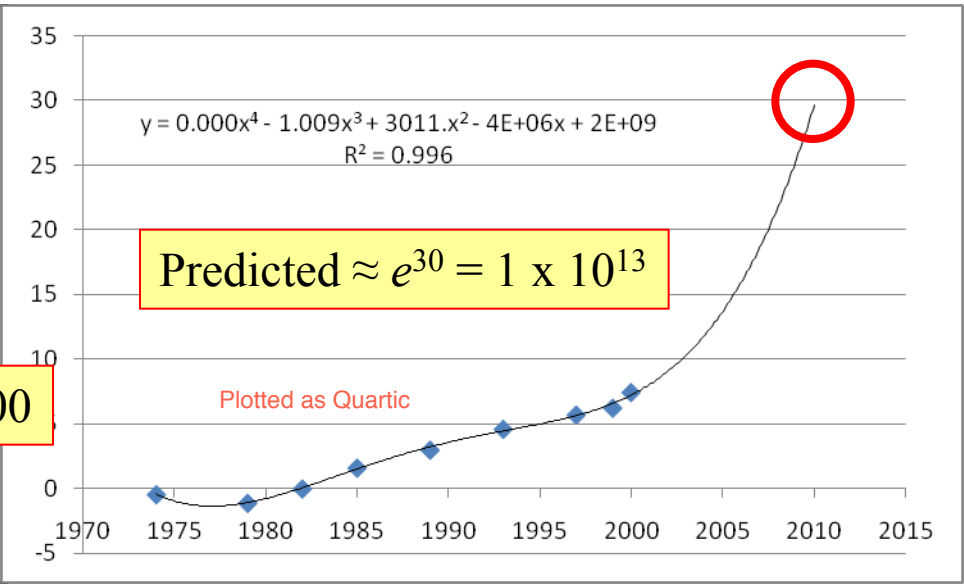


Moore's Law (Conjecture): computer speeds will increase exponentially with a doubling time of roughly 18 months.





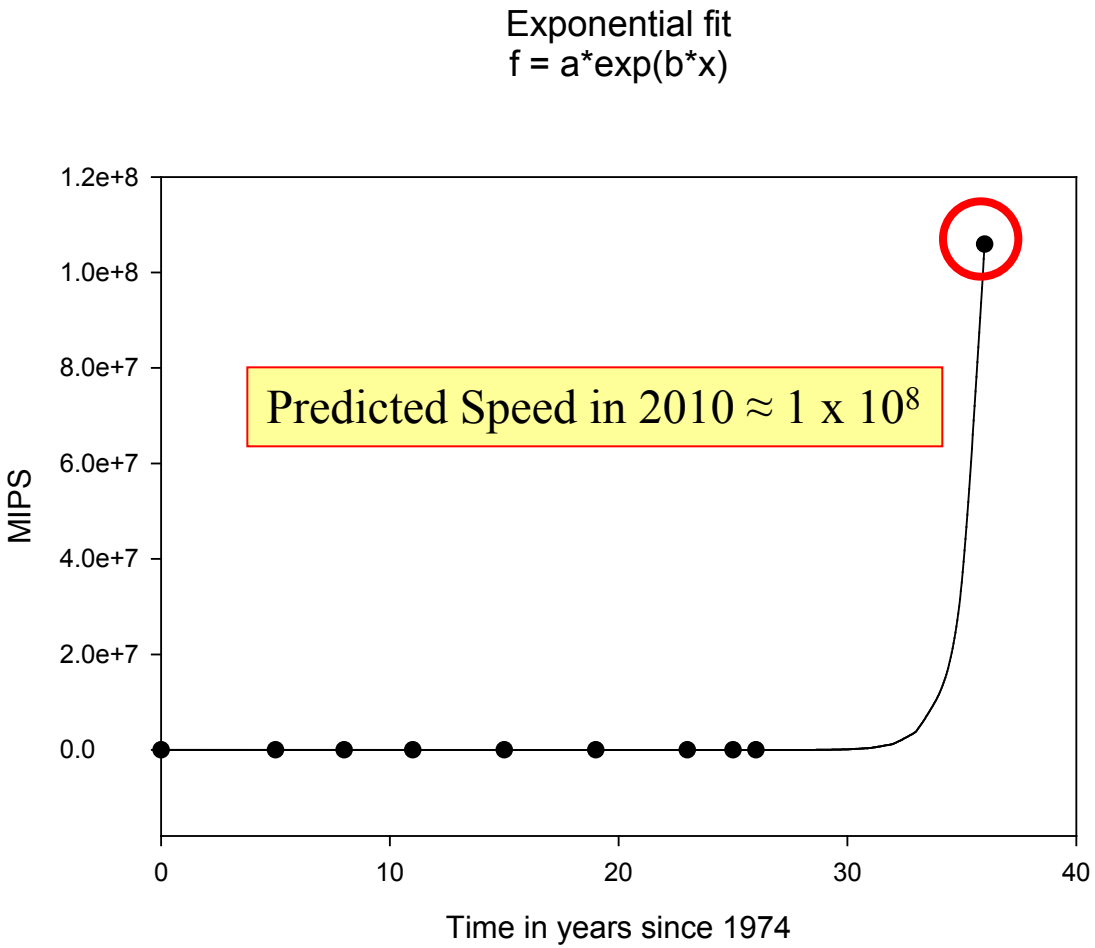




Vertical axis is natural log of MIPS

may assume the 0.996 is the best line. engineering judgement is required to choose best line. The straight line is probably the best because it follows physical values. The others are original data points that have been modified and remodified

The same data, but fitted to an exponential directly gives:



Bee careful, this analysis is also not sufficient !!

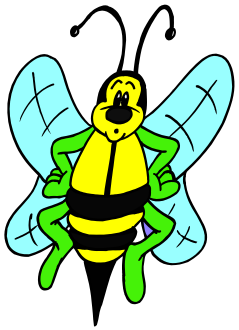
Never use Trend Lines for Serious Analysis !!!!

Be Careful

- For this reason, people are often careful when choosing their words, for instance,

  r^2 (explained variance) is "the amount of variance in y accounted for by a *linear relationship* between x and y"

- Often a nonlinear relationship will actually explain more of the overall variance than *you would estimate by simply squaring the linear correlation coefficient. Recall the parabola ($y=x^2$) fit a few slides back.*



Bee Careful

Competitive Interactions Between Neotropical Pollinators and Africanized Honey Bees

Abstract. *The Africanized honey bee, a hybrid of European and African honey bees, is thought to displace native pollinators. After experimental introduction of Africanized honey bee hives near flowers, stingless bees became less abundant or harvested less resource as visitation by Africanized honey bees increased. Shifts in resource use caused by colonizing Africanized honey bees may lead to population decline of Neotropical pollinators.*

SCIENCE, VOL 201, 15 SEPTEMBER 1978

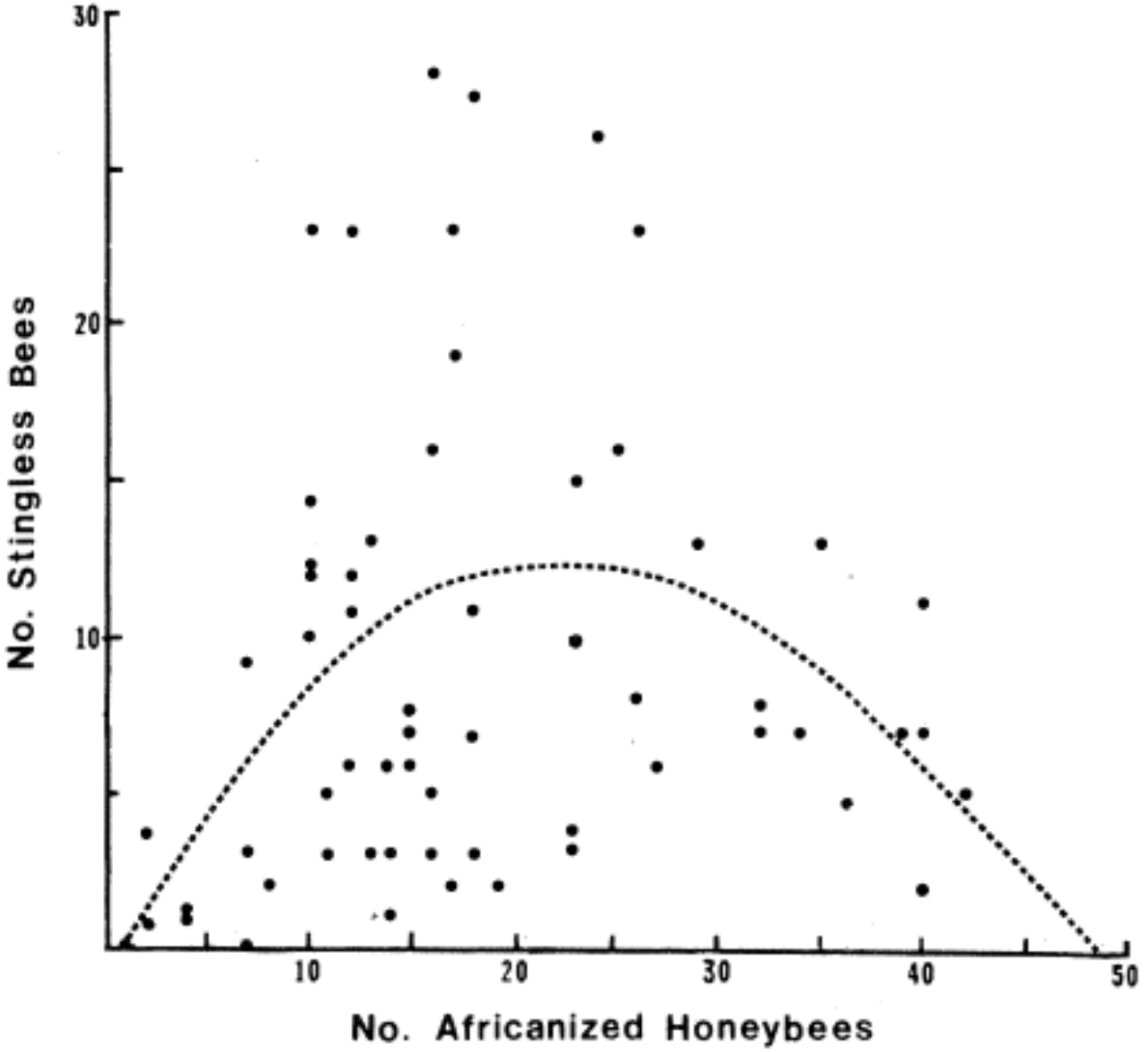


Fig. 1. The relations of Africanized and stingless (meliponine) bee abundances on flowering *Melochia villosa*. The dashed line is a quadratic polynomial (given by $y = -0.516 + 1.08x - 0.023x^2$) which gave the best fit to the points (*7*).

Curve-Fitting

The rather fanciful curve-fitting of Roubik (Reports, 15 Sept., p. 1030, Fig. 1) has prompted me to propose an alternative interpretation of his data (see below).

ROBERT M. HAZEN
Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D.C. 20018

- Bee careful using curve fitting programs:
  – it is easy to make mistakes!

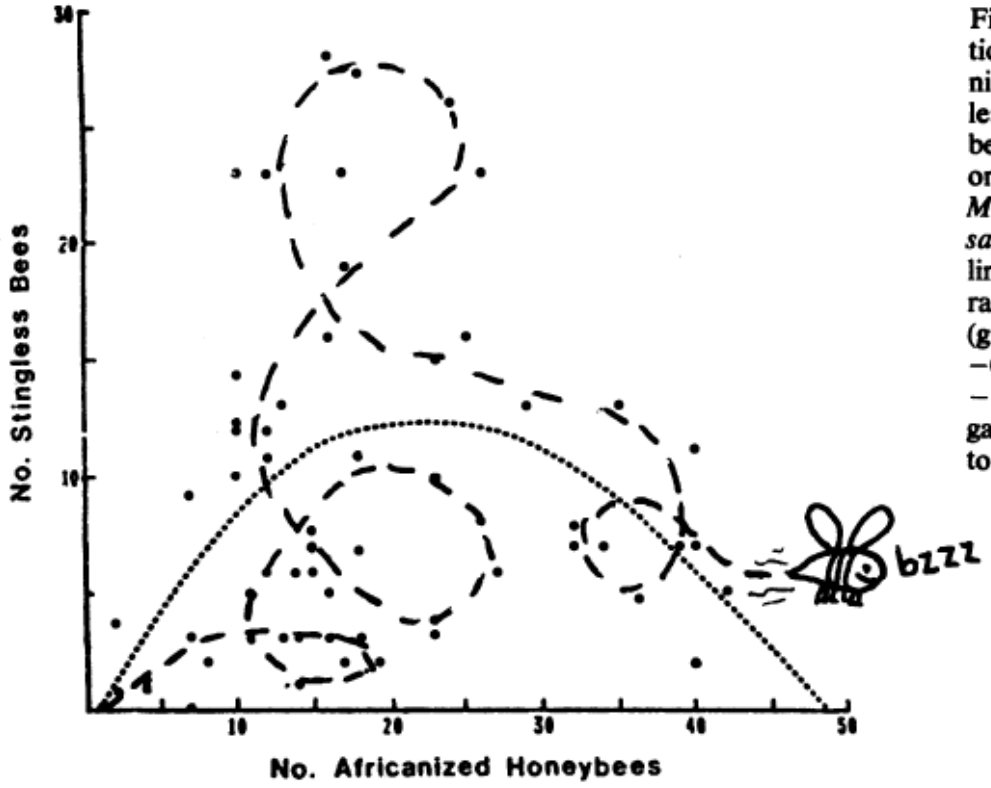
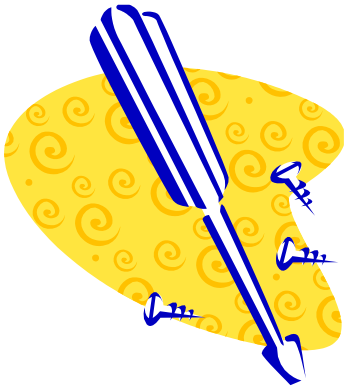


Fig. 1. The relations of Africanized and stingless (meliponine) bee abundances on flowering *Melochia villosa*. The dashed line is a quadratic polynomial (given by $y = -0.516 + 1.08x - 0.023x^2$) which gave the best fit to the points (7).

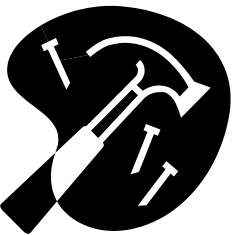
ECOR 1010
Lecture 16

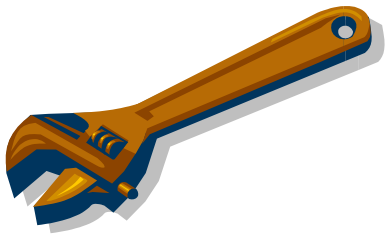
Linear Systems & MATLAB

Linear Systems



- Many problems in engineering can be approximated by **linear relationships**
- For linear systems, solutions to problems are often easy
  - Methods for structured data representation, management, and analysis
  - Clear, logical, algebraic methods exist for solving related engineering problems
- We will need tools from **linear algebra**





In the limit where (x-a) is very small, the higher order terms are extremely small

If they are so small, we can ignore them!

Taylor Series

The Taylor series of a function $f(x)$ that is infinitely differentiable in the region of a number 'a' is the power series:

The series responds in a linear way if you give it a small push is a linear system

1! = 1 * 2
2! = 2 * 3
n! = n * (n+1)

$$f(x) = f(a) + \frac{f'(a)}{1!}(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \frac{f^{(3)}(a)}{3!}(x-a)^3 + \cdots$$

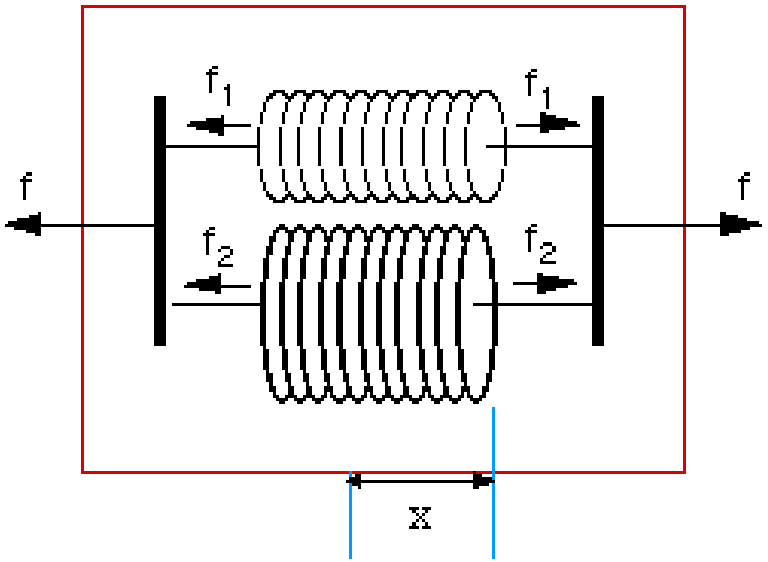
$$= \sum_{n=0}^{\infty} b_n (x-a)^n$$

When a is zero:

$$f(x) \to b_0 + b_1 x + b_2 x^2 + \ldots$$

This slide is added to give some justification for the linear approximation. Generally, functions can be expanded in a Taylor Series. If you know the value of a function at some point *a*, you can calculate the value as some different point, *x*, away from *a*, with the Taylor expansion. If *x* is not too far away, then *x*-*a* is small (i.e., much less than one), and therefore higher powers of *x*-*a* are progressively smaller and smaller. A linear system is one where the higher powers of *x*-*a* are so small that they can be ignored in the analysis. (Another point: at the same time, the higher derivatives must also get 'smaller' so that the series converges). The Taylor expansion is used to justify fitting to polynomials, such as power series in *x*. Linear systems are ones where we can truncate the series after the linear term.

Example Linear Model (mechanical system)



$$f = -kx$$

(There would be a greater series of terms, but if x is small you end up with the equation)

- Displacement of a spring when a force is applied (a linear relationship for ‘small’ displacements)

Linear Equation

- Linear equation in variables x_i

$$a_1 x_1 + a_2 x_2 + \cdots + a_n x_n = b$$

- The parameters a_i and b are usually constants
- Can you give an example of a nonlinear system/relationship?

if someone pushes a guy, he can move back to his original position if he wasn't pushed a lot. If he was pushed very hard, he'll fall over.

Linear System of Equations

- A linear system can be described with a set of *m* linear equations in the independent variables x_i

$$
\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &= b_1 \\
a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &= b_2 \\
&\vdots \\
a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &= b_m
\end{aligned}
$$

Vector and Matrix Representation

- We can represent linear systems in vector and matrix form $\mathbf{Ax} = \mathbf{b}$

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix}$$

A x = b

Vector and Matrix Representation

$$
\begin{aligned}
5x_1 - x_2 + x_3 &= 7 \\
-2x_1 + 6x_2 + 9x_3 &= 0 \\
-7x_1 + 5x_2 - 3x_3 &= -7
\end{aligned}
$$

$$
\begin{bmatrix} 5 & -1 & 1 \\ -2 & 6 & 9 \\ -7 & 5 & -3 \end{bmatrix}
\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}
=
\begin{bmatrix} 7 \\ 0 \\ -7 \end{bmatrix}
$$

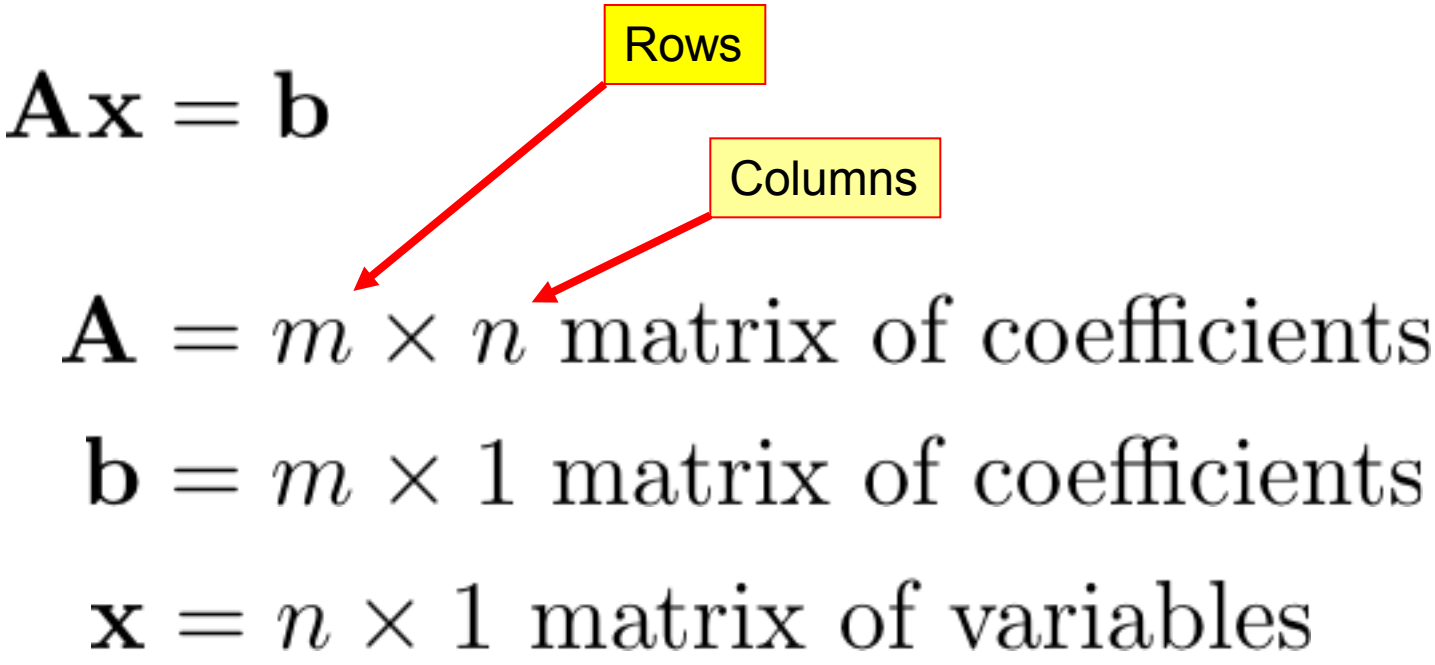
A x = b

3 x 3 3 x 1 3 x 1

Inner dimensions must be equal. Dimension of result, b, is the outer dimensions

Matrix Form

$$\mathbf{Ax} = \mathbf{b}$$



$$\mathbf{A} = m \times n \text{ matrix of coefficients}$$

$$\mathbf{b} = m \times 1 \text{ matrix of coefficients}$$

$$\mathbf{x} = n \times 1 \text{ matrix of variables}$$

Vector and Matrix Operations

- Asian mathematicians had already developed algorithms for solving linear systems by 250 BC
- Linear algebra as we know it was first formalized by German mathematician Hermann Grassmann(1809-77)
  - This new algebra was presented in his book *Die Ausdehnungslehre*(1844)
  - Grassmann algebra

Linear Algebra

- Deals with systems of linear equations and their solutions, and
- linear transformations and their properties.

Solutions to Linear Systems

Solving a set of a linear equations means we determine values for the n variables, x_1, x_2, ..., x_n, such that each of the m equations is satisfied.

- There are three possibilities:
- The system has a single *unique solution*.
  - e.g. Two lines meet at a point, if they are not parallel
- The system has *infinitely many solutions*.
  - e.g. Two planes meet in a line, if the planes are not parallel
- The system has *no solution*.
  - e.g. Two planes, or two lines, never meet if they are parallel

Solutions to Linear Systems

Under-determined ($m<n$)

- Fewer equations than unknowns
- If a finite solution exists, it is not unique
- If a solution exists there are an infinite number of solutions

Over-determined ($m>n$)

- More equations than unknowns
- A finite solution may exist
  - It may, or may not, be unique

- The equations must be independent. This means that if you have two equations, you cannot simply add them to get a third equation. You cannot simply multiply both sides of one equation by some number, say 6, to get another equation. Each equation must have new information, it cannot be a linear combination of other equations.

Determined System ($m = n$)

- The number of equations equals the number of unknowns
- If the equations are independent, then we can solve for the unknowns.
  - Unless the equations are inconsistent, like

$$x_1 + x_2 = 1 \quad \text{and} \quad x_1 + x_2 = 2$$

  - Both of the equations cannot be true simultaneously

- Consider first systems with $m = n = 2$

Recall: Two equations – Two unknowns

- Solve for x_1 and x_2 :

$$3x_1 - 2x_2 = 5$$
$$5x_1 + 7x_2 = 4$$

- Multiply the top equ by 5, and the bottom equ by 3:

$$15x_1 - 10x_2 = 25$$
$$15x_1 + 21x_2 = 12$$

- Subtract the bottom from the top:

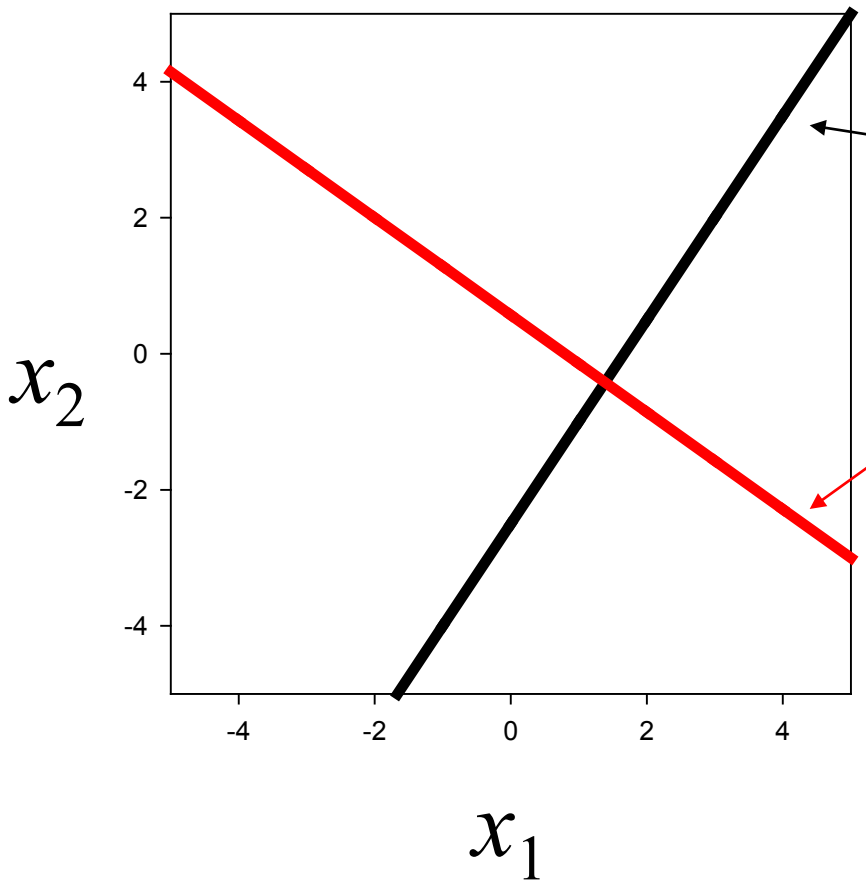
$$0x_1 - 31x_2 = 13$$

- Solve for x_2

$$x_2 = -13/31 = -0.4191$$

- Sub x_2 into either starting equ to get x_1:

$$x_1 = (5 - 2 \times 13/31)/3$$
$$= 1.3871$$



$$3x_1 - 2x_2 = 5$$

$$5x_1 + 7x_2 = 4$$

Solution:

$$x_1 = 1.3871$$

$$x_2 = -0.4194$$

With Matrices:

- Starting equations:

$$3x_1 - 2x_2 = 5$$
$$5x_1 + 7x_2 = 4$$

- Write as Matrix, A, times a vector, x, equal to a vector b:

$$\begin{bmatrix} 3 & -2 \\ 5 & 7 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 5 \\ 4 \end{bmatrix}$$

$$Ax=b$$

- Matrix multiply **on the left** by the inverse of A:

$$A^{-1}Ax=A^{-1}b$$

$$A^{-1}A=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \text{ Unit Matrix}$$

$$x=A^{-1}b$$

- The trick is to calculate A^{-1}: the matrix that is the inverse of the A matrix.

Aside:

$$\text{if } A = \begin{bmatrix} 3 & -2 \\ 5 & 7 \end{bmatrix}$$

- Do this calculation:
- Later, once you know MATLAB, calculate A^{-1}.

$$\text{then } A^{-1} = \begin{bmatrix} 0.2258 & 0.0645 \\ -0.1613 & 0.0968 \end{bmatrix}$$

$$\text{Show } A^{-1}A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = A^{-1}b = \begin{bmatrix} 0.2258 & 0.0645 \\ -0.1613 & 0.0968 \end{bmatrix} \begin{bmatrix} 5 \\ 4 \end{bmatrix} = \begin{bmatrix} 1.3871 \\ -0.4194 \end{bmatrix}$$

In 3-Dimensions

- One linear equation (in three unknowns) describes a **plane** in x-space

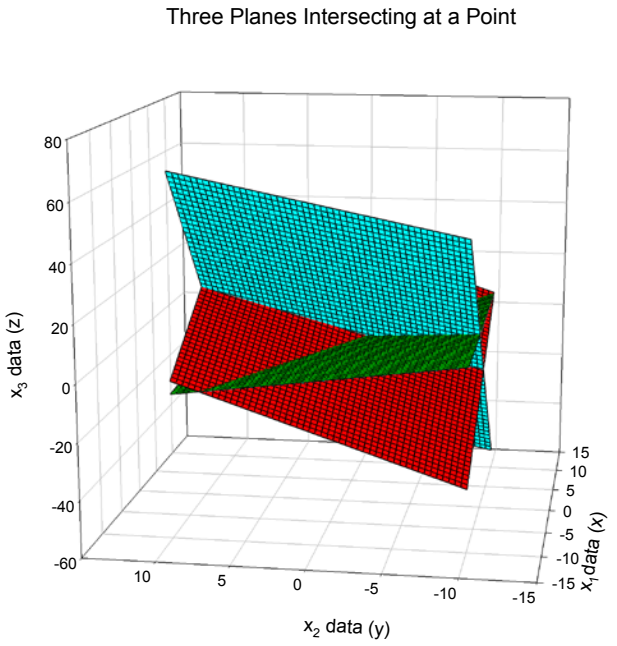
$$5x_1 - x_2 + x_3 = 7$$

- Three equations gives us three planes

$$5x_1 - x_2 + x_3 = 7$$

$$-2x_1 + 6x_2 + 9x_3 = 0$$

$$-7x_1 + 5x_2 - 3x_3 = -7$$



Example: System of Linear Equations

$$5x_1 - x_2 + x_3 = 7$$

$$-2x_1 + 6x_2 + 9x_3 = 0$$

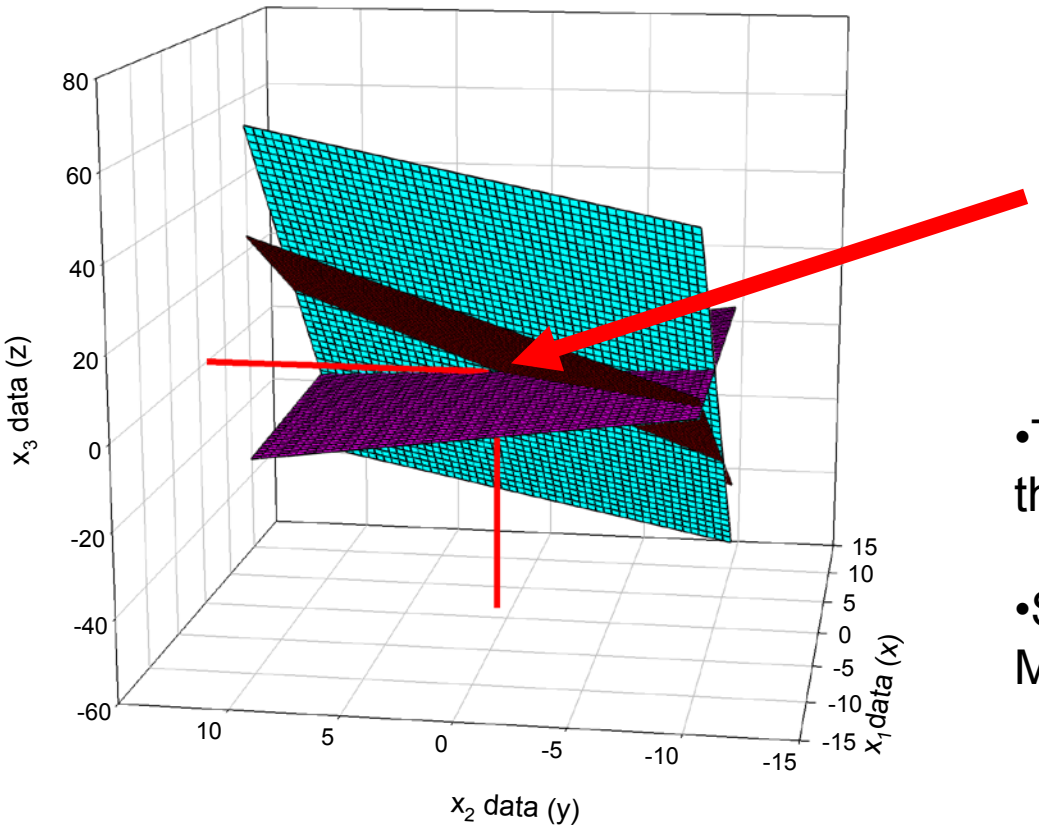
$$-7x_1 + 5x_2 - 3x_3 = -7$$

$$\underbrace{\begin{bmatrix} 5 & -1 & 1 \\ -2 & 6 & 9 \\ -7 & 5 & -3 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}}_{x} = \underbrace{\begin{bmatrix} 7 \\ 0 \\ -7 \end{bmatrix}}_{b}$$

Typical Engineering Application

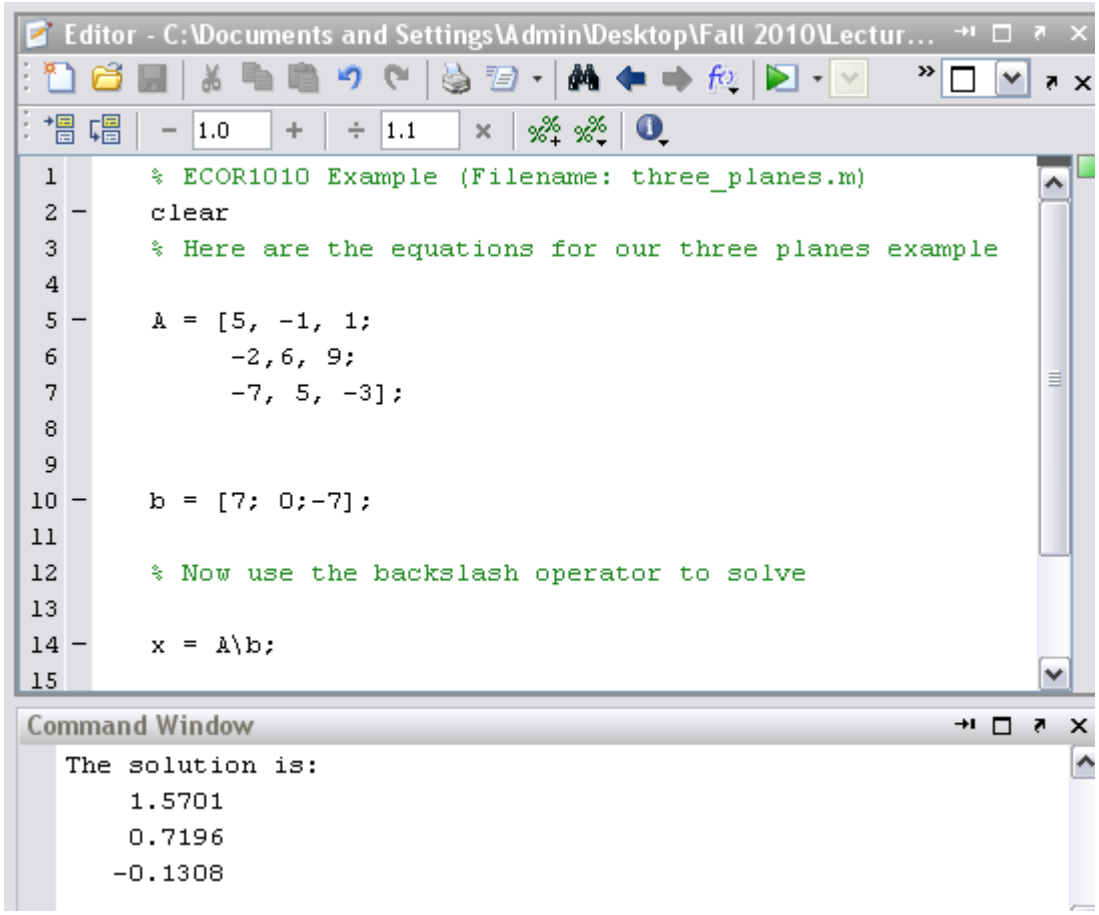
- Find $\mathbf{x}$ that satisfies $\mathbf{Ax} = \mathbf{b}$ ⟹ $\mathbf{x}=\mathbf{A}^{-1}\mathbf{b}$

Three Planes Intersecting at a Point



$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1.5701 \\ 0.7196 \\ -0.1308 \end{bmatrix}$$

- This is the intersection point of the three planes.
- Show this yourself later using MATLAB and Maple


Editor - C:\Documents and Settings\Admin\Desktop\Fall 2010\Lectur...
1.0
1.1
1 % ECOR1010 Example (Filename: three_planes.m)
2 clear
3 % Here are the equations for our three planes example
4
5 A = [5, -1, 1;
6 -2,6, 9;
7 -7, 5, -3];
8
9
10 b = [7; 0;-7];
11
12 % Now use the backslash operator to solve
13
14 x = A\b;
15
Command Window
The solution is:
1.5701
0.7196
-0.1308

C:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\lecture19.mw - [Server 4] - Maple 14

File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help

Favorites
MapleCloud
Handwriting
Expression
Units (SI)
Units (FPS)
Common Symbols
Matrix
Components
Greek
Arrows
Relational
Relational Round
Negated
Large Operators
Operators
Open Face
Fraktur
Script
Miscellaneous

Text Math | Maple Input | Monospaced | 12 | B I U

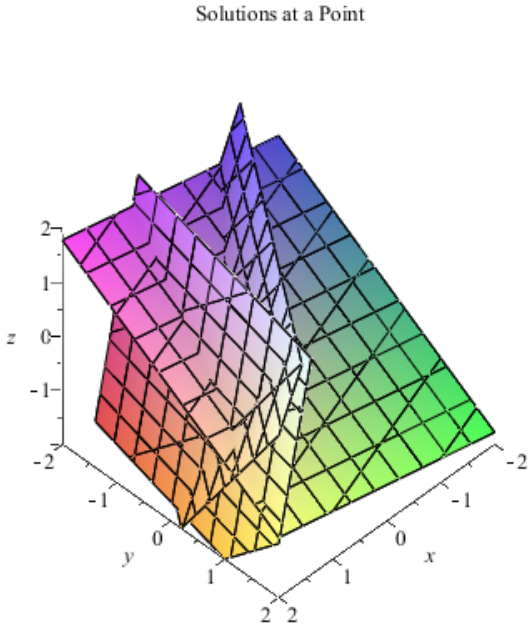
```
> restart:
> with(plots):
```

Example 1:

```
> eqn1:=5*x-y+z=7:
> eqn2:=-2*x+6*y+9*z=0:
> eqn3:=-7*x+5*y-3*z=-7:
> solve({eqn1,eqn2,eqn3},{x,y,z});
```

$$\left\{x = \frac{168}{107}, y = \frac{77}{107}, z = -\frac{14}{107}\right\} \quad (1)$$

```
> implicitplot3d([5*x-y+z=7,-2*x+6*y+9*z=0,-7*x+5*y-3*z=-7],x=-2..2,y=-2..2,z=-2.
  .2,axes=framed,title="Solutions at a Point");
```




```
>
```

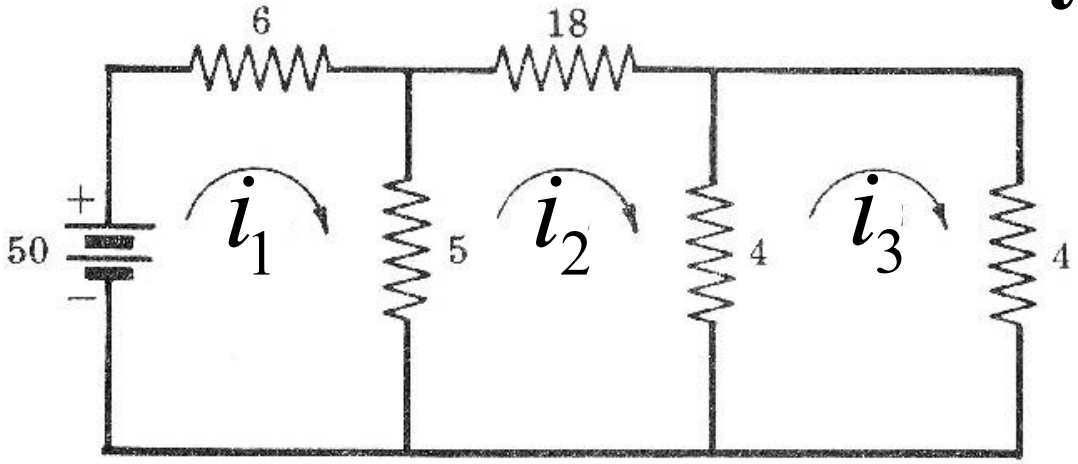
Example 2:

```
> eqn4:=5*x-y+2*z=7:
```

Ready

Memory: 0.74M Time: 0.06s Text Mode

Mesh Current Network Analysis



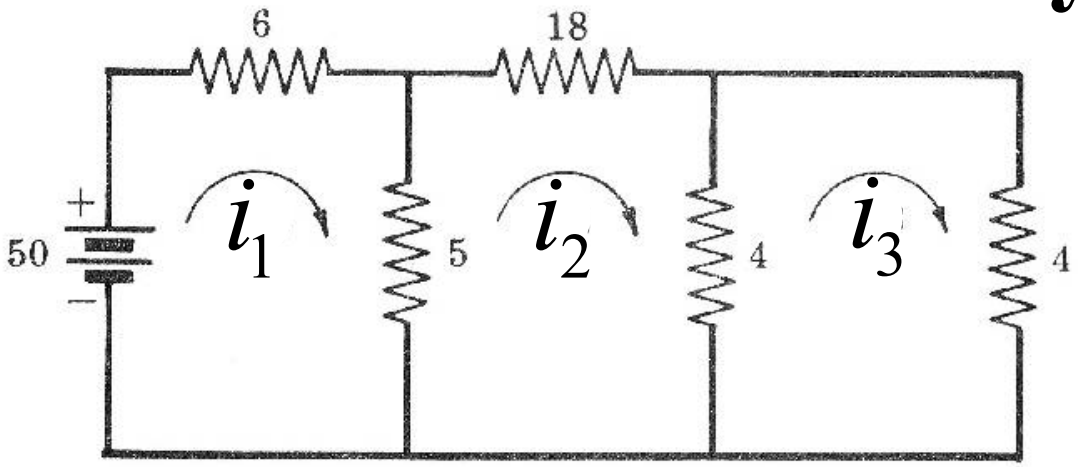
- Kirchhoff's voltage law: the sum of the voltage drops around any closed loop is equal to the sum of the voltage rises. (Recall Ohm's Law: V = i R)

Loop 1: $i_1(6+5) - i_2 5 + i_3 \times 0 = 50$

Loop 2: $-i_1(5) + i_2(5+18+4) - i_3 \times 4 = 0$

Loop 3: $i_1(0) - i_2 4 + i_3(4+4) = 0$

Mesh Current Network Analysis



- Kirchhoff's voltage law: the sum of the voltage drops around any closed loop is equal to the sum of the voltage rises.

$$\begin{bmatrix} 11 & -5 & 0 \\ -5 & 27 & -4 \\ 0 & -4 & 8 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 0 \\ 0 \end{bmatrix}$$

$$\mathrm{A} \qquad \mathrm{x} = \mathrm{b}$$

First, solve the slow way by hand ...

$$\begin{bmatrix} 11 & -5 & 0 \\ -5 & 27 & -4 \\ 0 & -4 & 8 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 0 \\ 0 \end{bmatrix}$$

$$\left[\begin{array}{ccc|c} 11 & -5 & 0 & 50 \\ -5 & 27 & -4 & 0 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

Row Reduction to Row Echelon Form

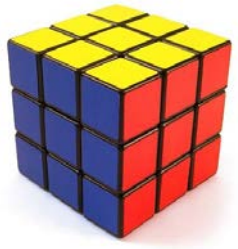
- The system of equations is written in this form:

$$\left[\begin{array}{ccc|c} 11 & -5 & 0 & 50 \\ -5 & 27 & -4 & 0 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

- This form is then modified using elementary row operations until it reaches reduced "row echelon form":

$$\left[\begin{array}{ccc|c} 1 & 0 & 0 & 5 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0.5 \end{array}\right]$$

- There are three types of elementary row operations:



  - **Type 1**: Swap the positions of two rows.
  - **Type 2**: Multiply a row by a nonzero scalar.
  - **Type 3**: Add to one row a scalar multiple of another.

$$\left[\begin{array}{ccc|c} 11 & -5 & 0 & 50 \\ -5 & 27 & -4 & 0 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

Take 1/2 of the third row and add it to the second row

$$\left[\begin{array}{ccc|c} 11 & -5 & 0 & 50 \\ -5 & 25 & 0 & 0 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

Take 1/5 of the second row and add it to the first row

$$\left[\begin{array}{ccc|c} 10 & 0 & 0 & 50 \\ -5 & 25 & 0 & 0 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

Take 1/2 of the first row and add it to the second row

$$\left[\begin{array}{ccc|c} 10 & 0 & 0 & 50 \\ 0 & 25 & 0 & 25 \\ 0 & -4 & 8 & 0 \end{array}\right]$$

Take 4/25ths of the second row and add it to the third row

$$\left[\begin{array}{ccc|c} 10 & 0 & 0 & 50 \\ 0 & 25 & 0 & 25 \\ 0 & 0 & 8 & 4 \end{array}\right]$$

Divide the first row by 10, the second row by 25 and the third row by 8.

$$\left[\begin{array}{ccc|c} 1 & 0 & 0 & 5 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0.5 \end{array}\right]$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 5 \\ 1 \\ 0.5 \end{bmatrix}$$

Unit Matrix in 3D

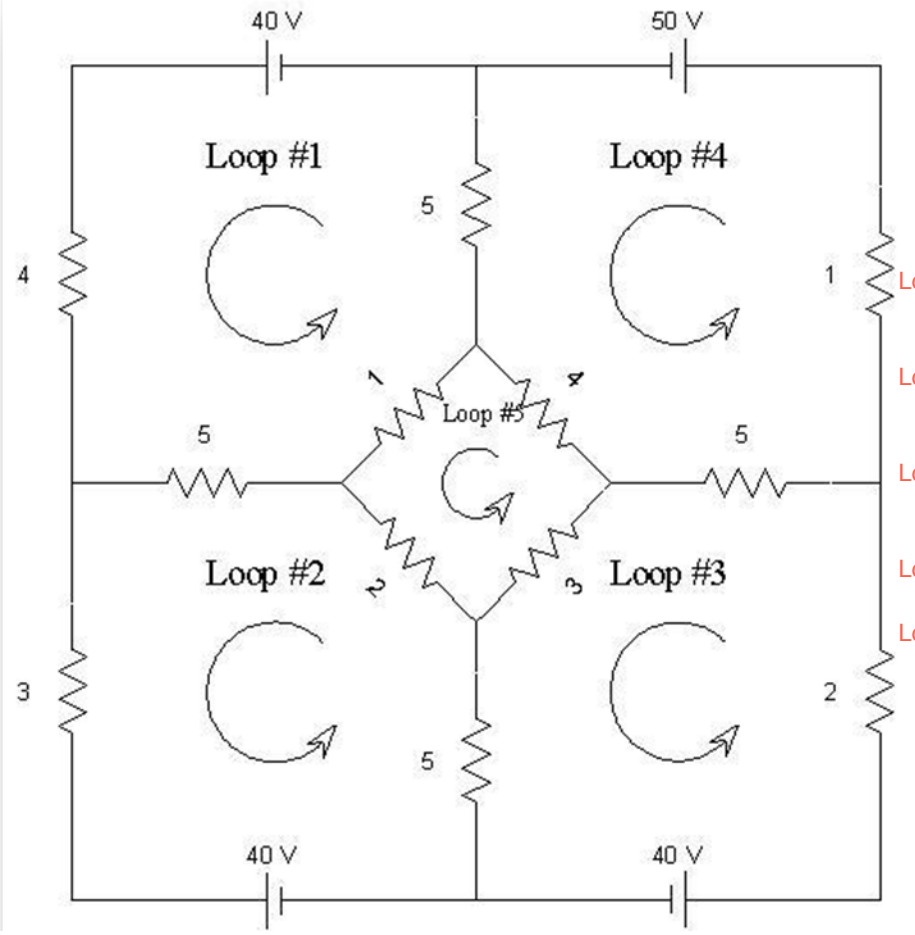
MATLAB code:

```
>> A=[11 -5 0;-5 27 -4;0 -4 8]
A =
    11    -5     0
    -5    27    -4
     0    -4     8
>> b=[50;0;0]
b =
    50
     0
     0
>> x=inv(A)*b
x =
    5.0000
    1.0000
    0.5000
>> x=A\b
x =
    5.0000
    1.0000
    0.5000
```

Different ways of getting the answer

A\b is faster

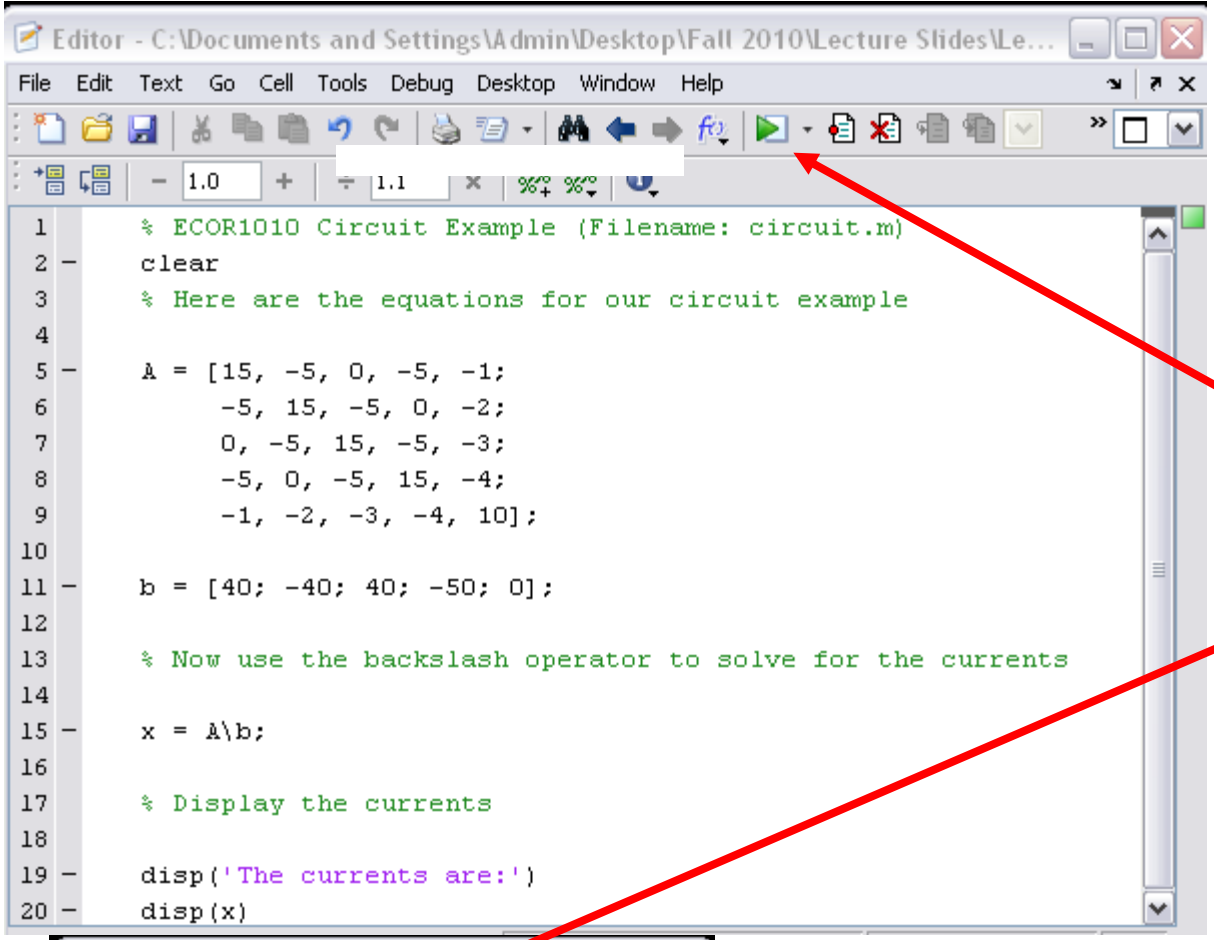
Another Linear Circuit Example



If Loop is Positive to Negative: Voltage = Positive
If Loop is Negative to Positive: Voltage = Negative
** Look at Loop 1 Total, and Loop 2 Total

$$\begin{array}{c} \\ \text{Loop1} \\ \text{Loop 2} \\ \text{Loop 3} \\ \text{Loop 4} \\ \text{Loop 5} \end{array} \begin{array}{c} \begin{array}{ccccc} \text{L1} & \text{L2} & \text{L3} & \text{L4} & \text{L5} \end{array} \\ \begin{bmatrix} 15 & -5 & 0 & -5 & -1 \\ -5 & 15 & -5 & 0 & -2 \\ 0 & -5 & 15 & -5 & -3 \\ -5 & 0 & -5 & 15 & -4 \\ -1 & -2 & -3 & -4 & 10 \end{bmatrix} \end{array} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \end{bmatrix} = \begin{bmatrix} 40 \\ -40 \\ 40 \\ -50 \\ 0 \end{bmatrix}$$

Difficult to solve by hand!!



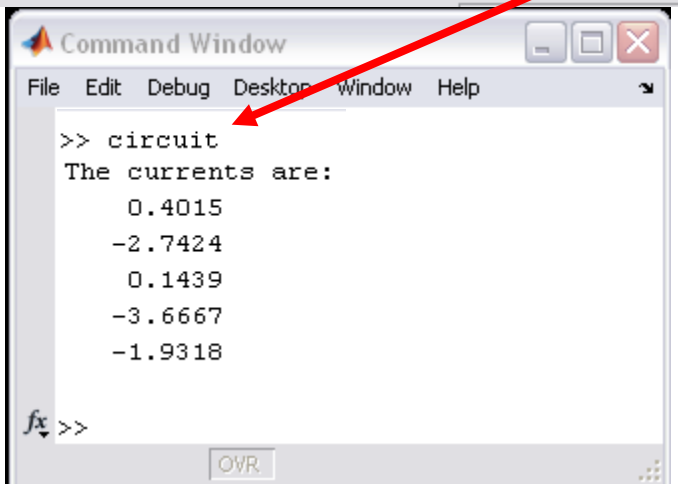
This MATLAB m-file example is called: circuit.m
This is the script file. It is the computer program.

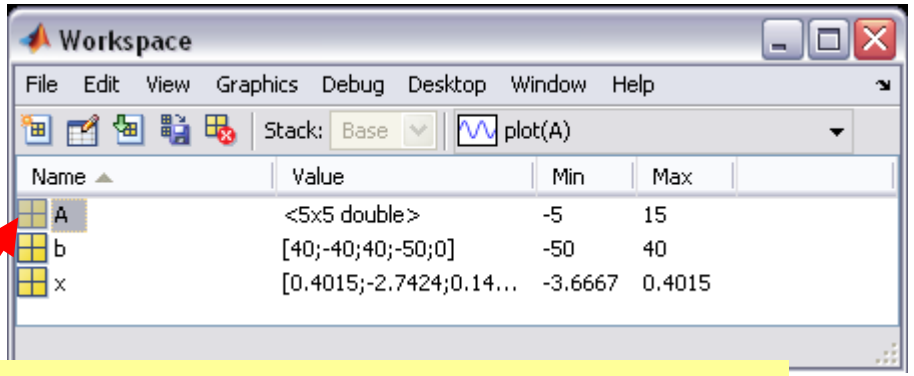
To run the script:

- Click the run icon in the editor

or

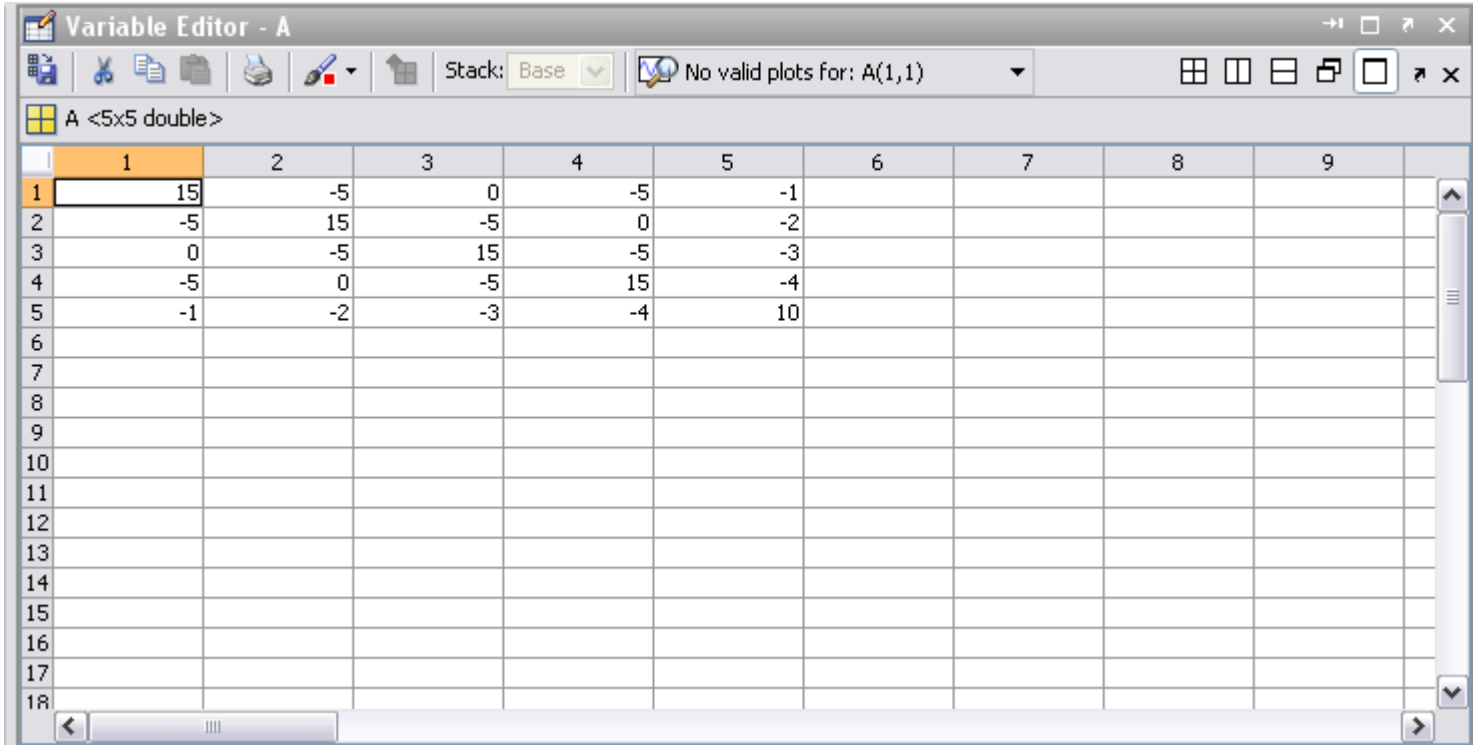
- Type 'circuit' in the command window





Click on the yellow icon by A and the window in the next slide pops up

This spreadsheet can be edited



	1	2	3	4	5	6	7	8	9
1	15	-5	0	-5	-1				
2	-5	15	-5	0	-2				
3	0	-5	15	-5	-3				
4	-5	0	-5	15	-4				
5	-1	-2	-3	-4	10				
6									
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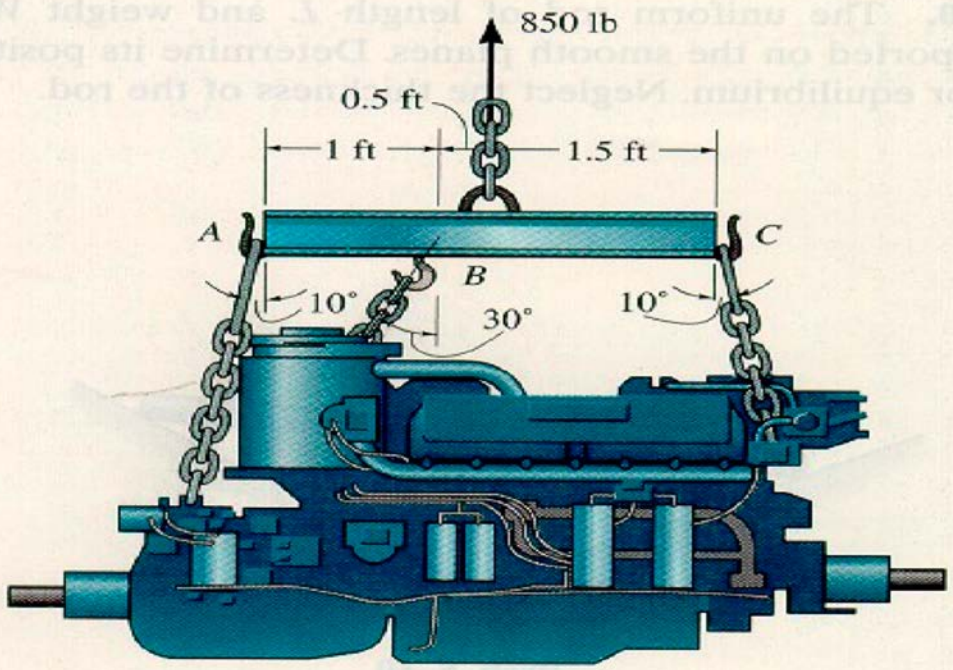
17									
18									

Example from Mechanics

5-47. The motor has a weight of 850 lb. Determine the force that each of the chains exerts on the supporting hooks at A, B, and C. Neglect the size of the hooks and the thickness of the beam.



Three Equations, Three Unknowns

$$\sum F_x = 0$$

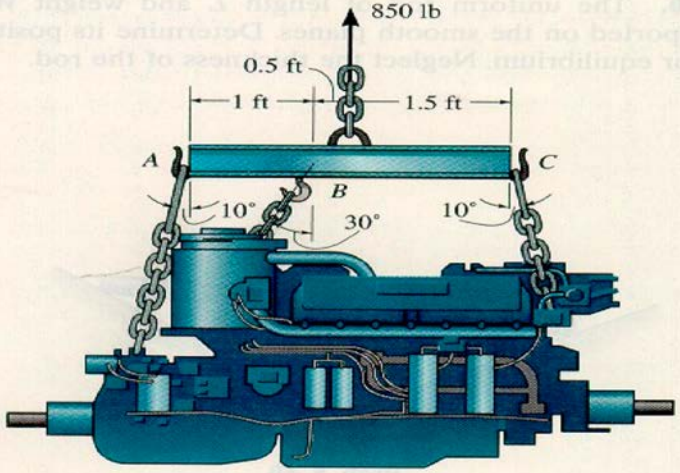
Sum of forces in x and y must be zero

$$\sum F_y = 0$$

$$\sum M_b = 0$$

Torque must be zero (Force * distance)

5-47. The motor has a weight of 850 lb. Determine the force that each of the chains exerts on the supporting hooks at A, B, and C. Neglect the size of the hooks and the thickness of the beam.



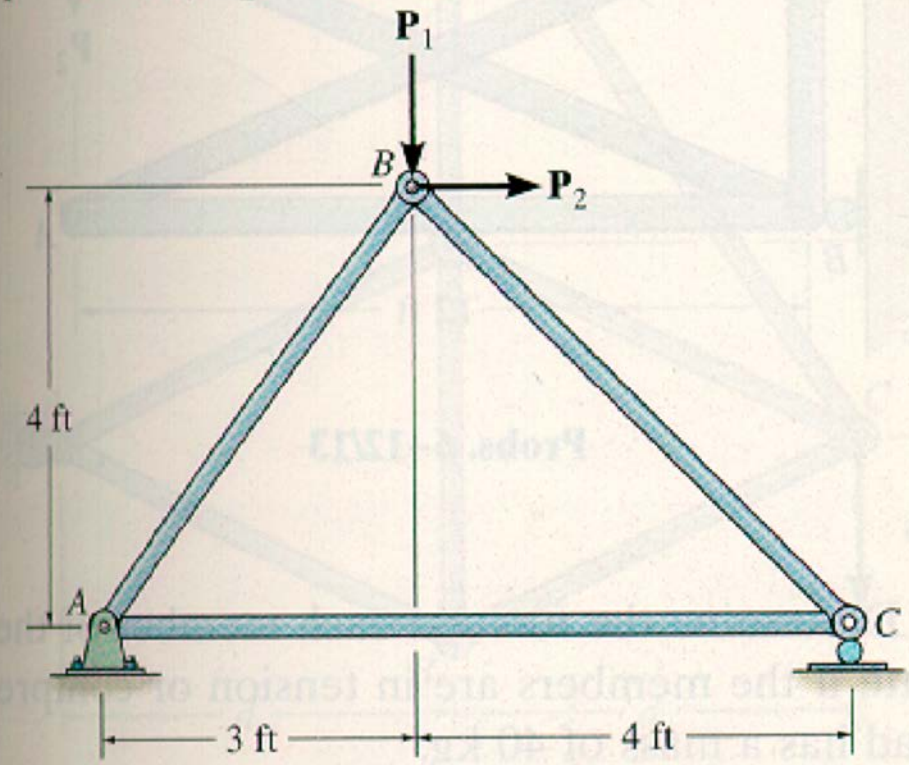
Linear System of Equations

$$
\begin{aligned}
-F_A \sin 10 - F_B \sin 30 + F_C \sin 10 &= 0 \\
-F_A \cos 10 - F_B \cos 30 + 850 - F_C \cos 10 &= 0 \\
(1)F_A \cos 10 + 850(0.5) - (2)F_C \cos 10 &= 0
\end{aligned}
$$

$$
\begin{bmatrix} -\sin 10 & -\sin 30 & \sin 10 \\ \cos 10 & \cos 30 & \cos 10 \\ \cos 10 & 0 & -2\cos 10 \end{bmatrix} \begin{bmatrix} F_A \\ F_B \\ F_C \end{bmatrix} = \begin{bmatrix} 0 \\ 850 \\ -425 \end{bmatrix}
$$

Example: Trusses

6-2. Determine the force in each member of the truss and state if the members are in tension or compression. Set $P_1 = 200$ lb, $P_2 = 500$ lb.

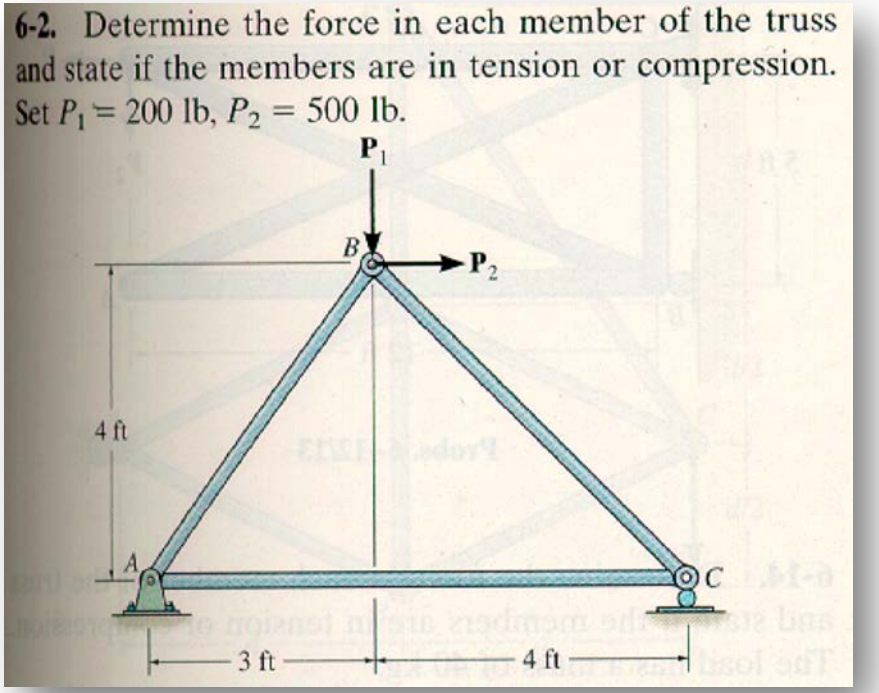


Example: Trusses

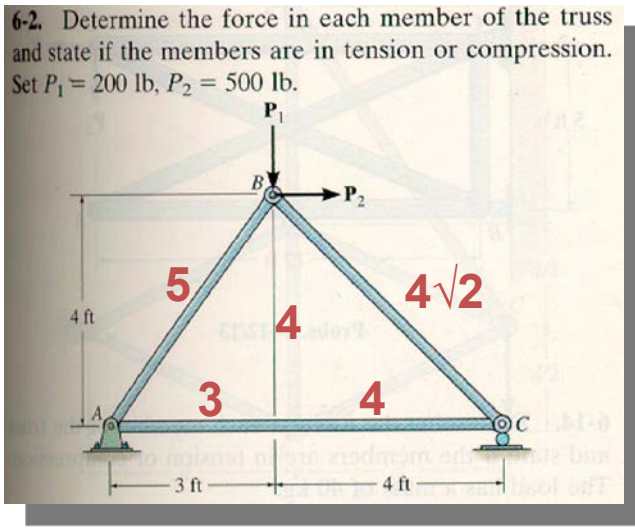
- For each joint, the sum of the forces in each direction (x and y) must be zero (static)

$$\sum F_x = 0$$

$$\sum F_y = 0$$



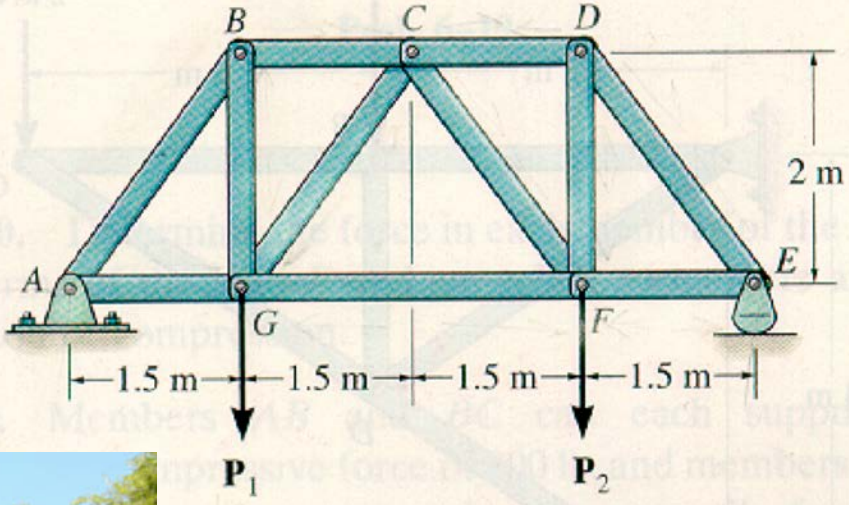
In Matrix Form



$$\begin{bmatrix} 3/5 & 1/\sqrt{2} & 0 & 0 & 0 & 0 \\ -4/5 & 1/\sqrt{2} & 0 & 0 & 0 & 0 \\ 3/5 & 0 & -1 & 1 & 0 & 0 \\ 4/5 & 0 & 0 & 0 & -1 & 0 \\ 0 & 1/\sqrt{2} & 0 & -1 & 0 & 0 \\ 0 & -1/\sqrt{2} & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} F_{AB} \\ F_{BC} \\ A_x \\ F_{CA} \\ A_y \\ C_y \end{bmatrix} = \begin{bmatrix} 500 \\ 200 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Another Truss Example

6-6. Determine the force in each member of the truss and state if the members are in tension or compression. Set $P_1 = 40$ kN, $P_2 = 20$ kN.



Solve this by hand?

$$\begin{bmatrix} -1 & 1 & 3/5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 4/5 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -1 & -3/5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -4/5 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 3/5 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 4/5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -3/5 & 0 & 0 & 0 & 0 & 1 & -1 & -3/5 & 0 & 0 & 0 & 0 \\ 0 & 0 & -4/5 & 0 & 0 & 0 & 0 & 0 & 0 & 4/5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -3/5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4/5 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3/5 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4/5 & 0 & 0 & 1 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3/5 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4/5 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} F_{GA} \\ F_{GF} \\ F_{GC} \\ F_{GB} \\ A_x \\ F_{AB} \\ Ay \\ F_{BC} \\ F_{CD} \\ F_{CF} \\ F_{DE} \\ F_{DF} \\ F_{EF} \\ E_y \end{bmatrix} = \begin{bmatrix} 0 \\ 40 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 20 \end{bmatrix}$$

Solving Systems of Linear Equations

- We can solve these linear equations either by hand, or with software
  - MATLAB and Maple in this course (... and Excel)
- **MATLAB** is good for numerical calculations and solving systems with unique solutions
- **Maple** can be useful for finding algebraic solutions when the solution is not unique

Brief Introduction to MATLAB

What is MATLAB?

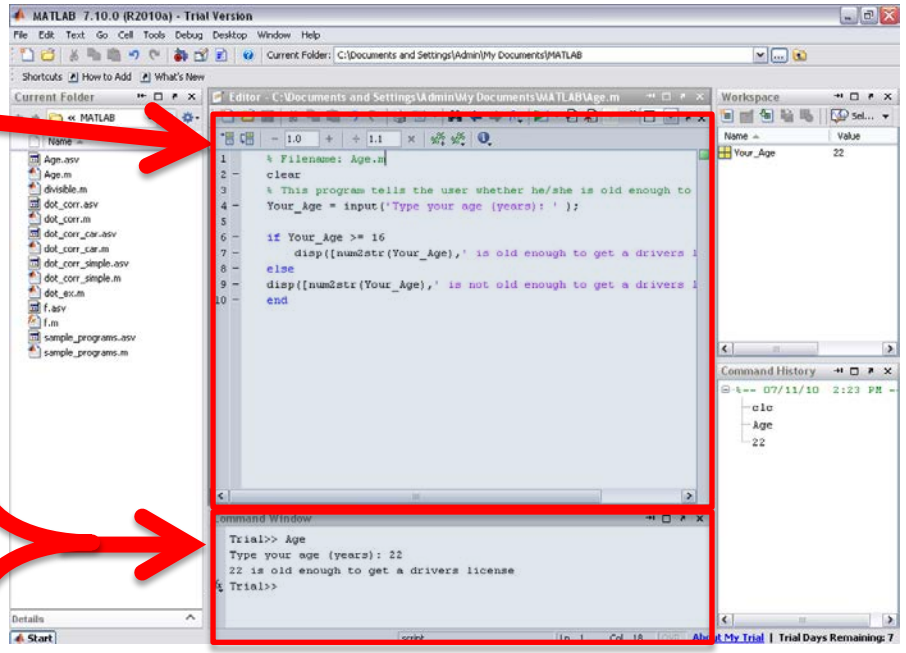
- MATrixLABoratory (MATLAB)
- Designed for matrix computations
- Used extensively in mathematics, engineering, and computer science
- Usually used for numerical purposes
- Has some symbolic capabilities (but Maple is better for symbolic manipulations)
- Handles large data sets quite well

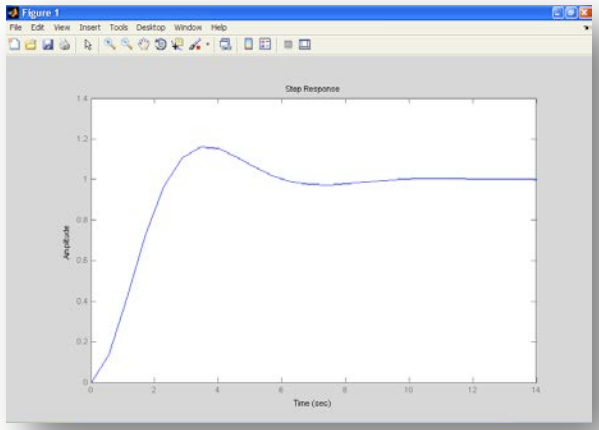
What can MATLAB do?

- Basic mathematics
- Matrix manipulation
- 2D graphing
- 3D graphing
- Surface plotting
- Sound Visualization
- Data Analysis
- Computer Programming
- Much more
  - There are many specialized “toolboxes”

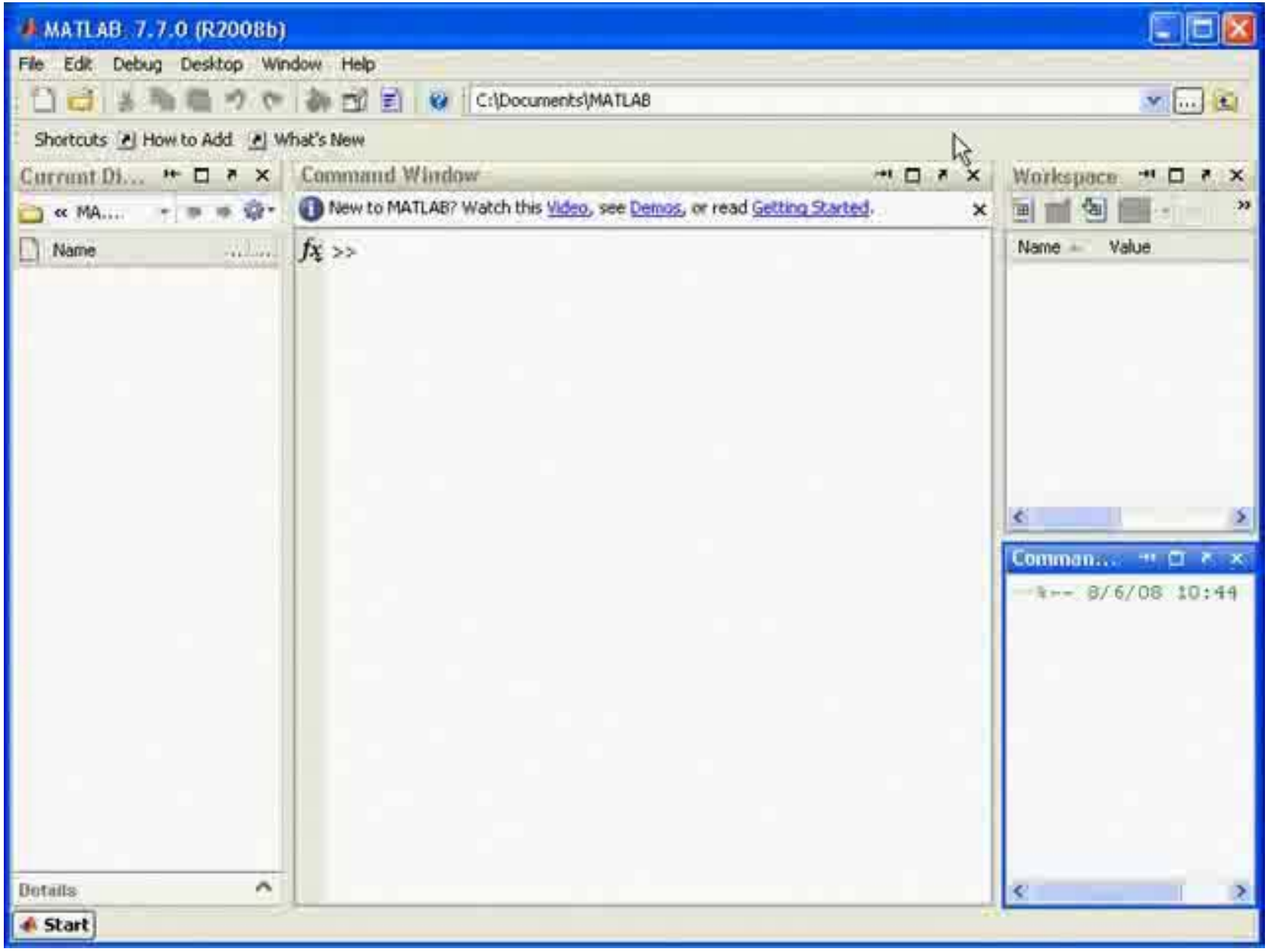
Three Basic Windows

- Editor Window
  - Used primarily for programming, and developing reusable code
- Command Window
  - Opens immediately when you start MATLAB
  - Used primarily for mathematical operations, testing/development, and for creating throw away programs
- Figure Window
  - Appears whenever a plot is created

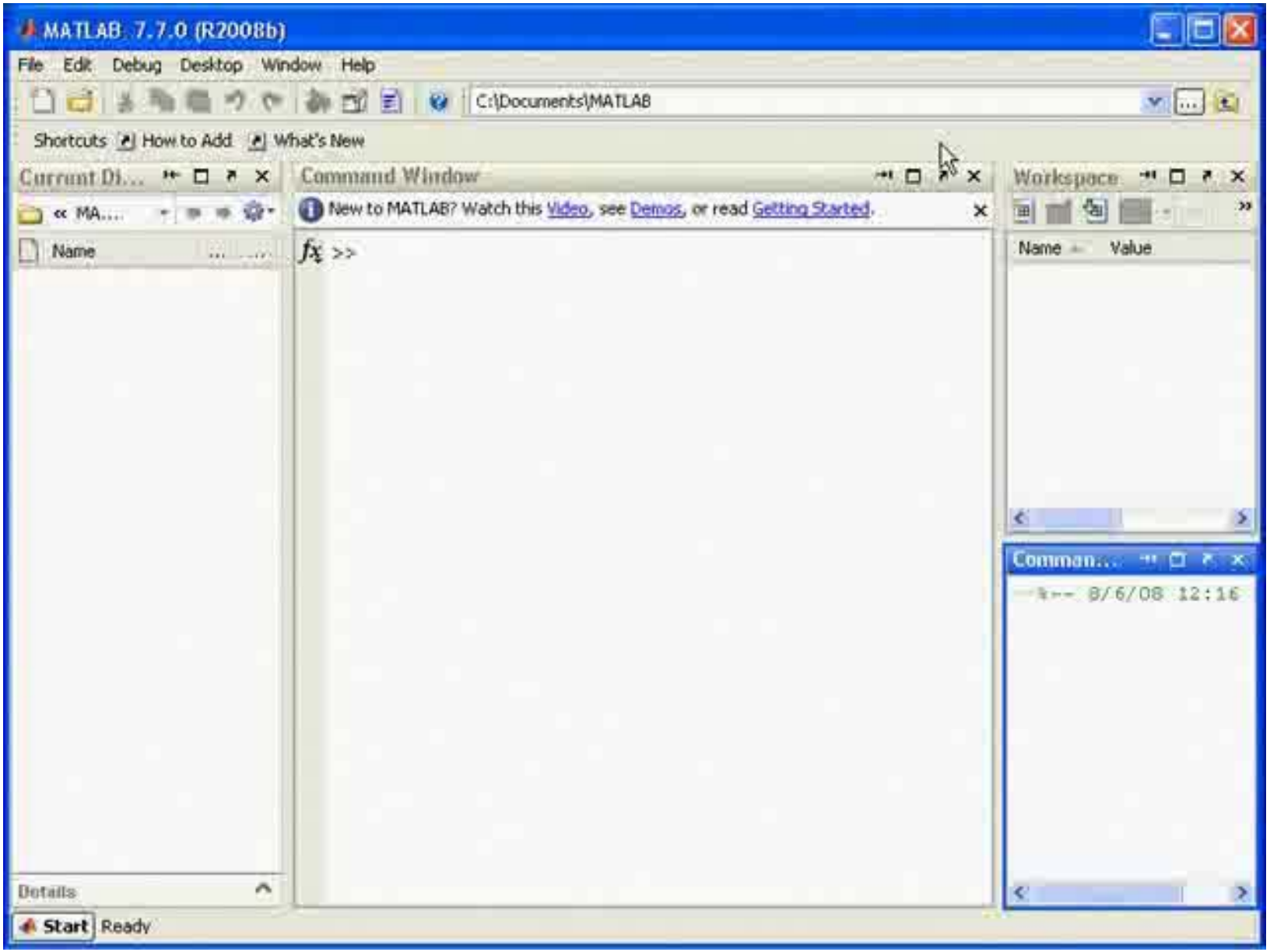




Getting Started With MATLAB



Working in the Development Environment



Video Time

1. http://www.mathworks.com/demos/matlab/getting-started-with-matlab-video-tutorial.html
2. http://www.mathworks.com/demos/matlab/working-in-the-development-environment-matlab-video-tutorial.html
3. http://www.mathworks.com/demos/matlab/writing-a-matlab-program-matlab-video-tutorial.html
4. http://www.mathworks.com/demos/matlab/analyzing-data-overview-matlab-video-demonstration.html
5. http://www.mathworks.com/demos/matlab/visualizing-data-overview-matlab-video-demonstration.html

Semicolons ;

- Follow commands when you do not want the output to be printed/echoed to the screen
- Can be used in the command window or in your m-files (so you see only what you want)

```
» 1+1

ans =

     2

» 2*18;

»
```

Parentheses and Brackets

- ( ) used to denote order of operations or standard functions

  `2*(3 + 4)` or `sin(3.145)`

- [ ] used to declare matrices and vectors

  `A = [1, 2; 3, 4]`

- ( ) used to denote elements of a matrix/vector

  `A(1,2)`

$$\mathbf{A} = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

Variables

- You do not need to initialize variables (i.e., no need to assign data types)
  - MATLAB does it automatically
- Can have different types
  - Double Precision (default)
  - Integers
  - Boolean
  - Strings
- Can be multidimensional (vectors, matrices)

Variables

- Use the = sign to define variables

```
Number1 = 412;
% Value 412 is assigned to the variable Number1
Number_1 = -18;
% Note that Number1 and Number_1 are different
Number 2 = 15;% Invalid -> Names cannot have spaces
A1 = [1 2 3; 4 5 6; 7 8 9];% Assigns a matrix A1
AVector = [-1; 0; 1; 0; -1; 0];
2V = [34; 52]; % Invalid: Names must begin with a letter
```

Displaying Variables in Scripts

```
disp(Number)

% Will display the contents of the variable Number
in the command window

disp('At dawn, my father and I picked carrots off
of the trees')

% Display the message in between quotations in the
command window

% If you want an apostrophe in the message, you
have to use 2 single quotes: ''
```

MATLAB Workspace

- When you create a variable it is stored in the MATLAB workspace
  - You can access it in later calculations
- If you want to clear the workspace
  - `clear all; % clears all variables`
  - `clear A1; % clears variable A1`

Cleaning Up

- You can clear the command window with the command `clc`
- You can close all open figure windows with the command `close all`

m-files

- m-files are **script files** that execute a sequence of MATLAB commands (a program)
  - including object-oriented programming
  - MATLAB comes with many preprogrammed scripts
- **Functions** are a special type of m-file

Running m-Files

- You can run m-file scripts in a number of ways
  - If they exist in your current path, just type the name of the m-file in the command window
  - You can use Tools > Run
  - There is a button on the toolbar

MATLAB Help

- There is an extensive Help feature
- If you know the command (e.g., `inv`)

```
help inv
doc inv
```

- Section 7 in your textbook
- Visit www.mathworks.com
  - Lots of tutorials
- Support material on WebCT

Vector Operations in MATLAB

Vector Operations in MATLAB

- Use square brackets to denote a vector: [ ]
- For row vectors, use a space or comma between elements

  a = [1,2,3] or a = [1 2 3]

$$\mathbf{a} = \begin{bmatrix} 1 & 2 & 3 \end{bmatrix}$$

- For a column vector, use a semicolon (;) between elements

  a = [1;2;3]

$$\mathbf{a} = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$$

Addition and Subtraction

```
>> A = [5;1;3;4];
>> B = [0;2;4;11];
>> C = A-B

C =

     5
    -1
    -1
    -7
```

Scalar-Vector Operations

```
>> a = [-1,-5,0,3,7,8];
>> 3*a

ans =

    -3   -15     0     9    21    24

>> 1 + a

ans =

     0    -4     1     4     8     9
```

Norm of a Vector

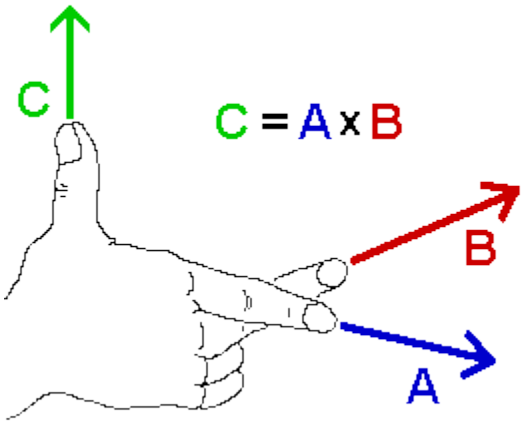
- Use the norm command

Length of a vector

$$\text{norm of vector a} \equiv \|a\| = \sqrt{a_1^2 + a_2^2 + a_3^2 \ldots + a_n^2}$$

```
>> a = [-1;-5;0;3;7;8]

a =

    -1
    -5
     0
     3
     7
     8

>>norm(a)

ans =

   12.1655
```

Cross Product




```
>> J = [2;1;-3];
>> K = [0;-2;4];
>>cross(J,K)

ans =

    -2
    -8
    -4

>>cross(K,J)

ans =

     2
     8
     4
```

Moment of a force $\mathbf{F}_b$ applied at point 'b' around point 'a' is given as : $\vec{\mathbf{M}}_a = \vec{\mathbf{r}}_{ab} \times \vec{\mathbf{F}}_b$.

Force on a moving charged particle in a magnetic field is: $F_B = q\vec{v} \times \vec{B}$

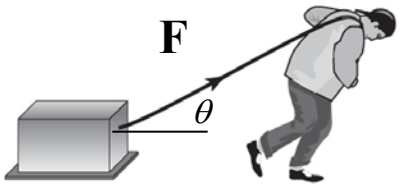
Dot Product (Inner Product)

- The dot product of two vectors is a scalar
- The vectors must have exactly the same number of elements

$$\mathbf{x} \cdot \mathbf{y} = x_1 y_1 + x_2 y_2 + \cdots x_n y_n = \mathbf{y} \cdot \mathbf{x}$$

- For vectors in 2D and 3D

$$\mathbf{x} \cdot \mathbf{y} = ||\mathbf{x}|| \; ||\mathbf{y}|| \cos\theta$$



A person pulling a load produces a tension force in the cable.

e.g. Mechanical Work, $W = \vec{\mathbf{F}} \cdot \vec{\mathbf{d}} = \|F\| \; \|d\| \cos\theta$

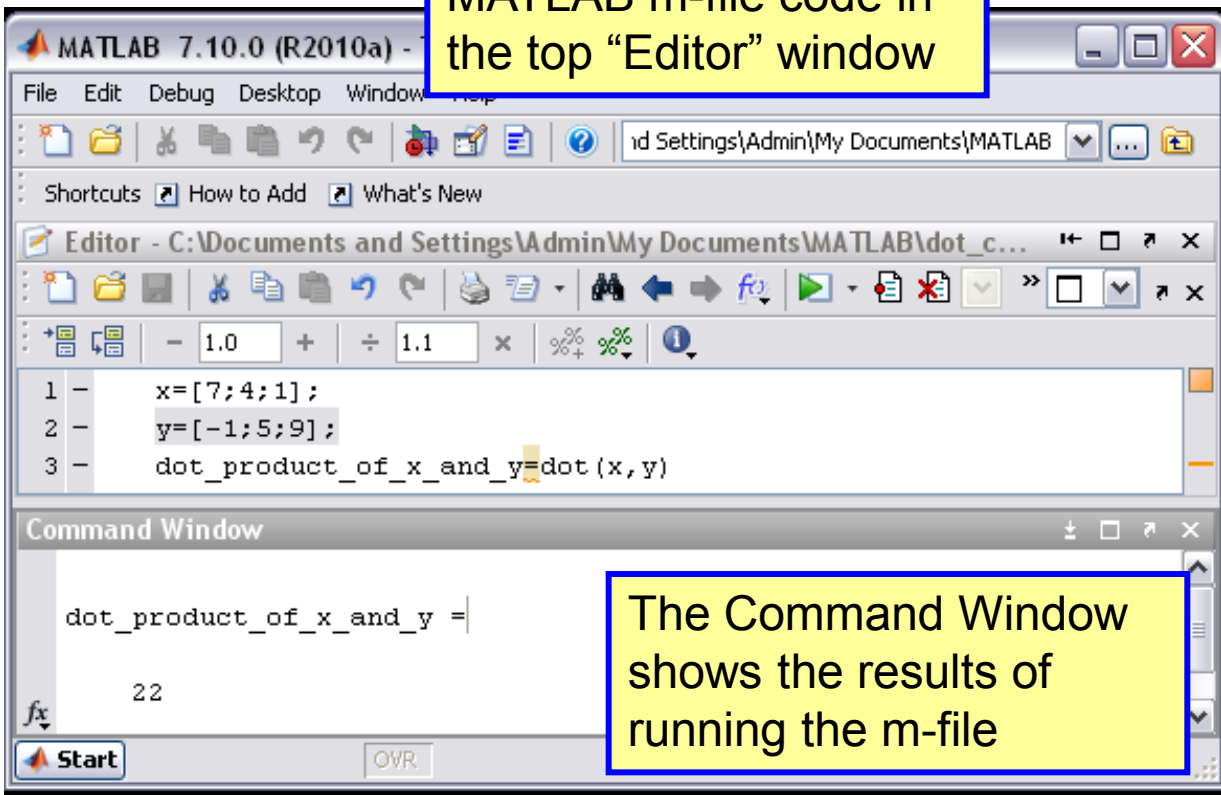
Dot Product Example

- Check the following dot product result

$$\mathbf{x} = \begin{bmatrix} 7 \\ 4 \\ 1 \end{bmatrix}, \quad \mathbf{y} = \begin{bmatrix} -1 \\ 5 \\ 9 \end{bmatrix}$$

$$\mathbf{x} \cdot \mathbf{y} = (7)(-1) + (4)(5) + (1)(9)$$

$$= 22$$

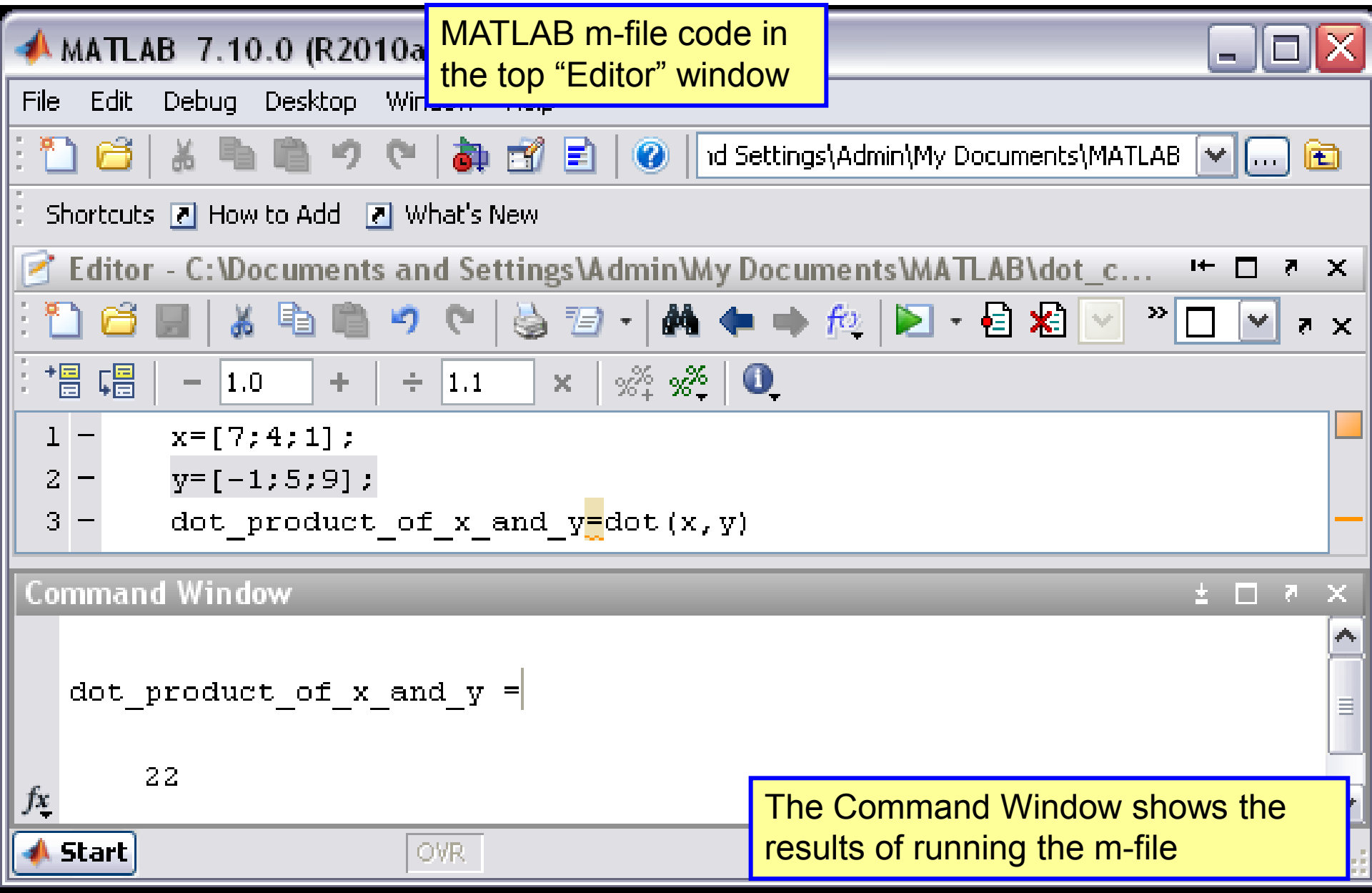


MATLAB m-file code in the top "Editor" window

The Command Window shows the results of running the m-file

The next slide has a magnified view of the code.

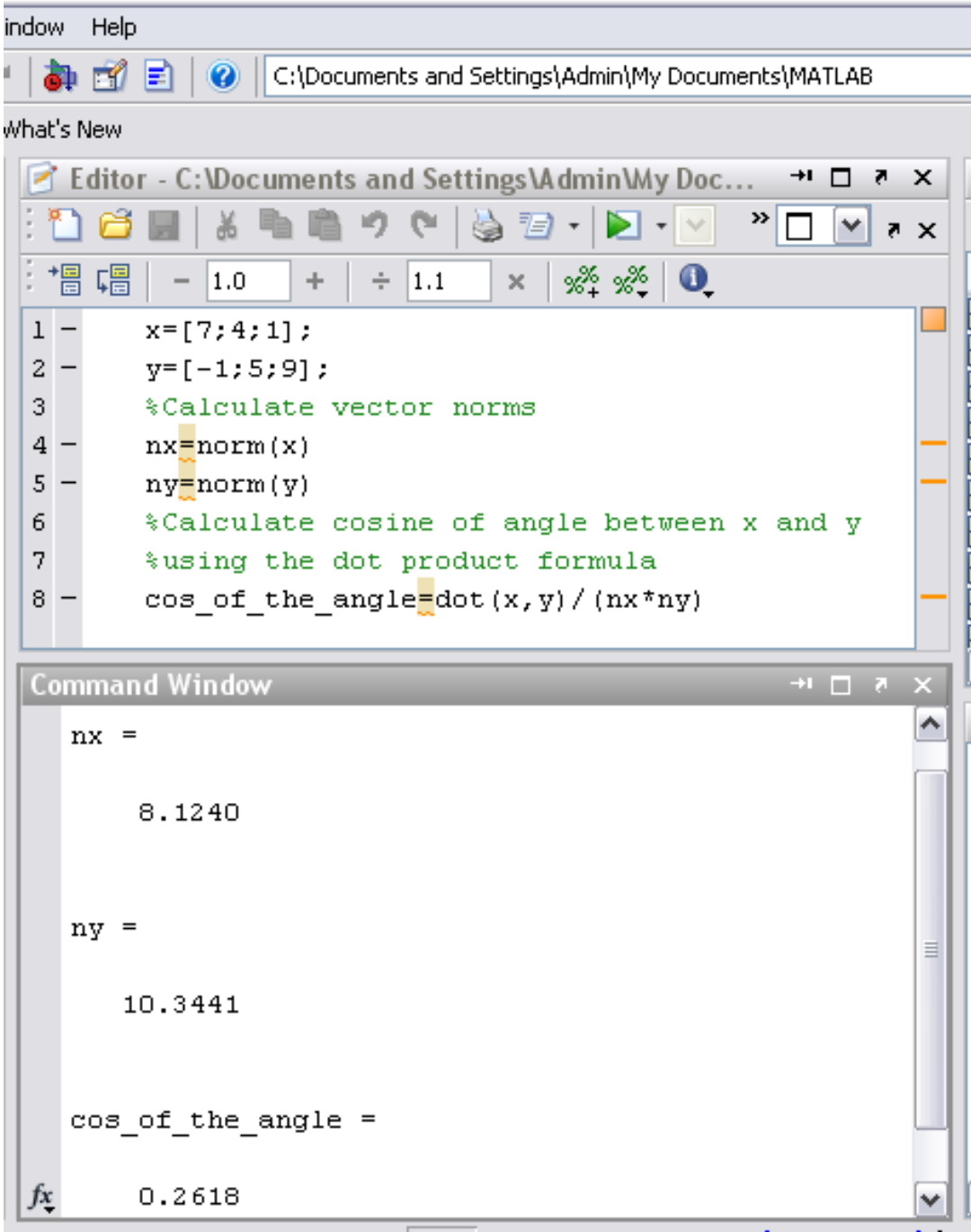
Dot Product Example



Calculate the Cosine of the Angle between the vectors x and y

$$\cos(\theta) = \frac{\mathrm{x} \cdot \mathrm{y}}{\|x\| \ \|y\|}$$

The next slide has a magnified view of the code.



indow Help

C:\Documents and Settings\Admin\My Documents\MATLAB

What's New

Editor - C:\Documents and Settings\Admin\My Doc...

1.0 1.1

```
1 -     x=[7;4;1];
2 -     y=[-1;5;9];
3       %Calculate vector norms
4 -     nx=norm(x)
5 -     ny=norm(y)
6       %Calculate cosine of angle between x and y
7       %using the dot product formula
8 -     cos_of_the_angle=dot(x,y)/(nx*ny)
```

$$\cos(\theta) = \frac{x \cdot y}{\|x\| \ \|y\|}$$

The Dot Product and the Correlation Coefficient

$$\cos(\theta) = \frac{\mathrm{x} \cdot \mathrm{y}}{\|x\| \ \|y\|} = \frac{x_1 y_1 + x_2 y_2 + \ldots x_n y_n}{\sqrt{x_1^2 + x_2^2 \ldots + x_n^2}\sqrt{y_1^2 + y_2^2 \ldots + y_n^2}}$$

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{(n-1)s_x s_y}$$

$$s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

$$s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \overline{y})^2}$$

Command Window

```
correlation_of_xy =

   -0.9934


correlation_of_XmYm =

   -0.9934


cos_of_the_angle =

   -0.9934
```

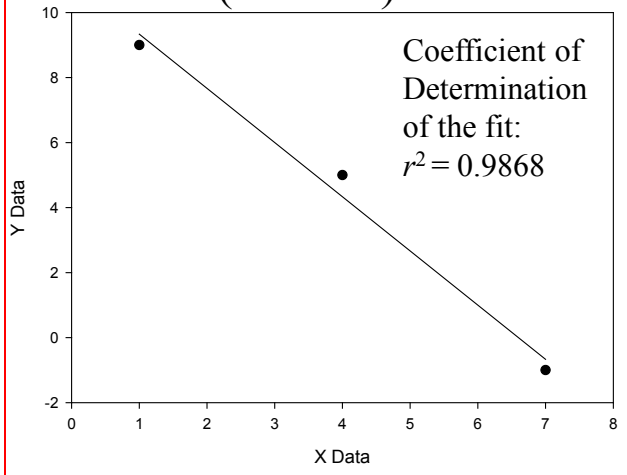
Current Folder: C:\Doc

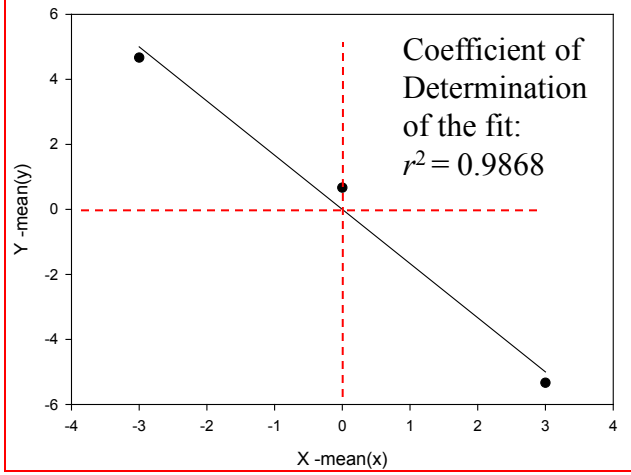
Editor - C:\Documents and

1.0

```
3 —   x=[7;4;1];
4 —   y=[-1;5;9];
5 —   correlation_of_xy=corr(x,y)
6     %Transform x and y to mean
7 —   Xm=x-mean(x);
8 —   Ym=y-mean(y);
9     %Calculate correlation coeff
10 —  correlation_of_XmYm = corr(Xm,Ym)
11    %Calculate vector norms
12 —  nXm=norm(Xm);
13 —  nYm=norm(Ym);
14    %Calculate cosine of angle between Xm and
15    % Ym using the dot product formula
16 —  cos_of_the_angle=dot(Xm,Ym)/(nXm*nYm)
```

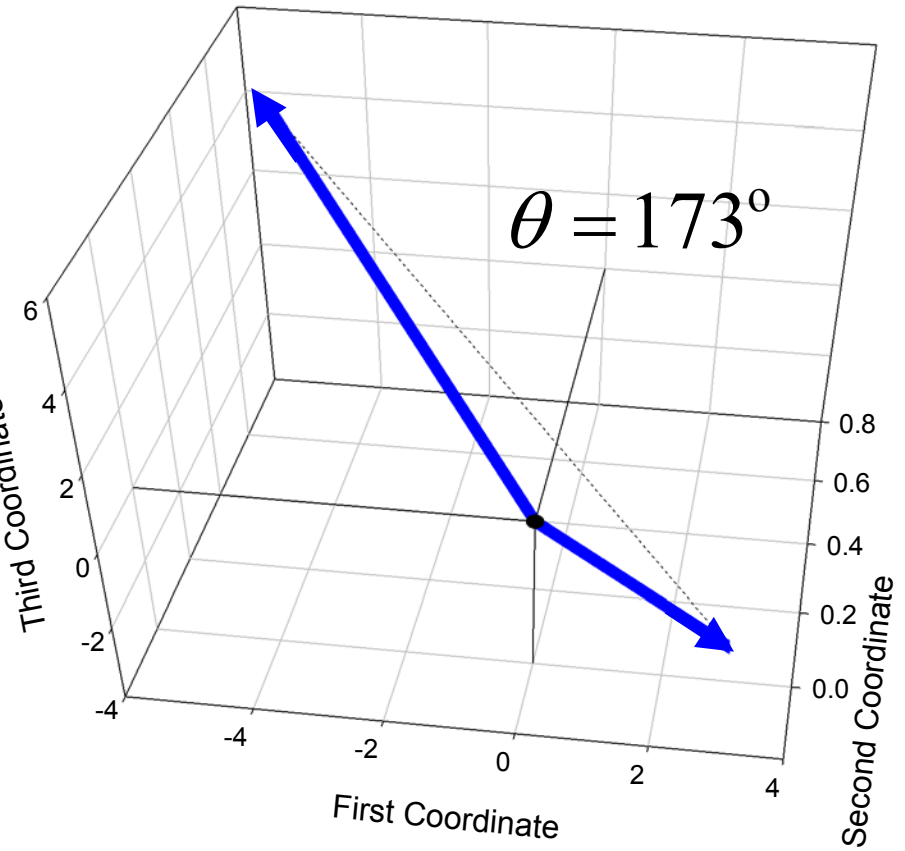
$r^2 = (-0.9934)^2 = 0.9868$





$$x - \text{mean}(x) = \begin{bmatrix} 7 \\ 4 \\ 1 \end{bmatrix} - 4 = \begin{bmatrix} 3 \\ 0 \\ -3 \end{bmatrix}$$

$$y - \text{mean}(y) = \begin{bmatrix} -1 \\ 5 \\ 9 \end{bmatrix} - 4.333 = \begin{bmatrix} -5.333 \\ 0.667 \\ 4.667 \end{bmatrix}$$



$$\cos\theta = -0.9934 \Rightarrow \theta = 173^{\circ}$$

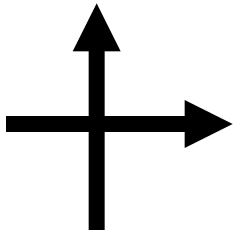
The angle between these two vectors is 173°

Correlation Coefficient and the Dot Product

- The correlation coefficient is the cosine of the ‘angle’ between the vectors:

  x-mean(x) and y-mean(y).

$r = 1$

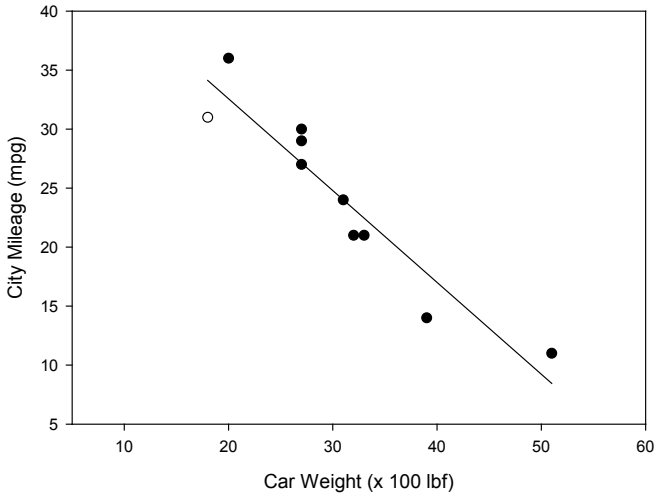


$r = 0$

$r = -1$

Recall the Car Mileage example

Fuel Consumption versus Car Weight



$$\hat{y} = -(0.8 \pm 0.1)x + (48 \pm 3) \quad [\text{mpg}]$$

$$r^2 = 0.89 \quad \Leftarrow \quad (-0.9425)^2$$

File Edit Debug Desktop Window Help

C:\Documents and Settings\Admin\M

Shortcuts How to Add What's New

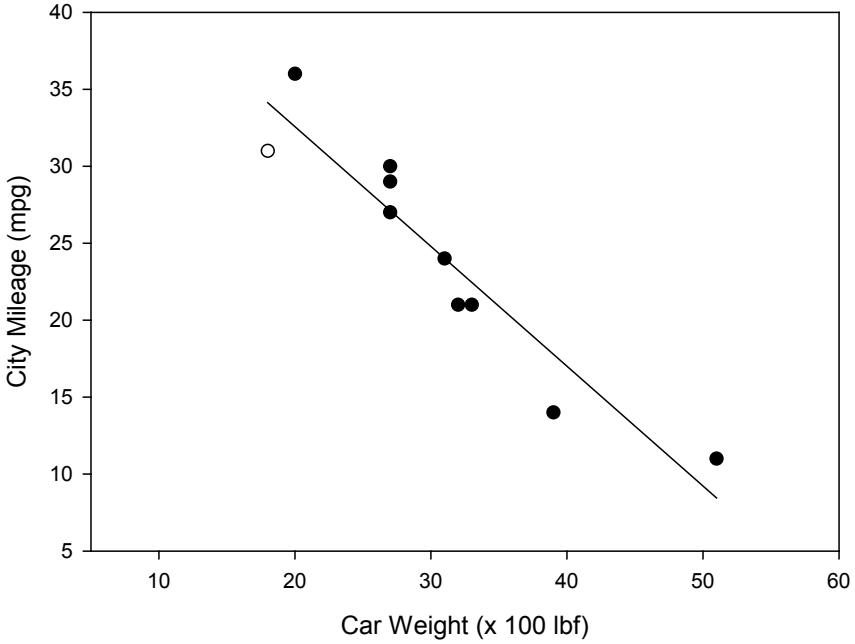
Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\do...

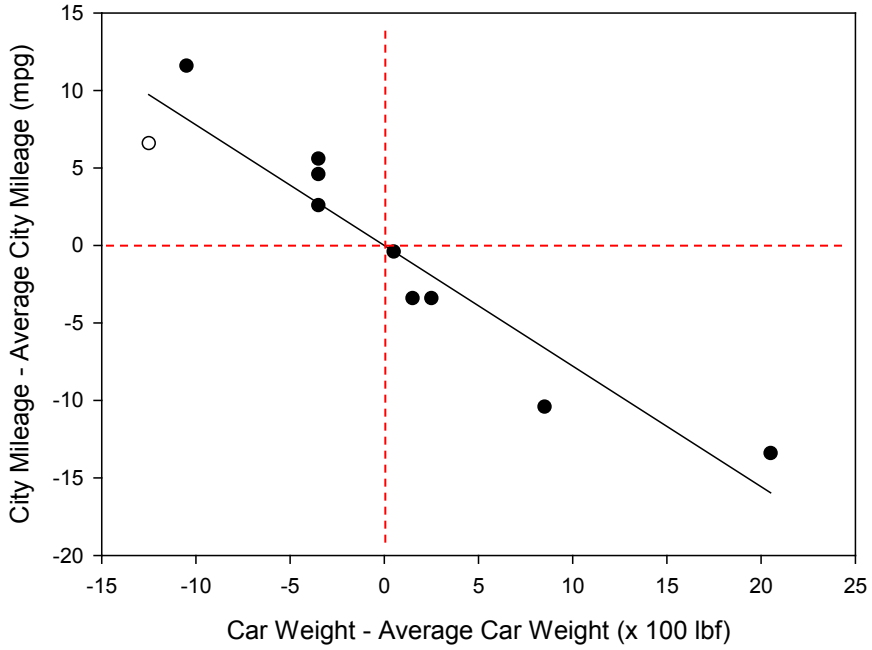
```
1 -  x=[18; 20; 27; 27; 27; 31; 32; 33; 39; 51];
2 -  y=[31; 36; 30; 27; 29; 24; 21; 21; 14; 11];
3 -  correlation_of_xy=corr(x,y)
4    %Transform x and y to mean
5 -  Xm=x-mean(x);
6 -  Ym=y-mean(y);
7    %Calculate correlation coeff
8 -  correlation_of_XmYm = corr(Xm,Ym)
9    %Calculate vector norms
10 - nXm=norm(Xm);
11 - nYm=norm(Ym);
12   %Calculate cosine of angle between Xm and
13   % Ym using the dot product formula
14 - cos_of_the_angle=dot(Xm,Ym)/(nXm*nYm)
```

Weight
Mileage

Command Window

```
correlation_of_xy =

   -0.9425


correlation_of_XmYm =

   -0.9425


cos_of_the_angle =

   -0.9425
```


City Mileage (mpg)
Car Weight (x 100 lbf)
40
35
30
25
20
15
10
5
10
20
30
40
50
60


City Mileage - Average City Mileage (mpg)
Car Weight - Average Car Weight (x 100 lbf)
15
10
5
0
-5
-10
-15
-20
-15
-10
-5
0
5
10
15
20
25

Matrix Operations in MATLAB

Assigning Matrices

- [ ] used to declare matrices and vectors

```
A = [1, 2; 3, 4]
```

- Matrix transpose

```
A'
```

- ( ) used to denote elements of a matrix/vector

```
A(1,2)=2
```

$$A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

$$A' = \begin{bmatrix} 1 & 3 \\ 2 & 4 \end{bmatrix}$$

Full-Colon Operator

- Use a full colon to pick out rows or columns

```
>> A = [1, 2, 3; 4, 5, 7; 8, 9, 10]

A =

    1    2    3
    4    5    7
    8    9   10
```

```
>> A(:,2)

ans =

     2
     5
     9

>> A(3,:)

ans =

     8     9    10
```

Full-Colon Operator

- Use a full colon to indicate a range

```
>> A = [1, 2, 3; 4, 5, 7; 8, 9, 10]

A =

     1     2     3
     4     5     7
     8     9    10

>> A(1:2,2:3)

ans =

     2     3
     5     7
```

Full-Colon Operator

- Easily create arrays with a fixed step size

```
>> [1:2:10]

ans =

     1     3     5     7     9

>> [0:0.5:2.5]

ans =

         0    0.5000    1.0000    1.5000    2.0000    2.5000
```

Operations on Matrices

- Addition and subtraction

```
>> A + B
```

- Multiplication

```
>> A*B
```

- Inversion

```
>>inv(A)
```

- Powers (works for what kind of matrices?)

```
>> A^4
```

Special Matrices

- Identity matrix

```
>> eye(4)
ans =
     1     0     0     0
     0     1     0     0
     0     0     1     0
     0     0     0     1
```

Special Matrices

- Zeros (a matrix of all zeros)

```
>> zeros(3,2)
ans =
     0     0
     0     0
     0     0
```

- Ones (a matrix of all ones)

```
>> ones(4,19)
```

Element-Wise Operations on Matrices

- You can perform element-wise operations rather than standard matrix operations
  - Matrices must have the same dimension
- Multiply element-by-element

```
>> A.*B
```

- Raise each element of the matrix to a Power

```
>> A.^4
```

- Divide element-by-element

```
>> A./B
```

Programming in MATLAB
- Powerful yet simple programming language with very little syntax
- Many built-in functions, saves you having to code your own but can be slow in some cases
- Able to do matrix manipulations
- Can develop two types of m-files (programs)
    - Scripts for running a sequence of commands

Practice

Function m-files
- Can accept arguments (inputs) and return outputs
- Uses local variables that do not appear in the MATLAB Workspace
- What happens in the function file stays in the function file.

Script m-files
- A sequence of commands (ex. you woult type them at a prompt)
- Cannot accept arguments (functions can have arguments)
- Uses the MATLAB workspace as its working environment

- In a previous lecture we found the matrix equations for some large systems (e.g., trusses)
  - Use MATLAB to solve these
- See the support material on WebCT

For Loops:
- Repeat a set of commands a specified number of times
- Example

```
for variable = expression
    statements
end

%create a horizontal vector with 5 components
for i=1:5
    x(i) = i/5;
end
%create a transpose
x'
```

Programming in MATLAB

- Powerful, yet simple programming language
  - Very little syntax
- Many built-in functions
  - Saves you having to code your own
  - Can be slow, in some cases …
- Able to do matrix manipulations
- Can develop two types of m-files (programs)
  - **Scripts** for running a sequence of commands
  - **Functions** for creating new tools (functions)

Script m-Files

- A sequence of commands
  - For example, as you would type them at a prompt
- Cannot accept arguments
  - Functions can have arguments
- Uses the MATLAB Workspace as its working environment
  - Global variables
- We have seen examples already

Function m-Files

- Creates a new MATLAB function
- Can accept arguments (inputs) and return outputs
- Uses local variables that do not appear in the MATLAB Workspace
- We will look at function files later

For Loops

- Repeat a set of commands a specified number of times:

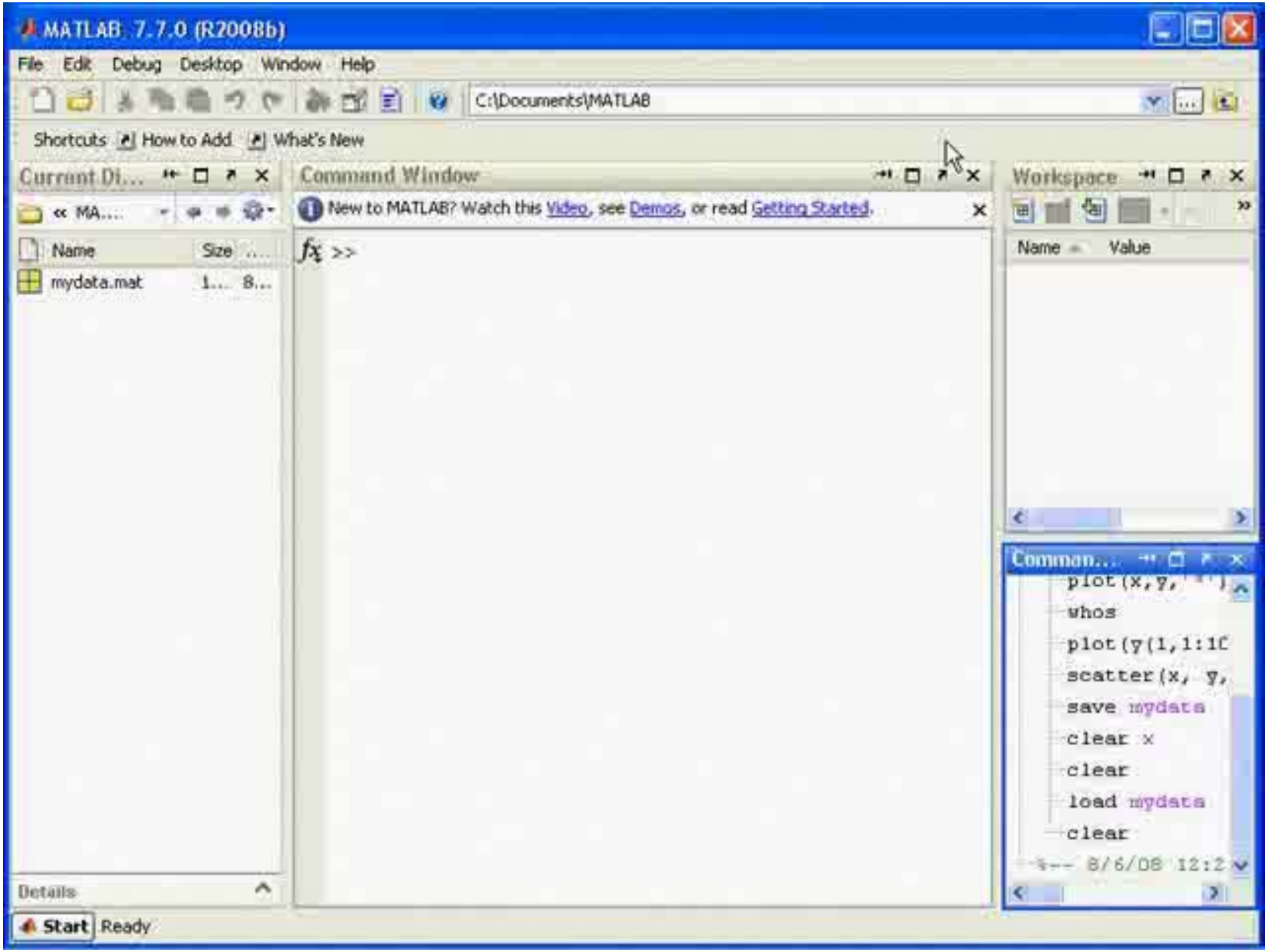
```
for variable = expression
   statements
end
```

```
for i=1:5
    x(i)=i/5;
end
```

```
x'
```

Writing a MATLAB Program

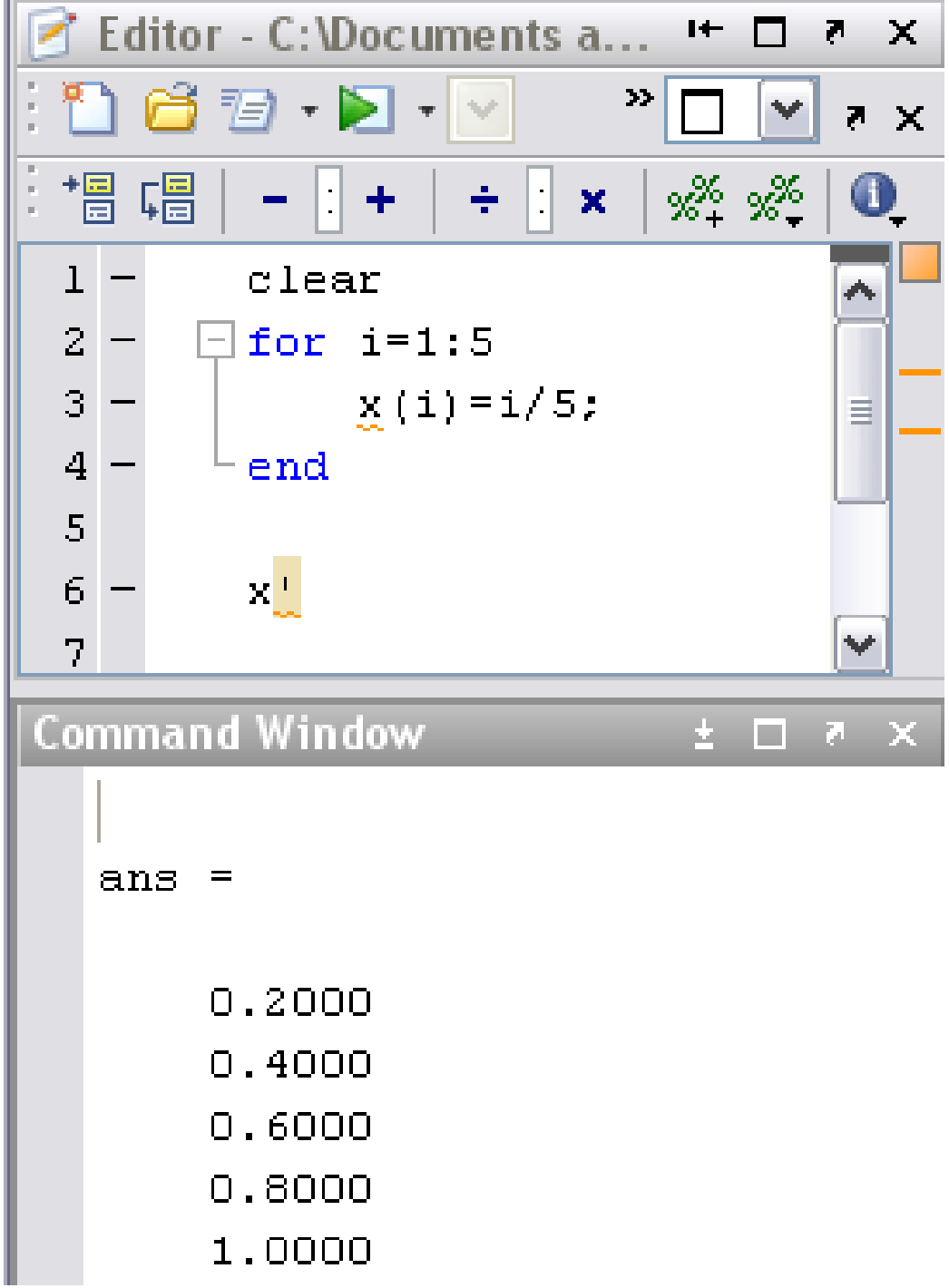
http://www.mathworks.com/demos/matlab/writing-a-matlab-program-matlab-video-tutorial.html



For Loops

- Repeat a set of commands a specified number of times:

```
for variable = expression
   statements
end
```



Taylor Expansion for e^x

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots$$

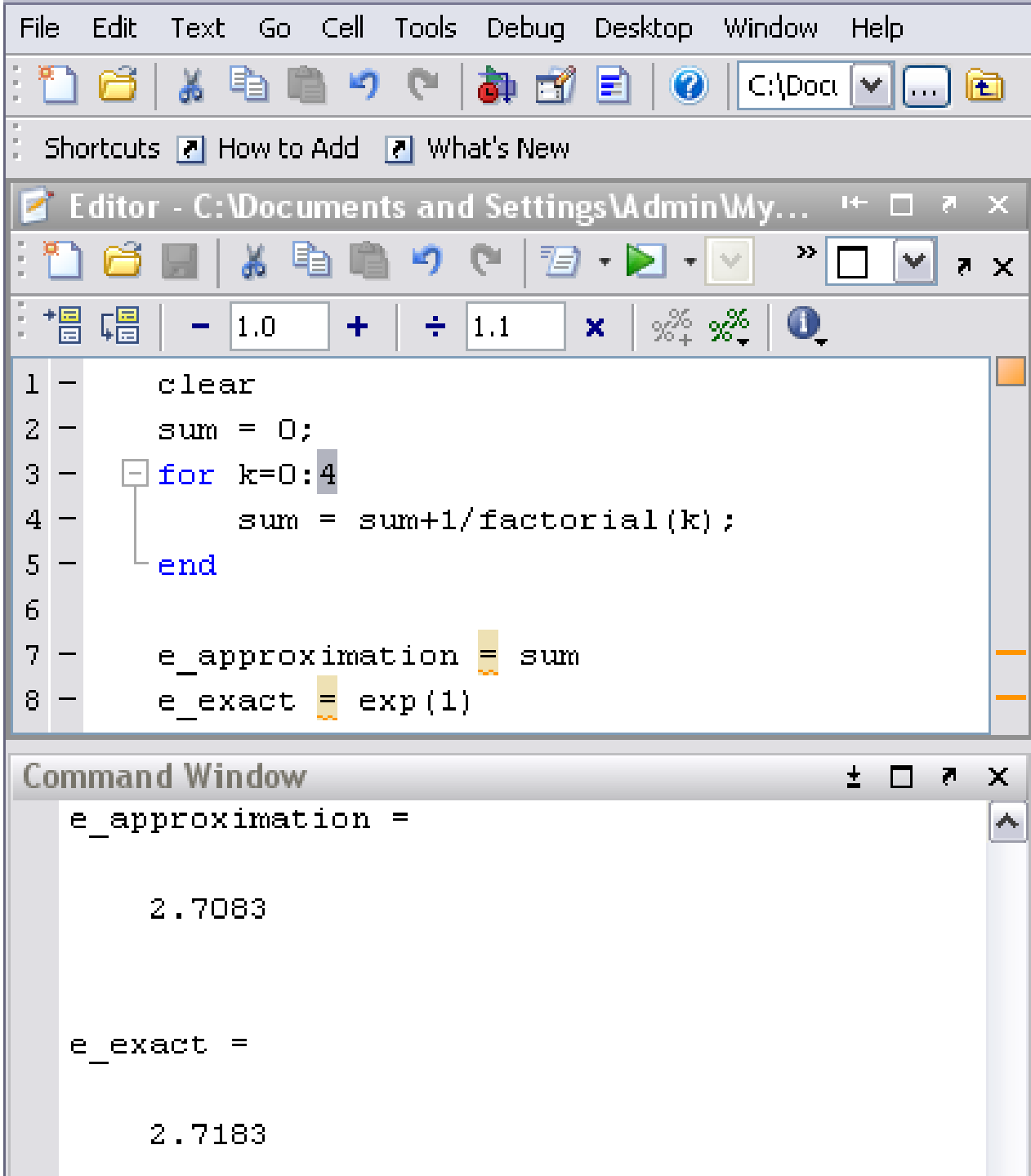
$$e^1 = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \ldots$$

```
sum = 0;
for k=0:4
    sum = sum+1/factorial(k);
end
```

4! = (4)(3)(2)(1)
x! = x factorial

$$e^{x} = 1 + \frac{x}{1!} + \frac{x^{2}}{2!} + \frac{x^{3}}{3!} + \frac{x^{4}}{4!} + \ldots$$

$$e^{1} = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \ldots$$



Nested Loops

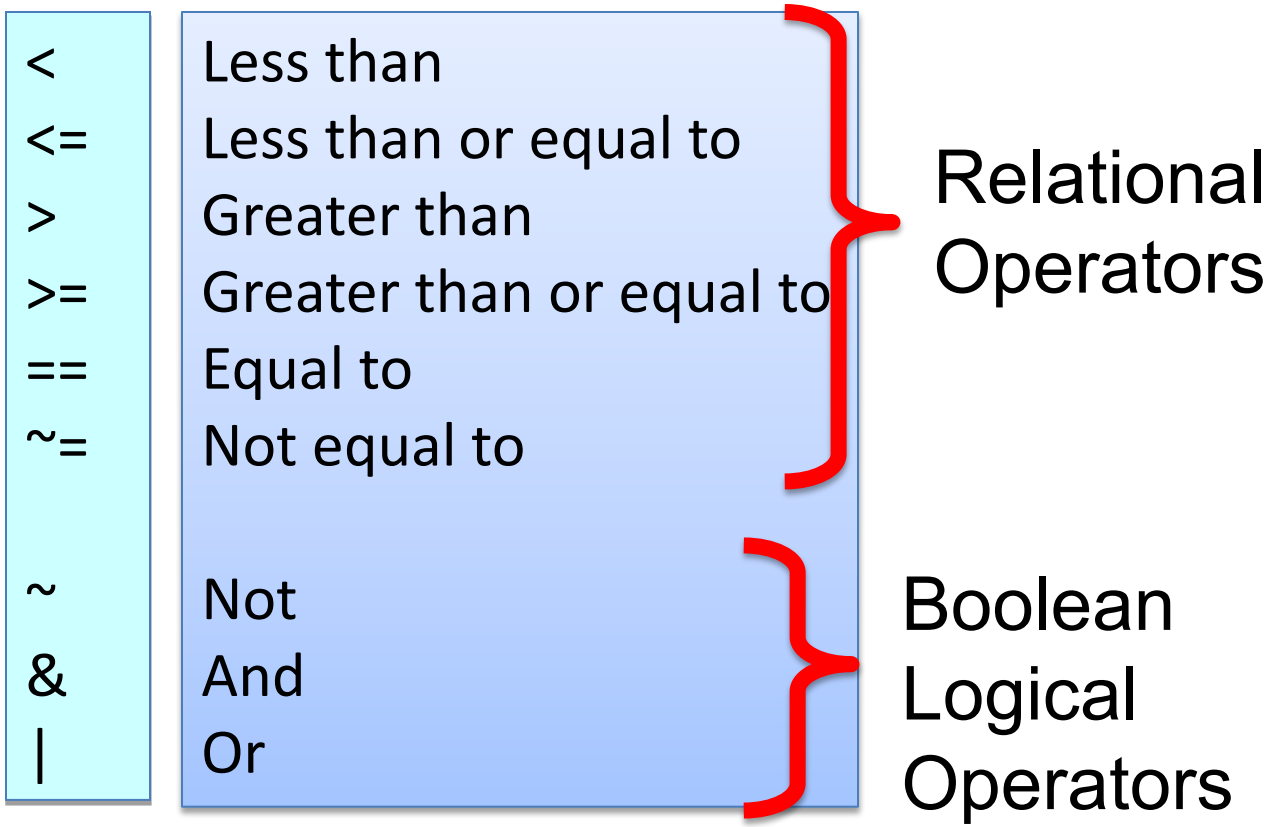
- You can also create nested loops

```
1 -    clear
2 -    for i=1:5
3 -        for j=1:5
4 -            A(i,j)=10*i+j;
           end
       end

8 -    A
```

Command Window

```
A =

    11    12    13    14    15
    21    22    23    24    25
    31    32    33    34    35
    41    42    43    44    45
    51    52    53    54    55
```

Relational and Logical Operators



Relational and Logical Operators

- Used when comparing and selecting values
- Used to determine if an expression will evaluate to **true** or **false**
- Used in **if** statements and **while** loops
- Used whenever a logical decision must be made

If Statements

- Executes the statements if the expression is **true**
  - Use the relational or logical operators
- Otherwise, skips the statements
- Statements can be any code or function
  - Can have multiple statements

```
if (expression)
   statements
end
```

Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\Age.m

```
1 -    clear
2      % This program tells the user whether he/she is old enough to get a
3      % drivers license.
4 -    disp('Are you old enough to get a driver''s license?');
5 -    Your_Age = input('Type your age (years): ' );
6
7 -    if Your_Age >= 16
8 -        disp([num2str(Your_Age),' is old enough to get a driver''s license']);
9 -    end
```

Command Window

```
Are you old enough to get a driver's license?
Type your age (years): 22
22 is old enough to get a driver's license
Are you old enough to get a driver's license?
Type your age (years): 11
```

Notice how you need to double apostrophes (‘’)

In the second example, when you type 11 for Your_Age, the program simply ends with no output.

Comments

- Use comments to clarify your code
  - VERY important for communicating your work
- Comments preceded by a %

If-Else Statements

- One of the two statements is always executed

```
if (expression)
   statements
else
   statements
end
```

Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\Age.m

```
1 -    clear
2      % This program tells the user whether he/she is old enough to get a
3      % drivers license.
4 -    disp('Are you old enough to get a driver''s license?');
5 -    Your_Age = input('Type your age (years): ' );
6
7 -    if Your_Age >= 16
8 -        disp([num2str(Your_Age),' is old enough to get a driver''s license']);
9 -    else
10 -       disp([num2str(Your_Age),' is not old enough to get a driver''s license']);
11 -   end
```

Command Window

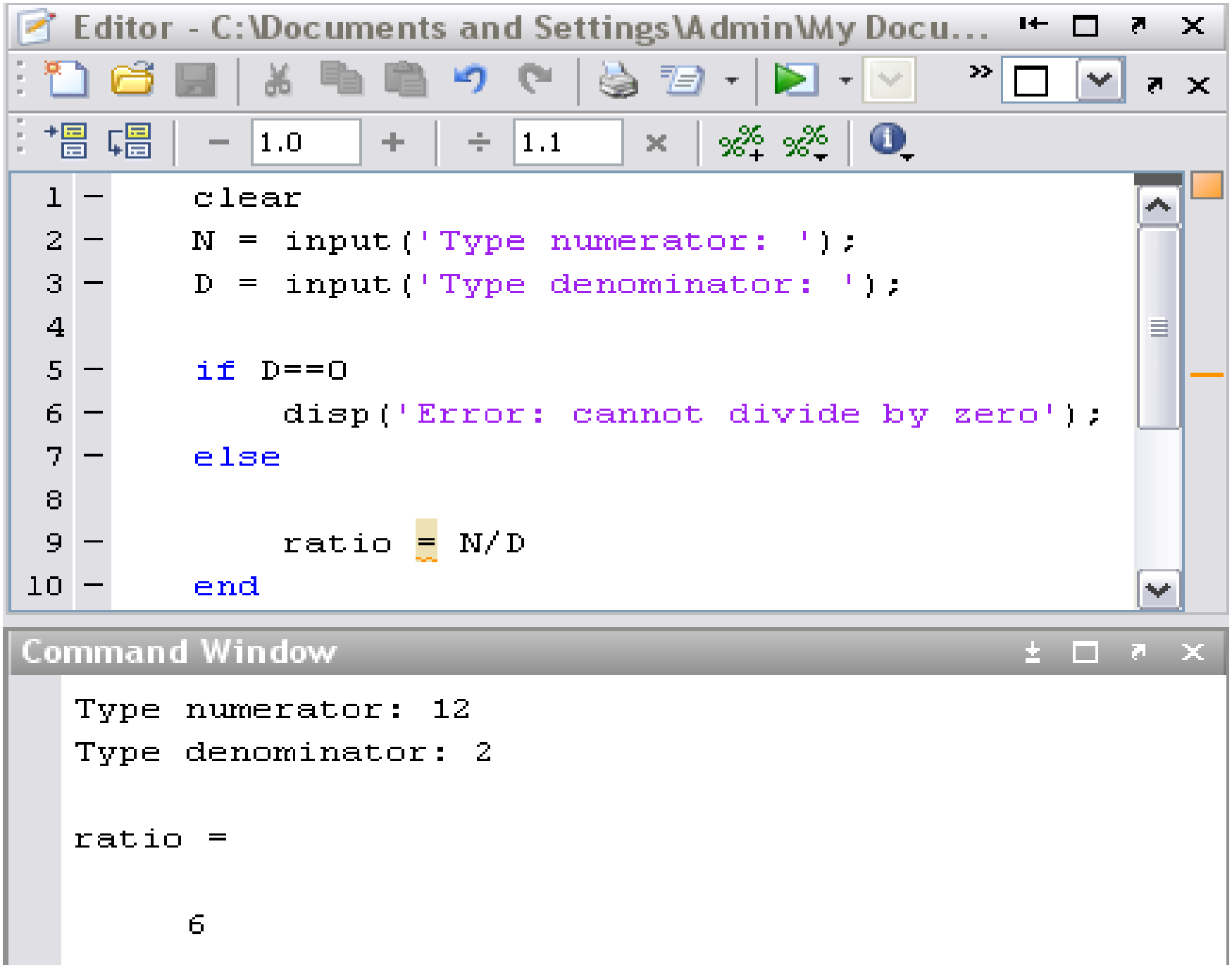
```
Are you old enough to get a driver's license?
Type your age (years): 22
22 is old enough to get a driver's license
Are you old enough to get a driver's license?
Type your age (years): 11
11 is not old enough to get a driver's license
```

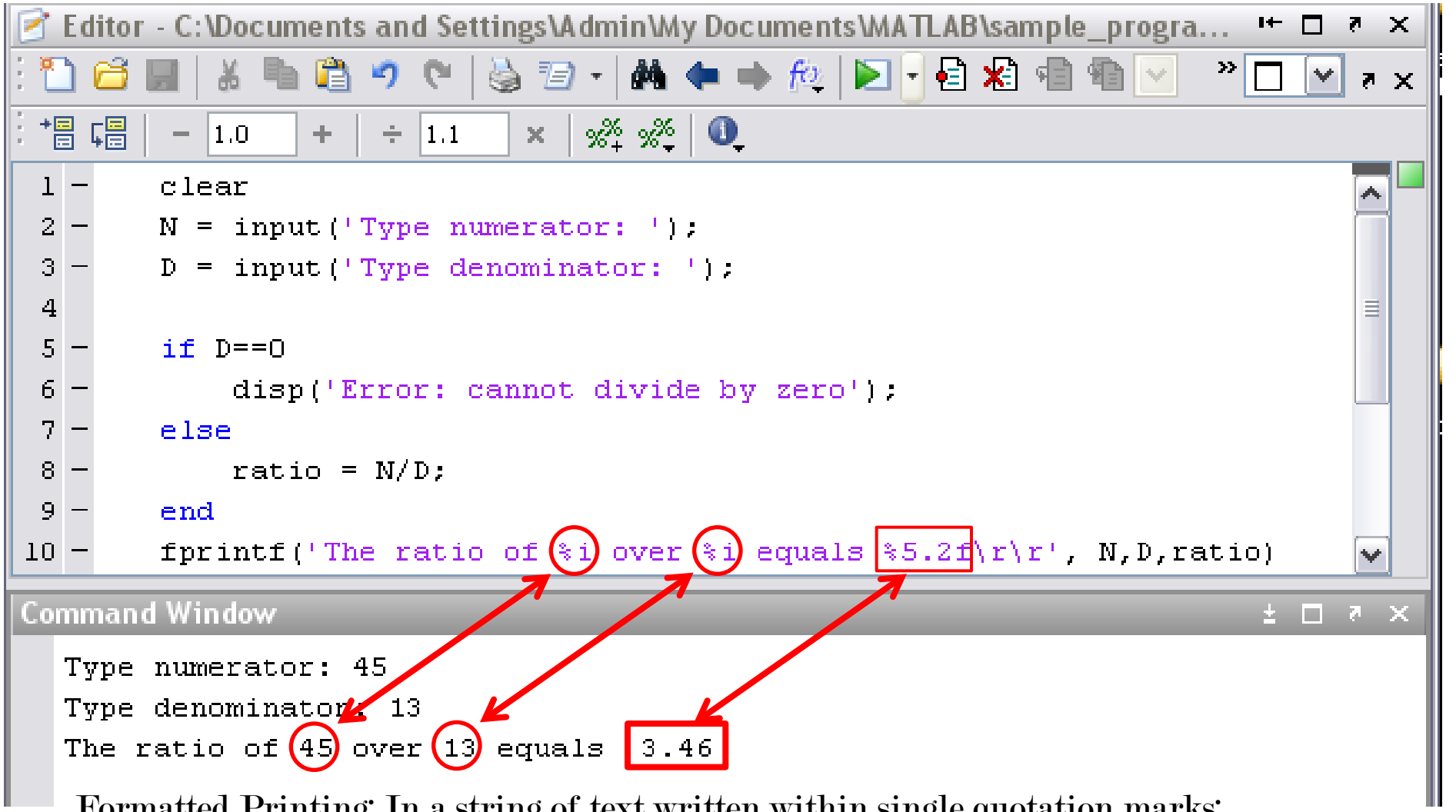
Always Include Error Messages!

```
1 -     clear
2 -     N = input('Type numerator: ');
3 -     D = input('Type denominator: ');
4
5 -     if D==0
6 -         disp('Error: cannot divide by zero');
7 -     else
8
9 -         ratio = N/D
10 -    end
```

Command Window

```
Type numerator: 5
Type denominator: 0
Error: cannot divide by zero
```


Editor - C:\Documents and Settings\Admin\My Docu...
1.0
1.1
1 clear
2 N = input('Type numerator: ');
3 D = input('Type denominator: ');
4
5 if D==0
6 disp('Error: cannot divide by zero');
7 else
8
9 ratio = N/D
10 end
Command Window
Type numerator: 12
Type denominator: 2
ratio =
6



Formatted Printing: In a string of text written within single quotation marks:

% followed immediately with a formatting code means place the corresponding value listed at the end of the command in this location in the string using the specified format.

Format for output: 'i' for integer; '5.2f' for floating point number of five characters with 2 digits to the right of the decimal point.

(\r means carriage return, and is the same as \n which means new line)

Elseif (and MATLAB Help)

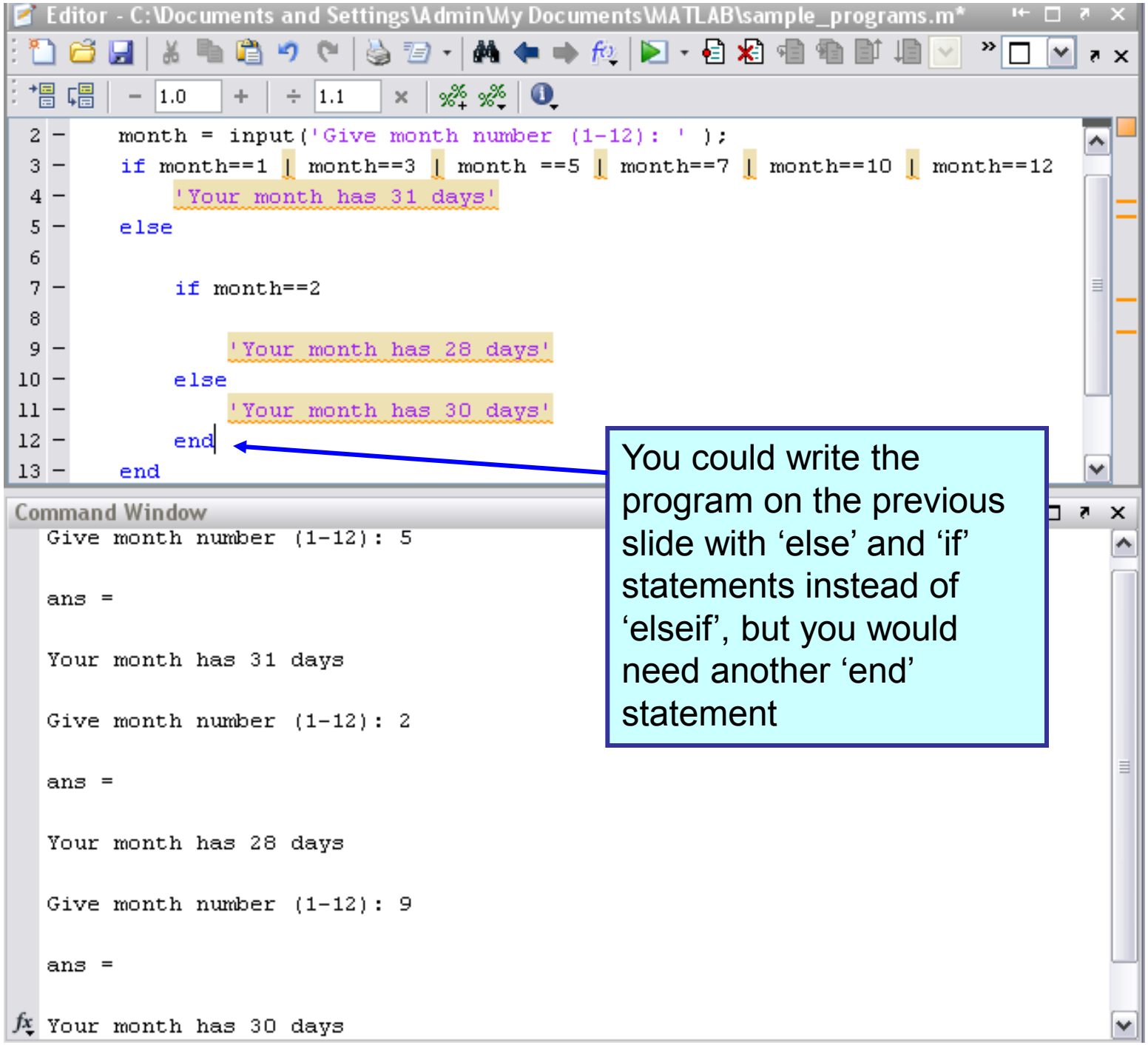
```
>> help elseif
 ELSEIF IF statement condition.
    ELSEIF is used with IF. The statements after the ELSEIF are
    executed if the expression is true and all the preceding IF and
    ELSEIF expressions are false. An expression is considered true
    if the real part has all non-zero elements.

    ELSEIF does not need a matching END, while ELSE IF does.

    The general form of the IF statement is
       IF expression
         statements
       ELSEIF expression
         statements
       ELSE
         statements
       END

    See also if, else, end.

    Reference page in Help browser
       doc elseif
```

Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\sample_programs.m

```
1  -    clear
2  -    month = input('Give month number (1-12): ' );
3
4  -    if month==1 | month==3 | month ==5 | month==7 | month==10 | month==12
5  -        'Your month has 31 days'
6  -    elseif month==2
7
8  -        'Your month has 28 days'
9  -    else
10 -        'Your month has 30 days'
11 -    end
```

Command Window

```
Give month number (1-12): 3

ans =

Your month has 31 days

Give month number (1-12): 2

ans =

Your month has 28 days

Give month number (1-12): 4

ans =

Your month has 30 days
```


Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\sample_programs.m*
2 month = input('Give month number (1-12): ');
3 if month==1 | month==3 | month ==5 | month==7 | month==10 | month==12
4 'Your month has 31 days'
5 else
6
7 if month==2
8
9 'Your month has 28 days'
10 else
11 'Your month has 30 days'
12 end
13 end
Command Window
Give month number (1-12): 5
ans =
Your month has 31 days
Give month number (1-12): 2
ans =
Your month has 28 days
Give month number (1-12): 9
ans =
Your month has 30 days
You could write the program on the previous slide with 'else' and 'if' statements instead of 'elseif', but you would need another 'end' statement

Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\divisi...

```
1 -    clear
2 -    number = input('Give an integer: ' );
3 -    remainder2 = rem(number,2);
4 -    remainder3 = rem(number,3);
5
6 -    if remainder2==0 & remainder3==0
7 -        disp('Your number is divisible by both 2 and 3');
8 -    elseif remainder2==0
9 -        disp('Your number is divisible by 2 but not by 3');
10 -   elseif remainder3==0
11 -       disp('Your number is divisible by 3 but not by 2');
12 -   else
13 -       disp('Your number is not divisible by either 2 or 3');
14 -   end
15
```

Command Window

```
Give an integer: 8
Your number is divisible by 2 but not by 3
Give an integer: 27
Your number is divisible by 3 but not by 2
Give an integer: 6
Your number is divisible by both 2 and 3
Give an integer: 11
Your number is not divisible by either 2 or 3
```

While Loops

- Repeat a set of commands while a condition holds **true (1)**
  - Tests the condition before action is taken
- Exits when the condition is found **false (0)**
- Used when you do not know how many times you will loop
- While loops carry an implicit danger: there is no guarantee, in general, that you will exit a while loop.

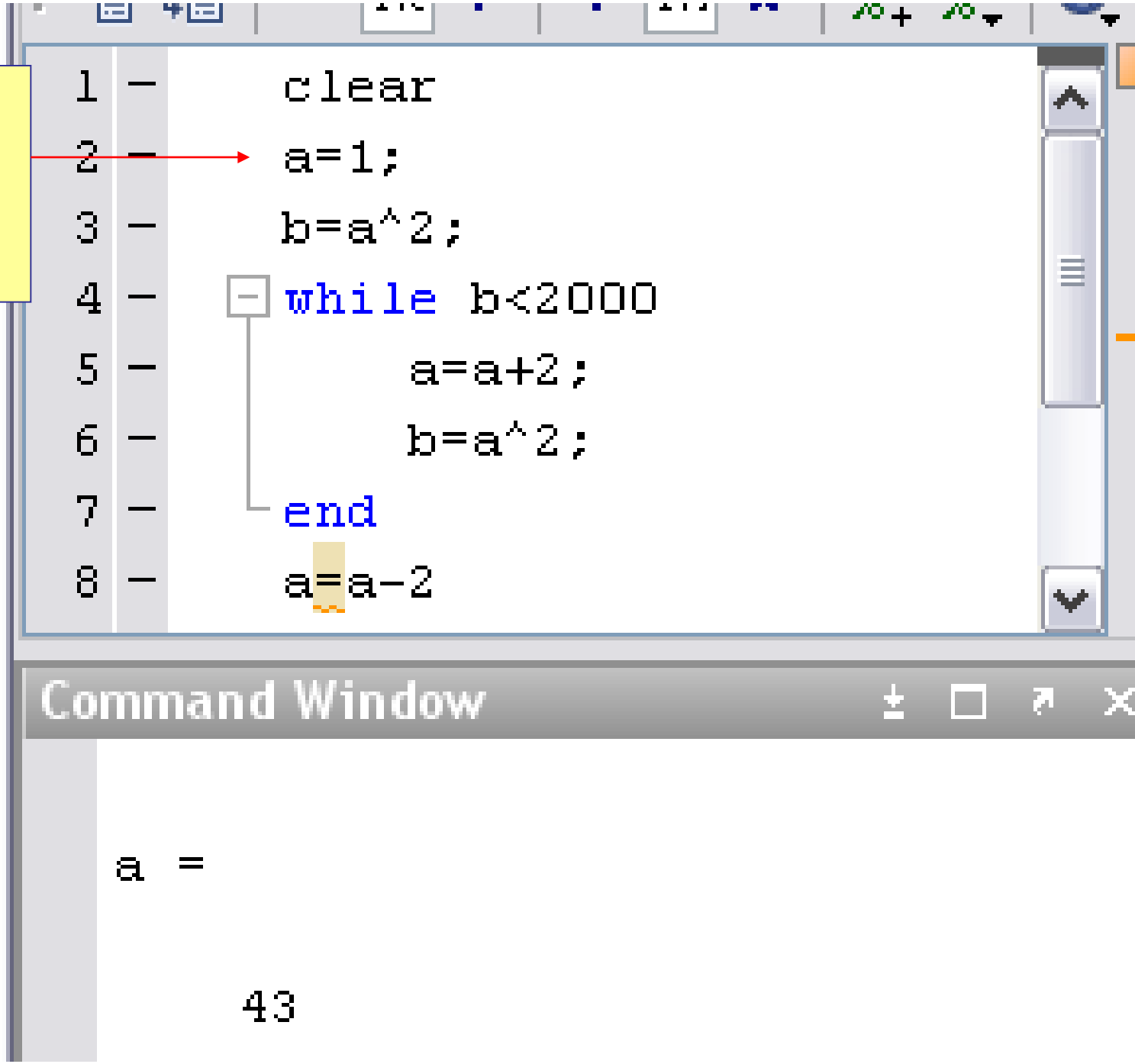
```
while expression
   statements
end
```

While Loops

```
a = 2;
b = a^2;
while b< 2000
    a = a + 2;
    b = a^2;
end
a = a - 2;
disp(a)
```

- Loop while the square of a number is less than a value of 2000
- Find the largest even integer with a square less than 2000

Changed to largest odd integer whose square is less than 2000.



The example codes so far were all written as script m-files

- Now we will look at function files
- In this case we create out own functions:
  - for instance, the computer has built-in functions like sin(x), cos(x), tan(x), log(x), which take an input, x, and return a value depending on what the function does.
- Our functions will be similar. They will have input(s), do something with the input(s), and output some value(s).

Function m-Files

- Syntax is given by:

```
function [out1, out2, ...]
  =funname(input1, input2, ...)
```

- The function name must be the same as the file name (funname.m)
  - The m-file begins with the function declaration
- Output arguments are specified in square brackets
- Use the function from the command prompt or in a script file, just like any other MATLAB function

Editor - C:\Documents and Settings\Admin\My Documents\MATLAB\f.m

```
1     % Filename: f.m
2     function y=f(x)
3 -   y=x.^2   +(1-exp(-2.*x)).^2;
4
```

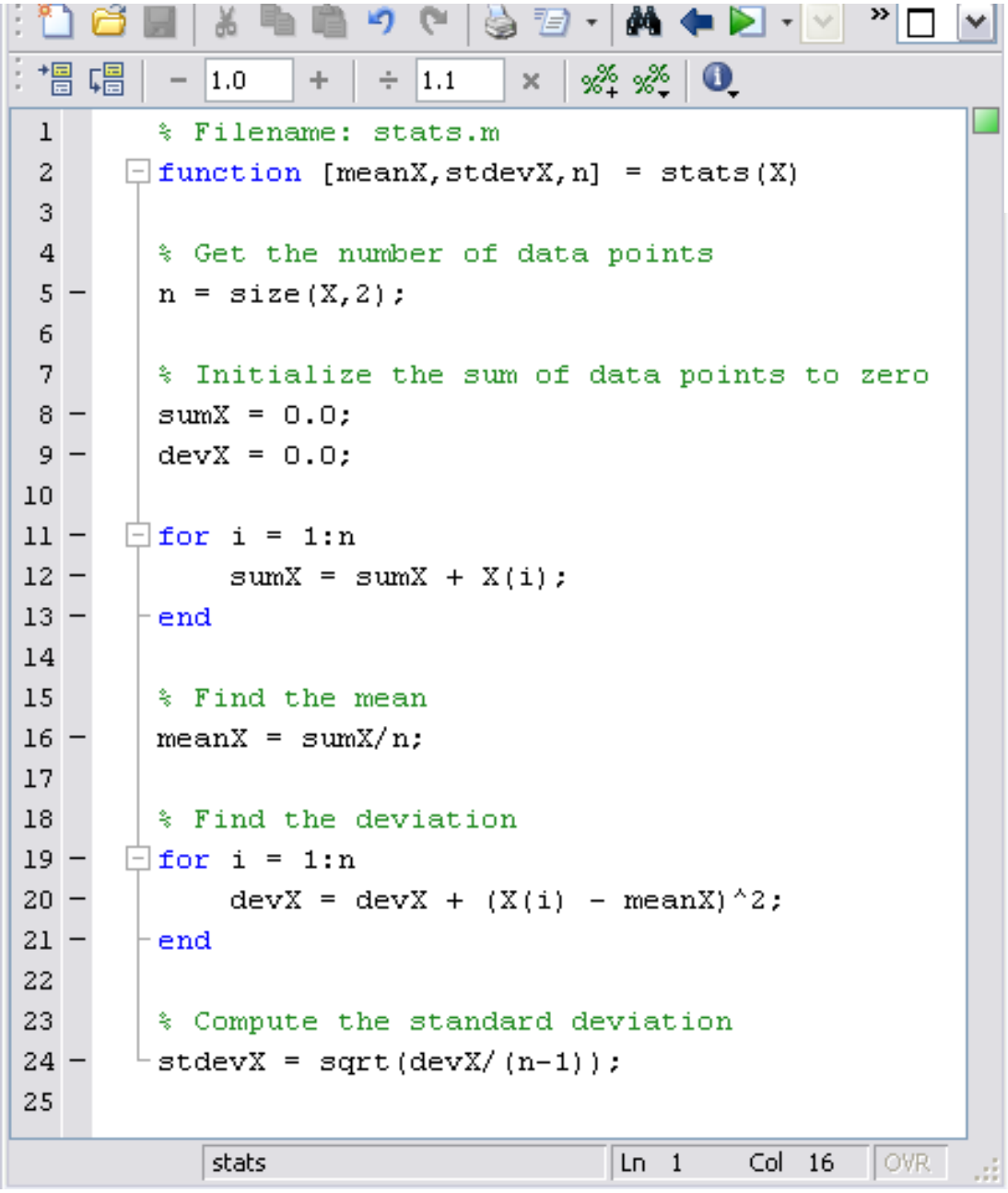
Notice the use of the dot in the formula

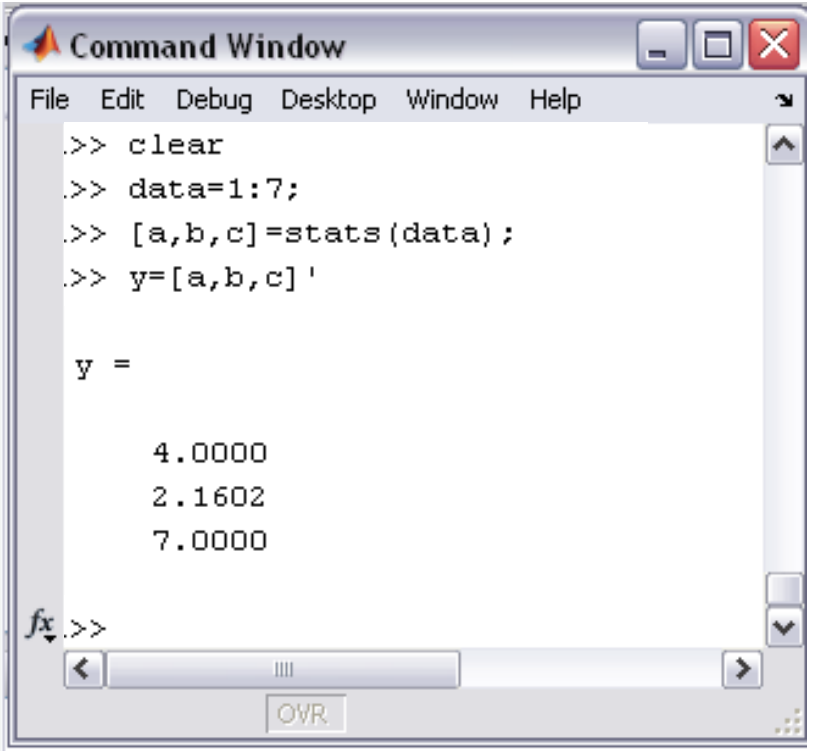
Command Window

```
>> x=1:6

x =

     1     2     3     4     5     6

>> w=f(x)

w =

    1.7476    4.9637    9.9950   16.9993   25.9999   37.0000
```

Notice that there is no clear command on the first line, as there was in the previous script files. This is because all variables inside functions are local to that function. It doesn't matter what symbols you use inside a function; for instance, they can be the same symbols you used in the program that called the function.

- On the next slide is a function that has a vector output: stats.m
- You read a vector in of any length, called ‘data’ in this example
- The function returns a 1x3 vector with the mean, standard deviation, and the number of data points in the vector called ‘data’.


1.0
1.1
% Filename: stats.m
function [meanX,stdevX,n] = stats(X)
% Get the number of data points
n = size(X,2);
% Initialize the sum of data points to zero
sumX = 0.0;
devX = 0.0;
for i = 1:n
sumX = sumX + X(i);
end
% Find the mean
meanX = sumX/n;
% Find the deviation
for i = 1:n
devX = devX + (X(i) - meanX)^2;
end
% Compute the standard deviation
stdevX = sqrt(devX/(n-1));
stats
Ln 1
Col 16
OVR


Command Window
File Edit Debug Desktop Window Help
>> clear
>> data=1:7;
>> [a,b,c]=stats(data);
>> y=[a,b,c]'
y =
4.0000
2.1602
7.0000
>>
OVR

Things to Remember when Writing Computer Programs

- Use the indented style that you have seen in the previous programs. It makes the programs easier to read, the syntax is easier to check, and it forces you to think in terms of building your programs in blocks.
- Put lots of comments in your program to tell the reader in plain English what is going on. Some day that reader will be you, and you will wonder what you did.
- Put error messages in your programs, like the test for when the denominator was zero. As you go through your career, your programs will build on each other. Error messages will help you debug future programs.
- If you are having trouble writing a program, get a small part of it running and try to build on that.

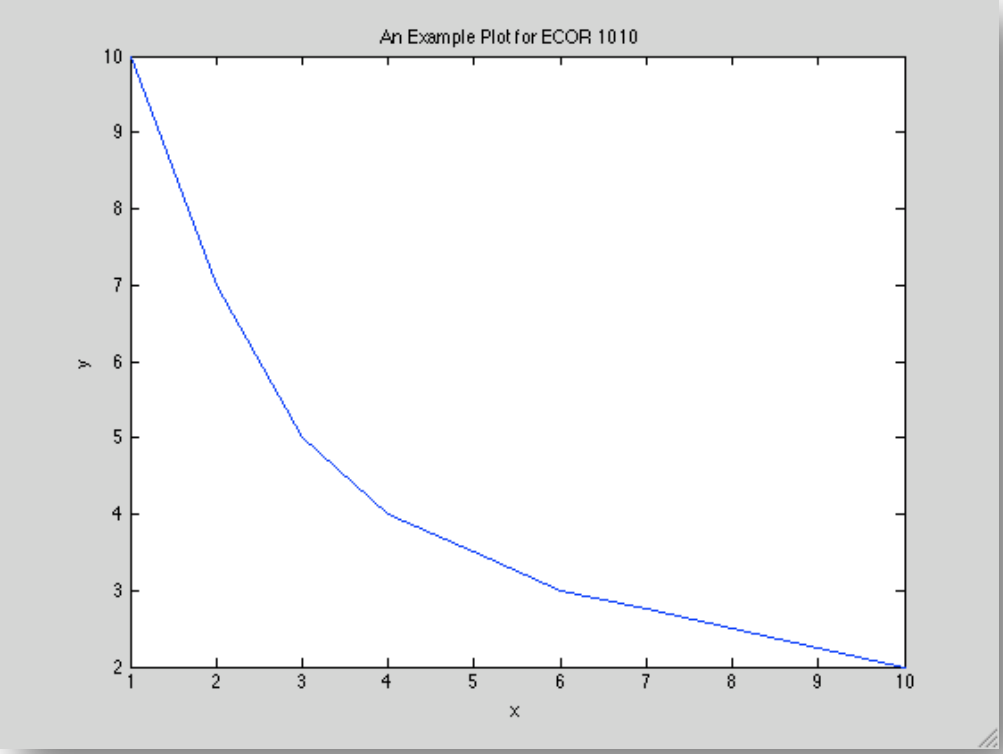
MATLAB Plotting Tools

- MATLAB has very extensive plotting (graphing) tools, for many types of information
- Basic command is plot
  - plot(x,y) plots a *y* versus *x* graph
  - You can plot multiple data sets on one graph
    - plot(x1,y1,'b',x2,y2,'r')
    - One in blue (b), one in red (r)

Plotting Example

```
>>x = [1;2;3;4;5;6;7;8;9;10];
>>y = [10;7;5;4;3.5;3;2.75;2.5;2.25;2];
>>plot(x,y)
>>xlabel('x')
>>ylabel('y')
>>title('An Example Plot for ECOR 1010')
```

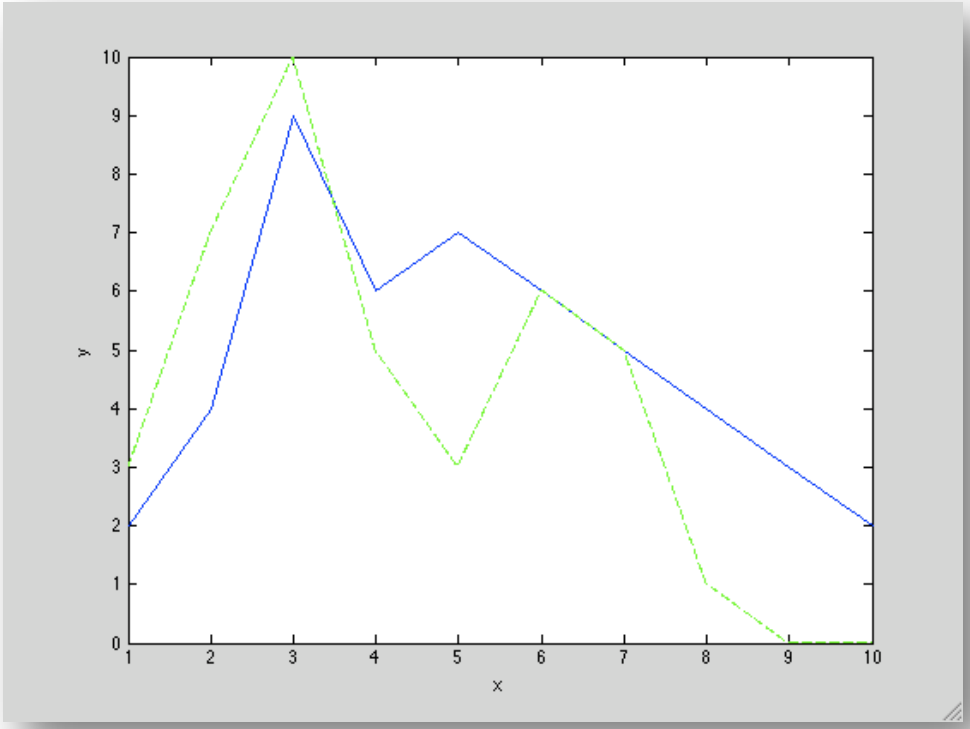
x	y
1	10
2	7
3	5
4	4
5	3.5
6	3
7	2.75
8	2.5
9	2.25

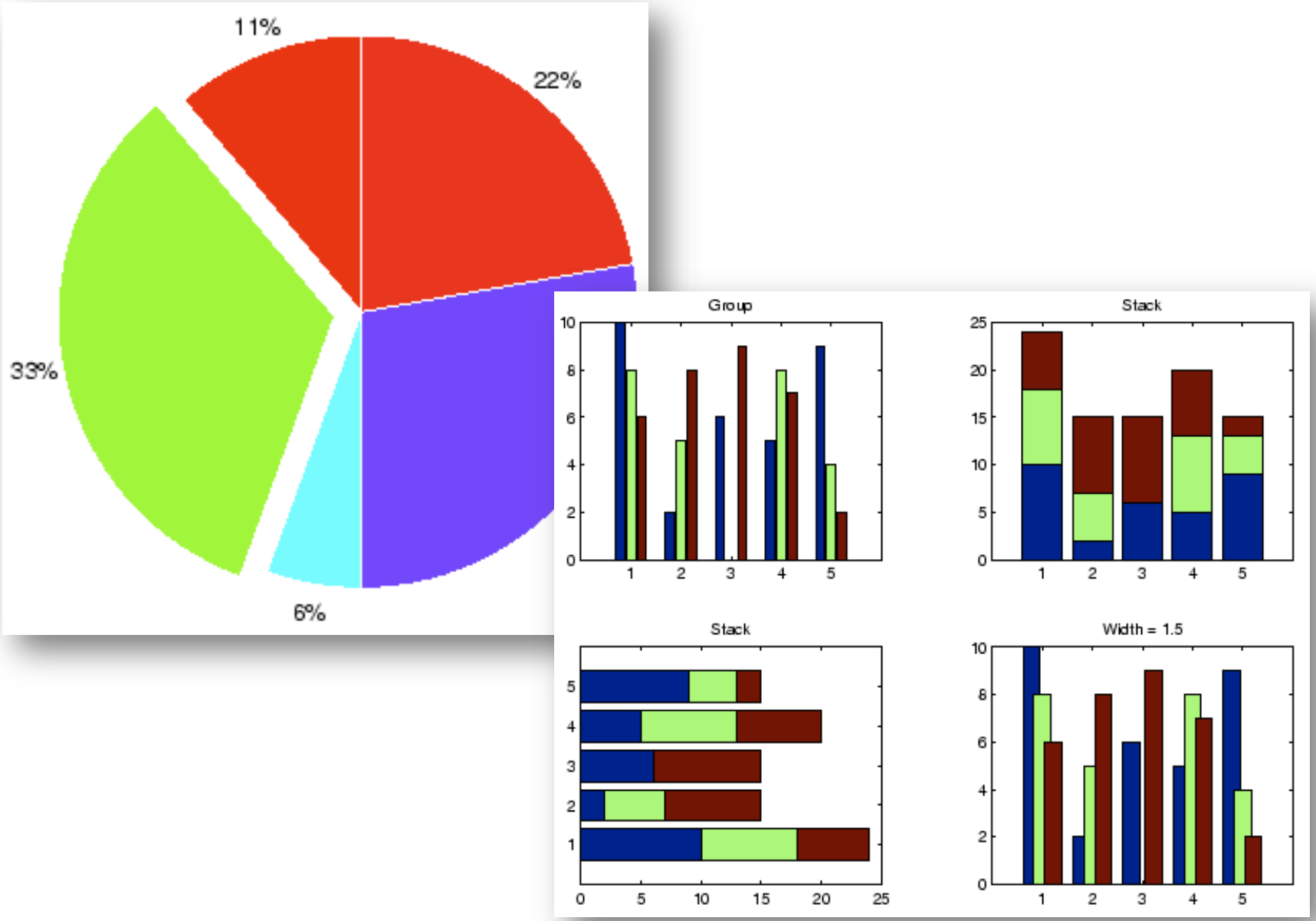


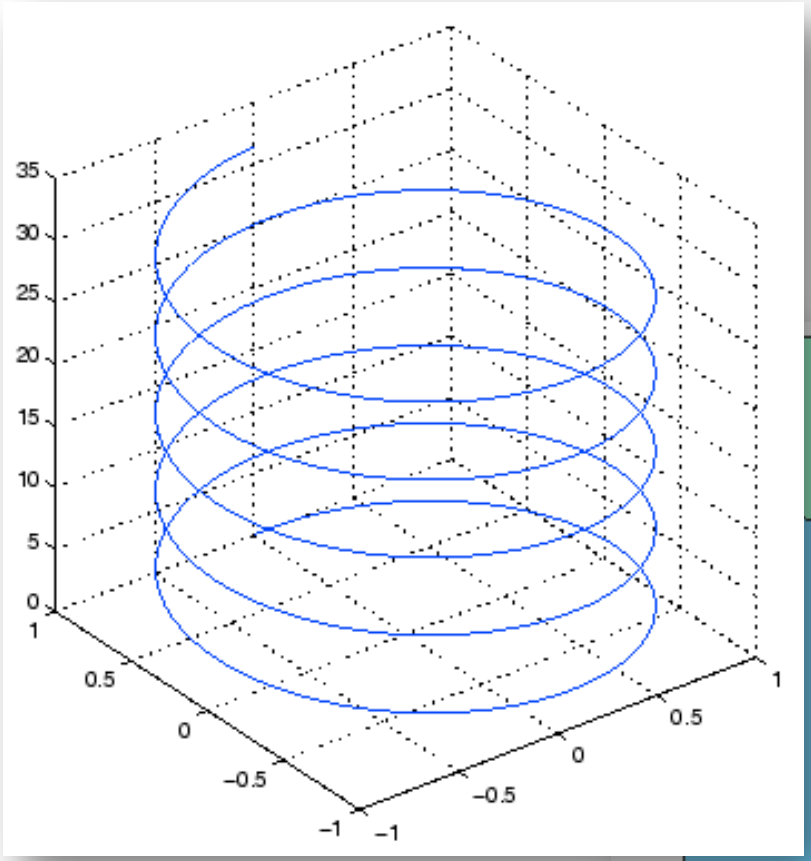
Another Plotting Example

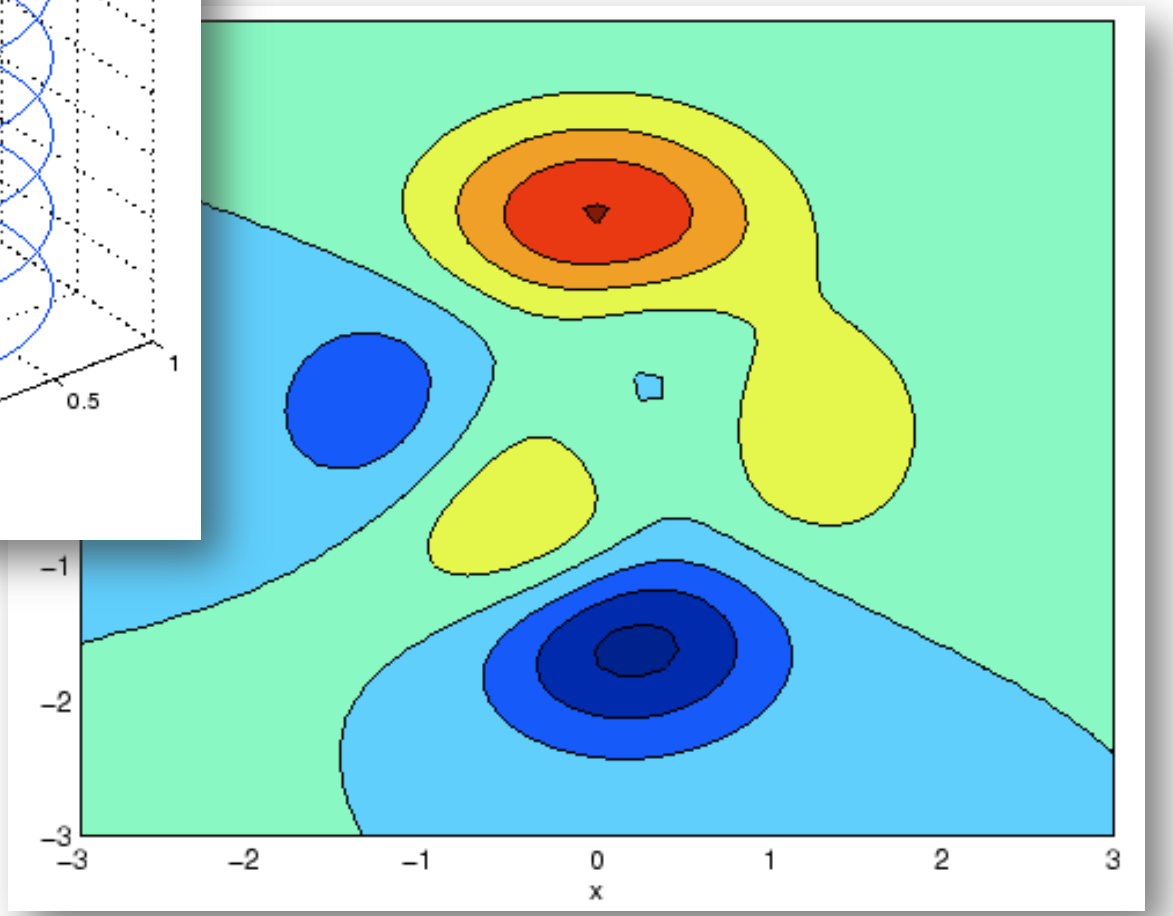
```
>>x = [1;2;3;4;5;6;7;8;9;10];
>> y1 = [2;4;9;6;7;6;5;4;3;2];
>> y2 = [3;7;10;5;3;6;5;1;0;0];
>> plot(x,y1,'b',x,y2,'g--')
>>xlabel('x')
>>ylabel('y')
```

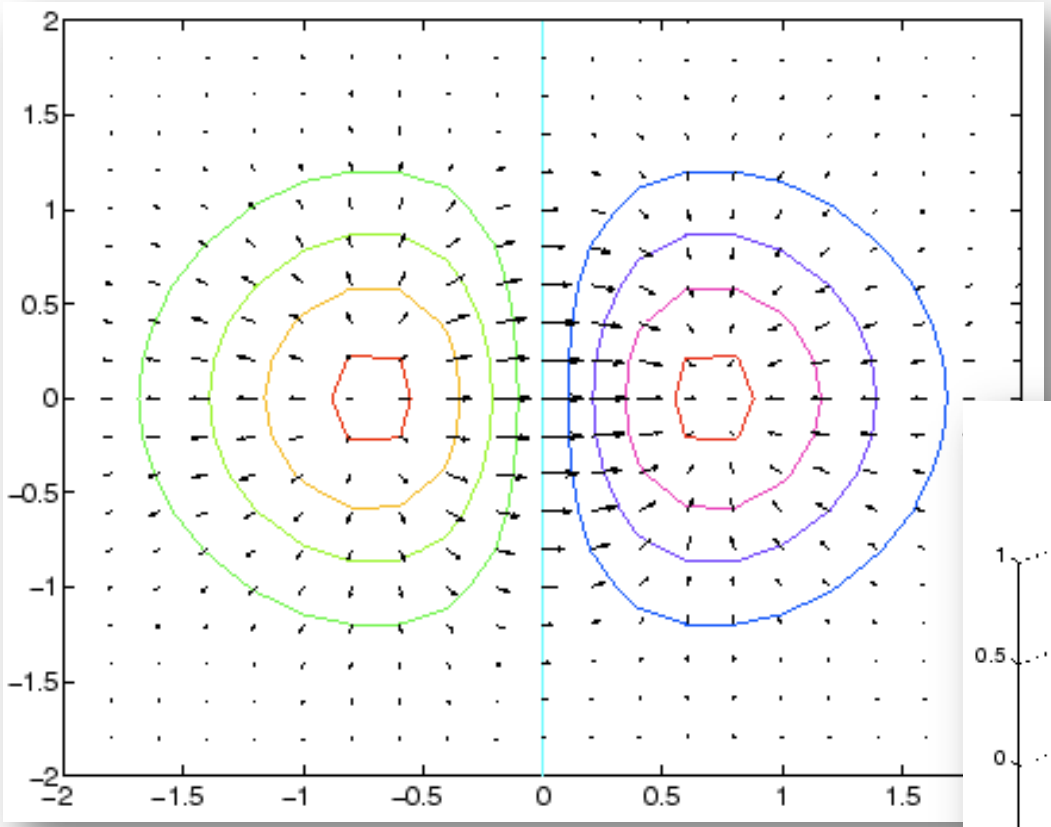
x	y1	y2
1	2	3
2	4	7
3	9	10
4	6	5
5	7	3
6	6	6
7	5	5
8	4	1
9	3	0
10	2	0

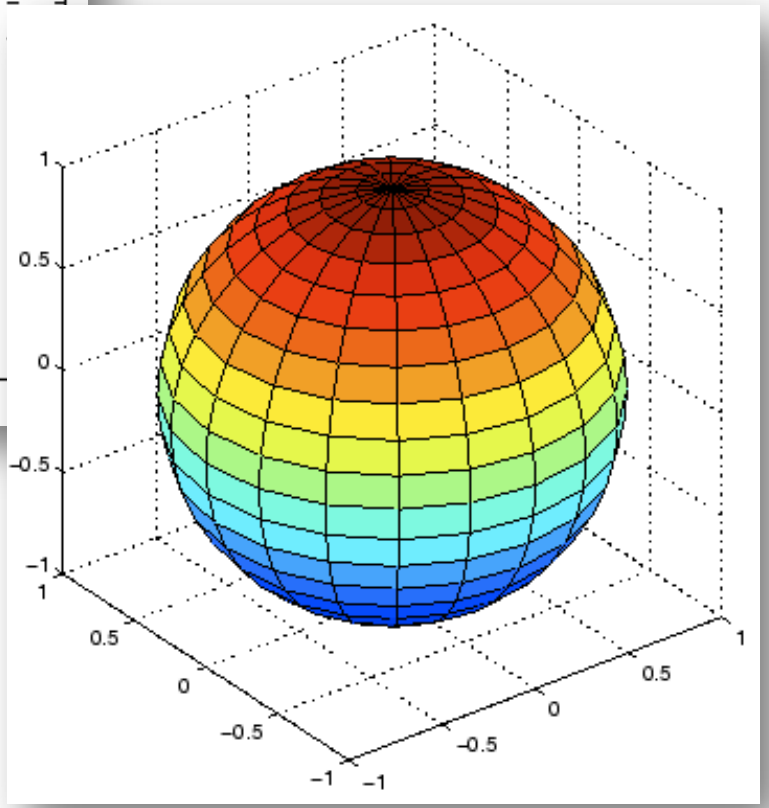


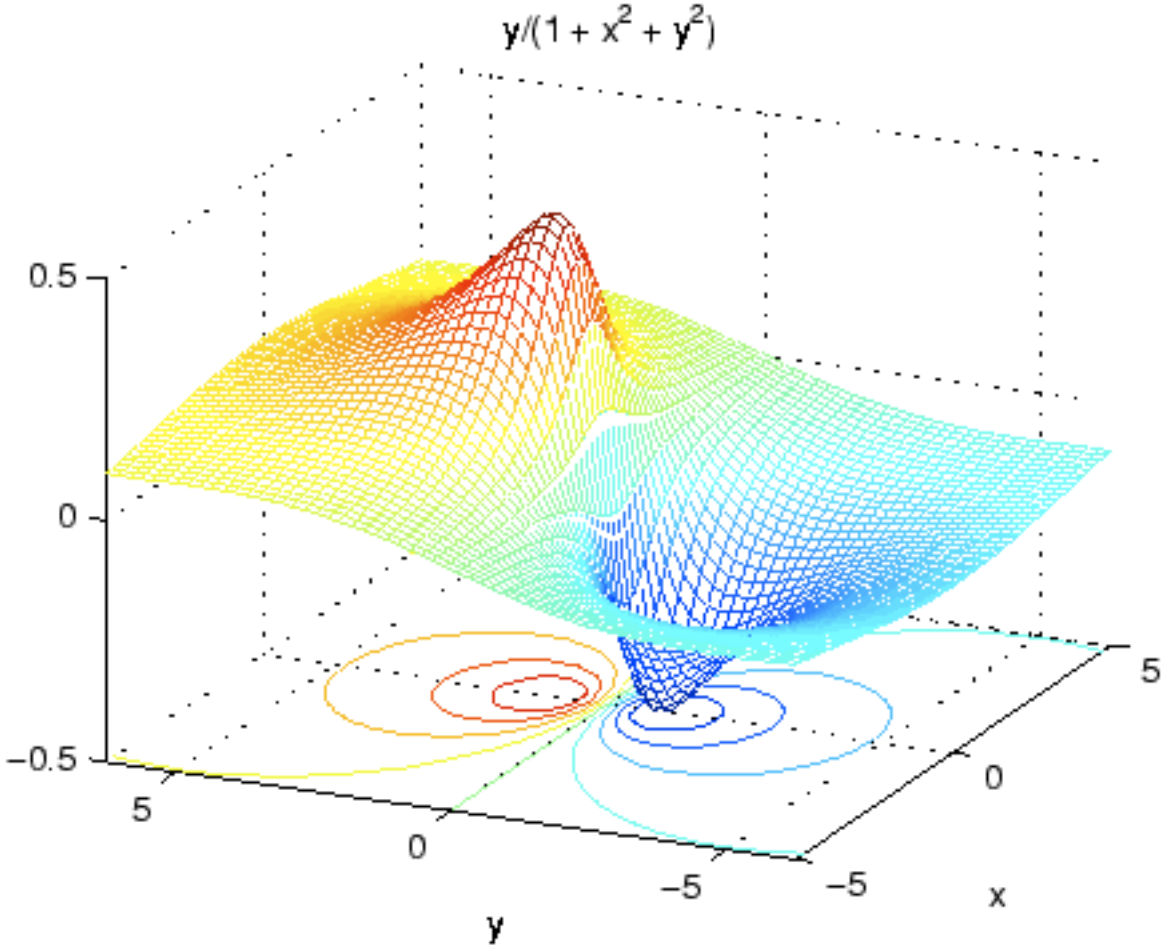

11%
22%
33%
6%
Group
Stack
Stack
Width = 1.5


35
30
25
20
15
10
5
0
1
0.5
0
−0.5
−1
−1
−0.5
0
0.5
1


−1
−2
−3
−3
−2
−1
0
1
2
3
x


2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2
−1.5
−1
−0.5
0
0.5
1
1.5


1
0.5
0
−0.5
−1
1
0.5
0
−0.5
−1
−1
−0.5
0
0.5
1


y/(1 + x^2 + y^2)
0.5
0
−0.5
5
0
−5
y
−5
0
5
x

MATLAB Support

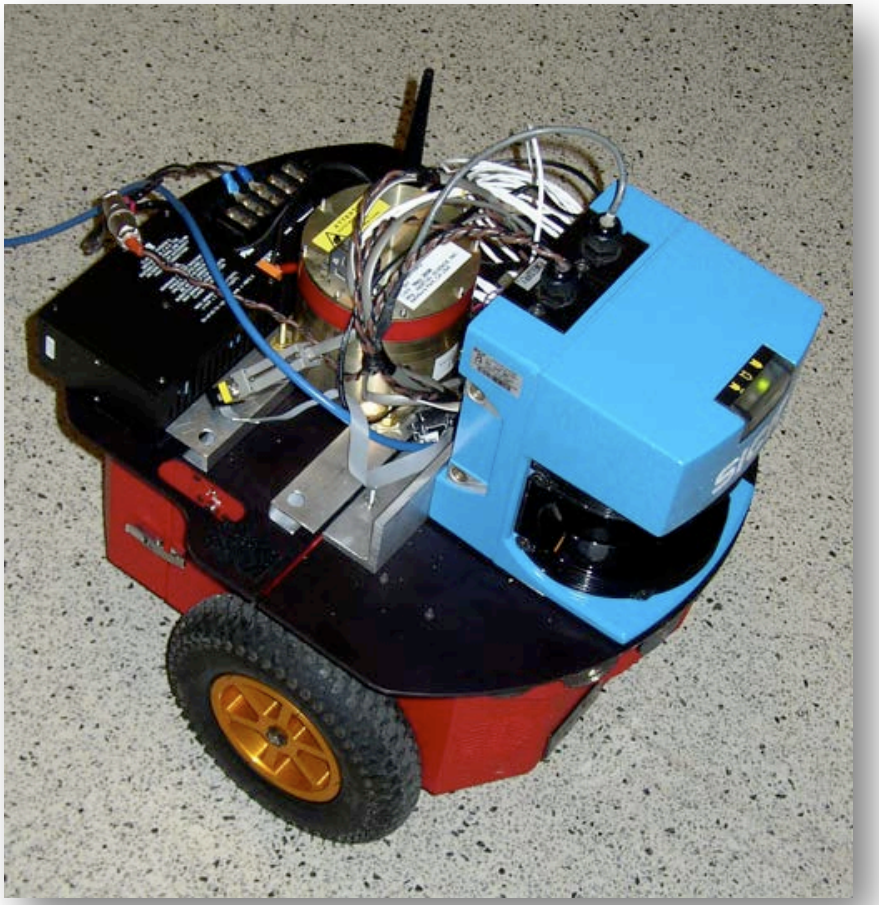
- Check out the support material on WebCT
- The Mathworks website has many tutorials and many interesting examples
  - www.mathworks.com

MATLAB for Simulation

- MATLAB is a powerful tool for creating **simulations** of physical systems
  - Can be used to efficiently solve differential equations (e.g., equations of motion)
  - Simulations can be used to check anticipated results before building real systems
- Simulink is a powerful graphical tool in MATLAB for creating simulations

Simulation Example (MobotSim)

- Simulate the motion of a mobile robot
- Simulate the sensors on a mobile robot
  - Wheel rotations
  - Laser rangefinder readings
- Save the data to test algorithms without needing a real robot



ECOR 1010
Lecture 19
Introduction to Maple

Maple

- Maple is computer algebra software
- Great for symbolic computations
  - Historically, MATLAB has been used for numerical calculations and MAPLE for symbolic, but both now do both
- Originally developed at the University of Waterloo (now Maplesoft)
  - www.maplesoft.com

What Can Maple Do?

- 2D Plotting
- Great for 3D plotting
- Symbolic and numerical computations
- Differential and integral calculus
- Matrix manipulation
- Statistics and data management
- Algebraic geometry
- Differential geometry
- Much more, …

C:\Program Files\Maple 14\examples\MaplePortal.mw - [Server 1] - Maple 14

File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help

Favorites
MapleCloud
Handwriting
Expression
Units (SI)
Units (FPS)
Common Symbols
Matrix
Components
Greek
Arrows
Relational
Relational Round
Negated
Large Operators
Operators
Open Face
Fraktur
Script
Miscellaneous

Text Math | Annotation Title | Times New Roman | 12

Maple™ Portal

The Maple Portal is designed as a starting place for any Maple user. Maple's Tutorials will help you get started with Maple, learn about the key tools available in Maple, and lead you through a series of problems. From here, investigate more detailed topics in the Portals for Engineers, Students, and Math Educators.

Tutorials: Getting Started with Maple

Each tutorial will take approximately 5-10 minutes to complete.

Talking to Maple	How to Get Started Entering Math
Putting Your Ideas Together	Combining Text and Math Solving Equations Expressions, Functions, and Procedures
Commands and Packages	Using Top Commands and Packages Getting Help
Plotting	2-D and 3-D Plots Using the Plot Builder Assistant
Working with Matrices	Creating Matrices and Vectors
Data Structures	including lists and Arrays
Data Manipulation	Importing and Exporting Data Random Distributions Statistics, Regression, and Curve Fitting
Word Processing Tools	Sections and Tables Document Enhancements
Dynamic Applications	Exploration Assistant Expression Plotting Interactive Circle Plotting More Examples
Units	Working with Units Customizing Unit Settings Tolerances

How do I...

Topics covering essentials for working in Maple

How do I...

...enter a simple expression?
...enter a function?
...enter a matrix?
...evaluate an expression?
...plot a function?

Tools and Features

Learn more about Maple's tools and features, such as palettes and context-sensitive menus.

Palettes
Context-Sensitive Menus
Command Completion
Equation Labels
Assistants
Maple Help
Plotting Guide
Applications
Example Worksheets
Manuals

Portals for...

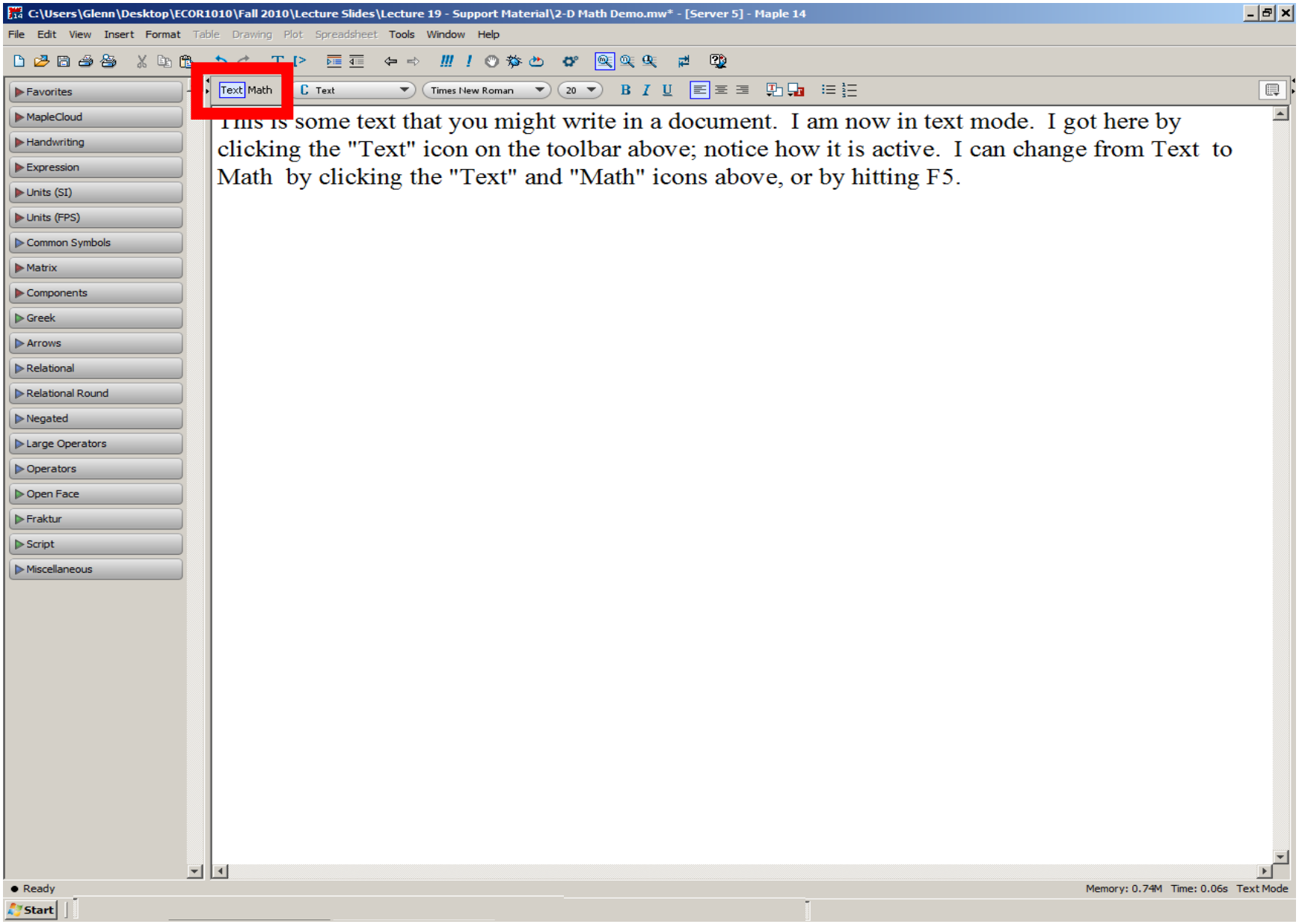
Engineers
Students
Math Educators

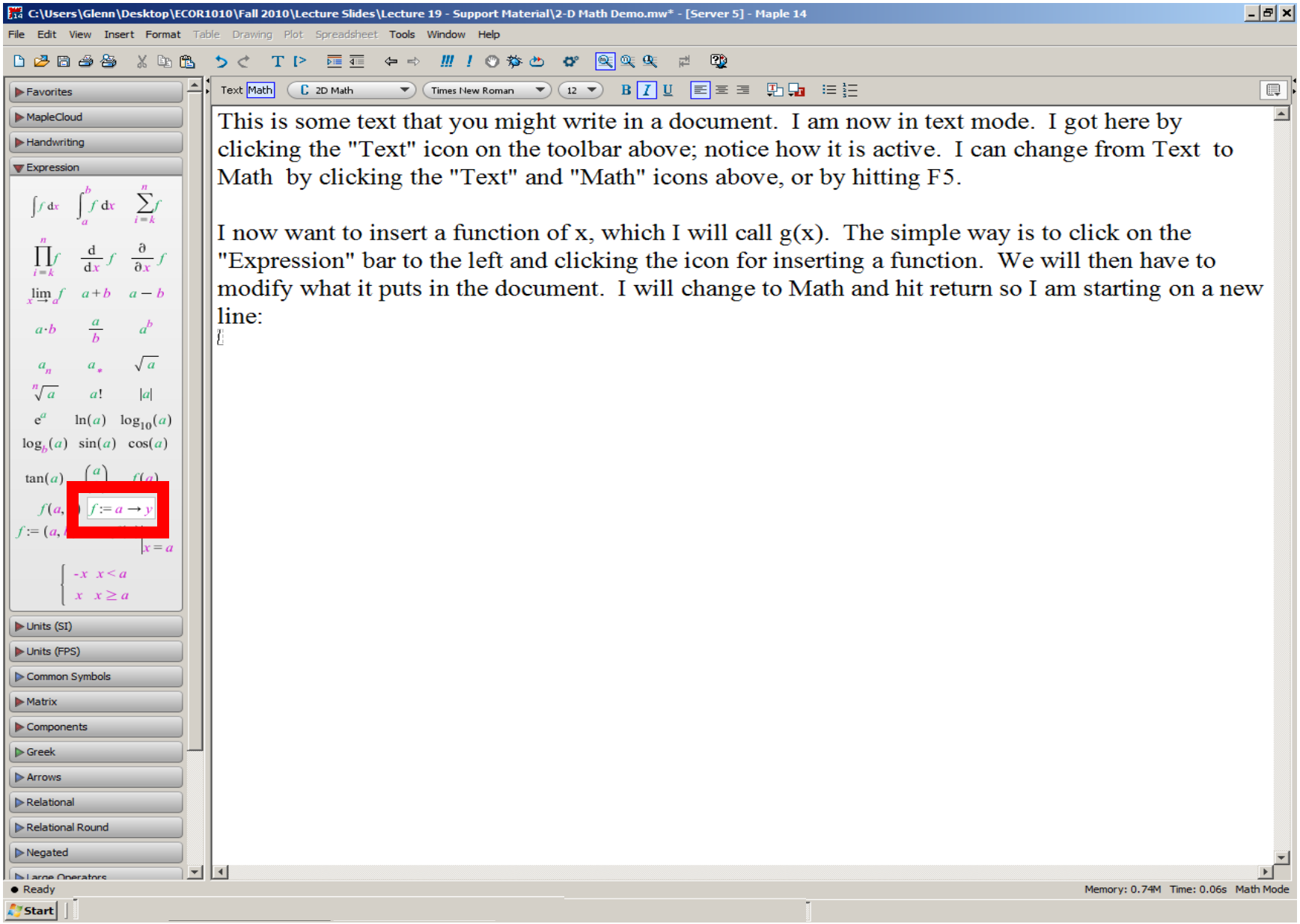
Maple Help

Refer to **Help>Quick Reference** for basic getting started tips.

Note for non-Windows users: The keystrokes given in this document are for Windows. There will be differences for other platforms. If you are using a different platform, see **Help>Quick Help** for the list of the most common keystrokes.

Ready
Memory: 0.74M Time: 0.01s Text Mode


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Text Math
Text
Times New Roman
20
Favorites
MapleCloud
Handwriting
Expression
Units (SI)
Units (FPS)
Common Symbols
Matrix
Components
Greek
Arrows
Relational
Relational Round
Negated
Large Operators
Operators
Open Face
Fraktur
Script
Miscellaneous
This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
Ready
Memory: 0.74M Time: 0.06s Text Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Favorites
MapleCloud
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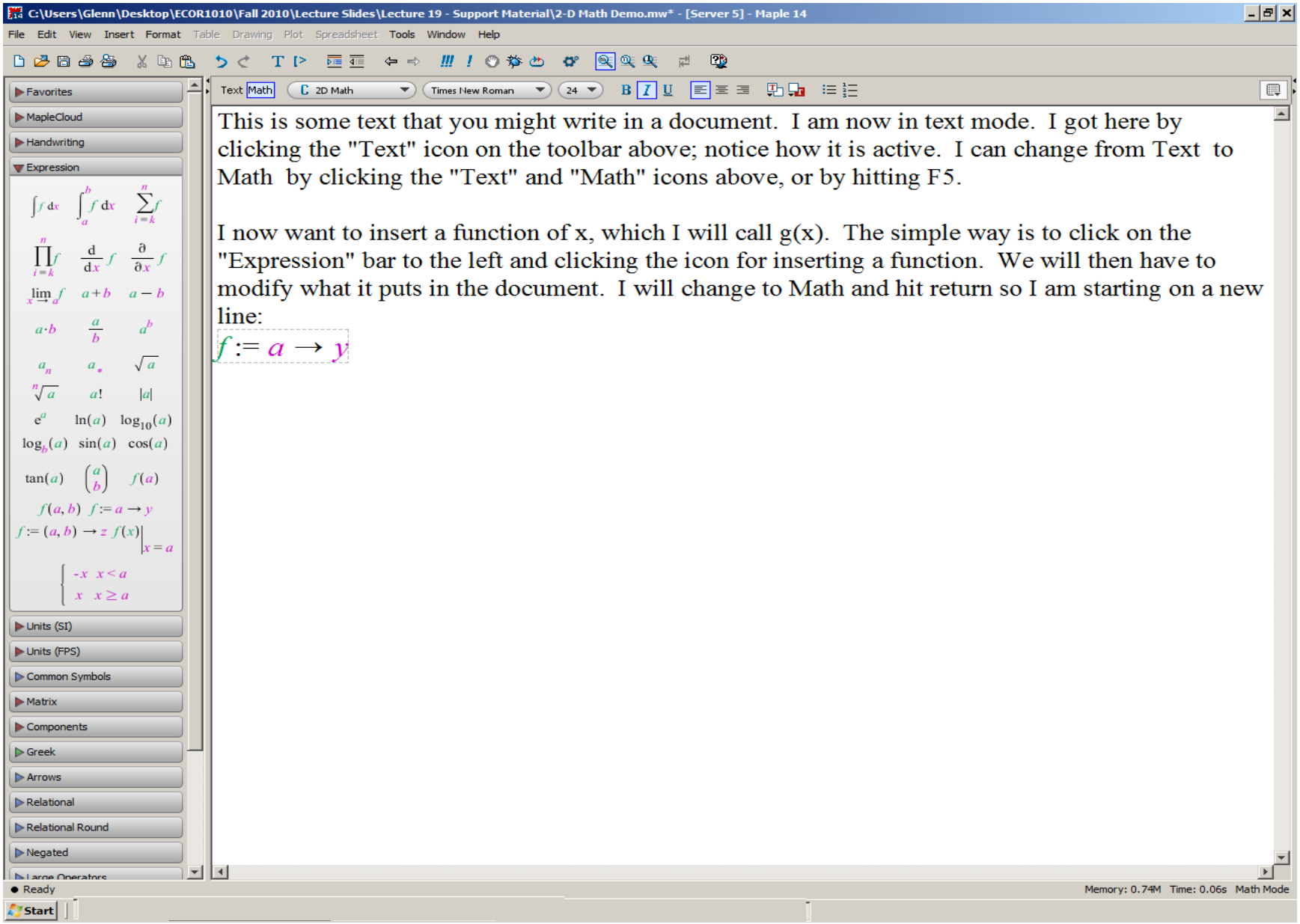
Text Math
2D Math
Times New Roman
12
This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Text Math
2D Math
Times New Roman
24
Favorites
MapleCloud
Handwriting
Expression
Units (SI)
Units (FPS)
Common Symbols
Matrix
Components
Greek
Arrows
Relational
Relational Round
Negated
Large Operators
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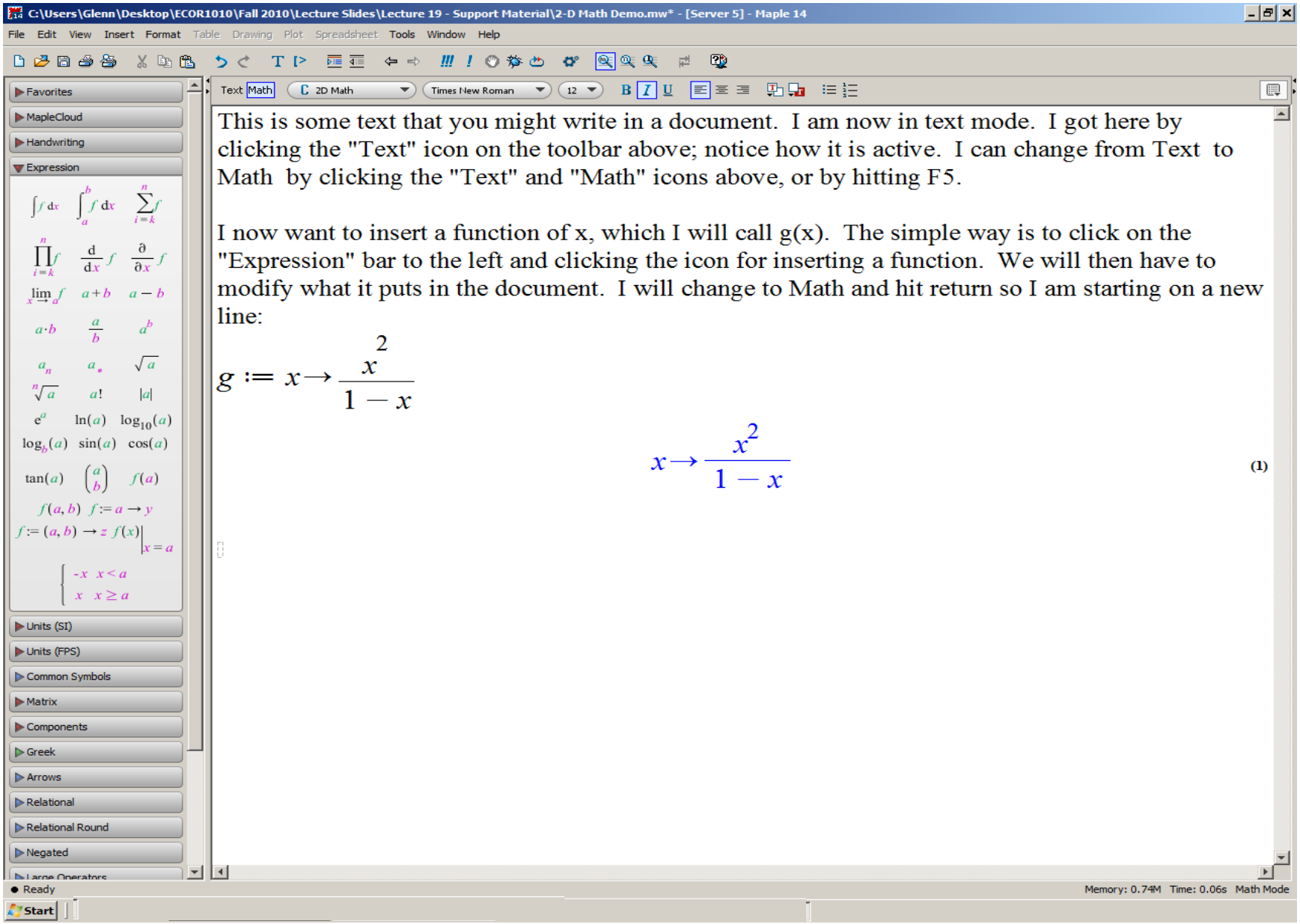
I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:
f := a → y
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Favorites
MapleCloud
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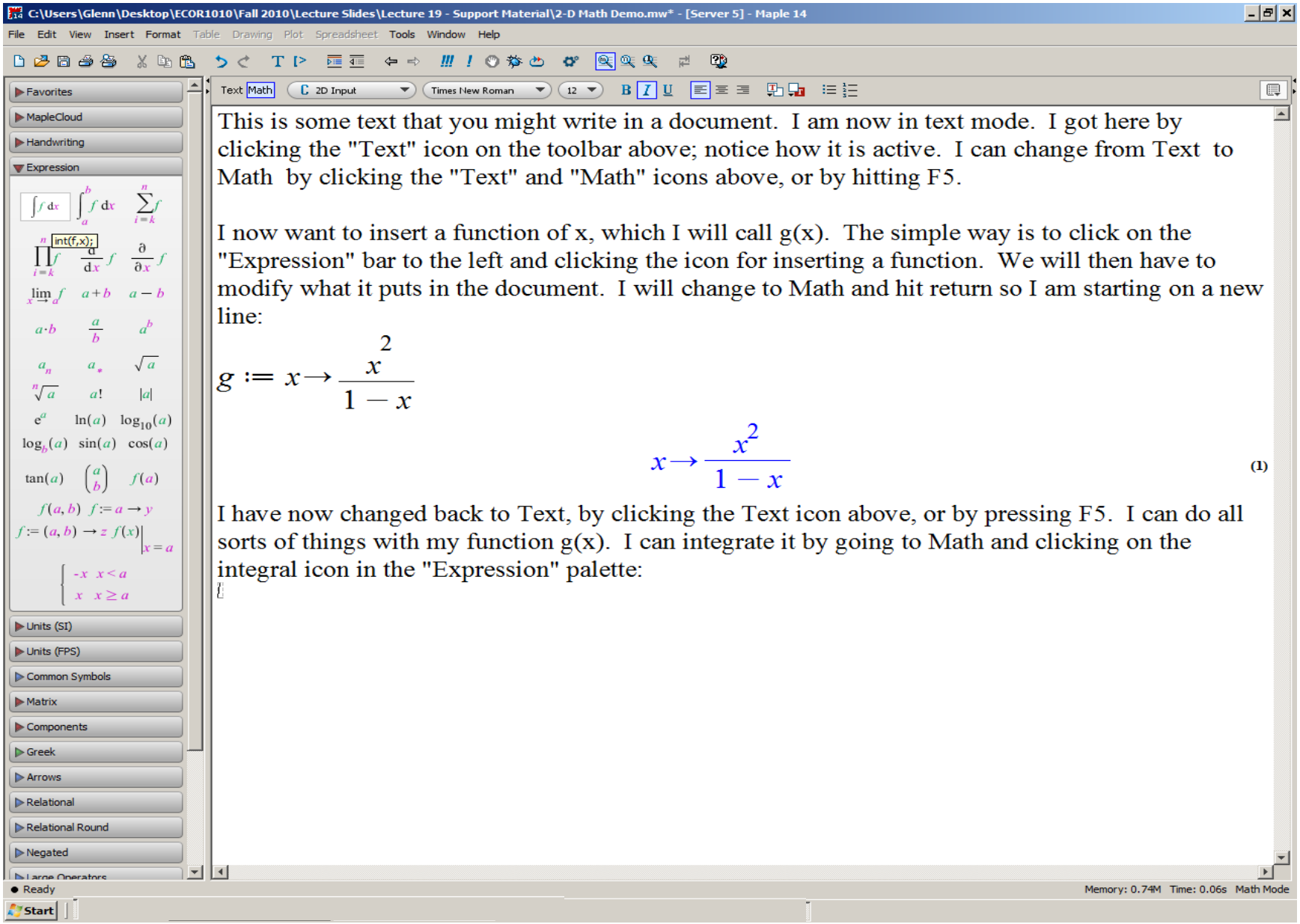
Negated
Text Math
2D Math
Times New Roman
12
This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:
g := x → x^2 / (1 − x)
x → x^2 / (1 − x) (1)
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Favorites
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Expression
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Common Symbols
Matrix
Components
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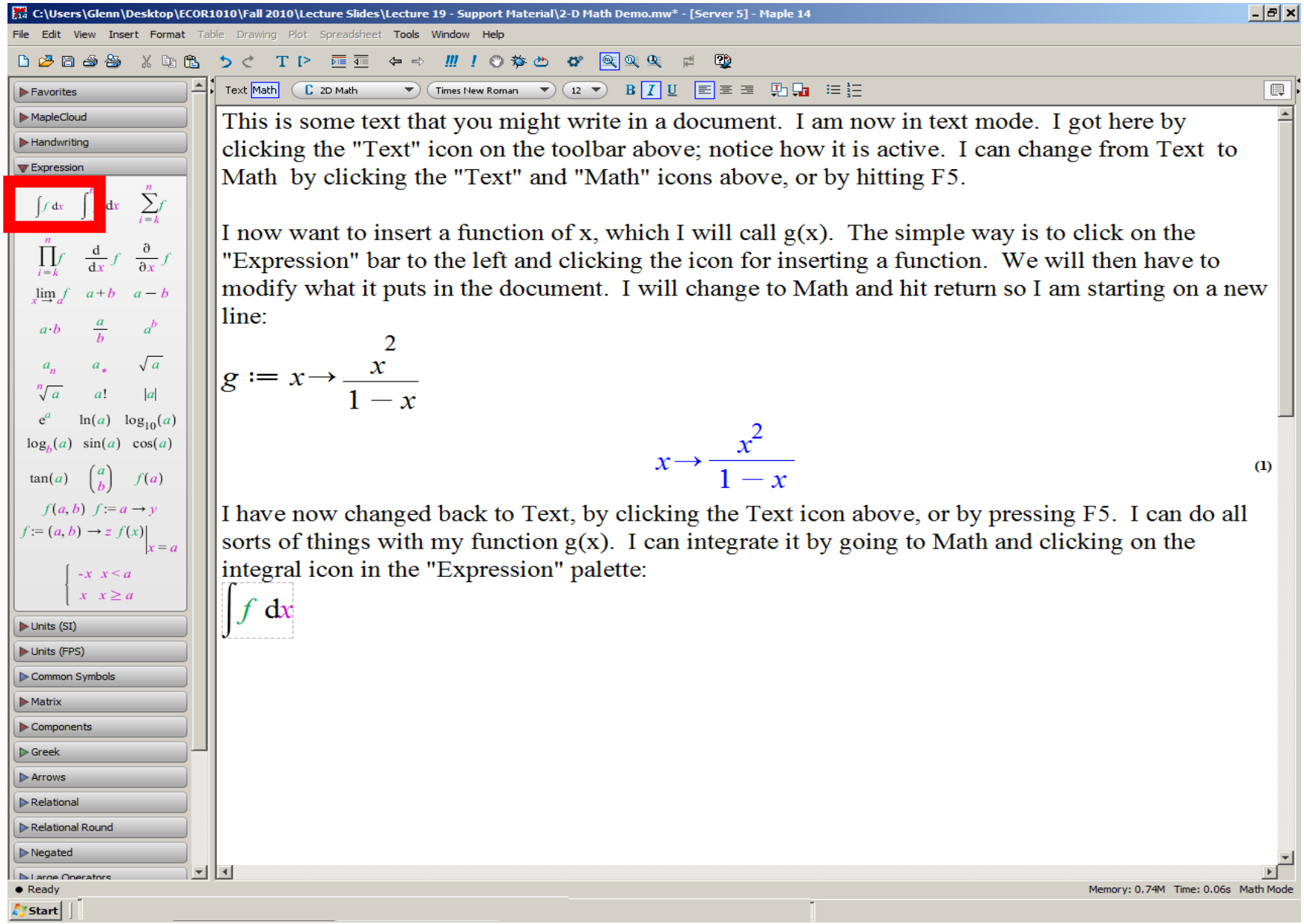
Arrows
Relational
Relational Round
Negated
Large Operators
Text Math
2D Input
Times New Roman
12
This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:
g := x → x^2 / (1 − x)
x → x^2 / (1 − x) (1)
I have now changed back to Text, by clicking the Text icon above, or by pressing F5. I can do all sorts of things with my function g(x). I can integrate it by going to Math and clicking on the integral icon in the "Expression" palette:
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
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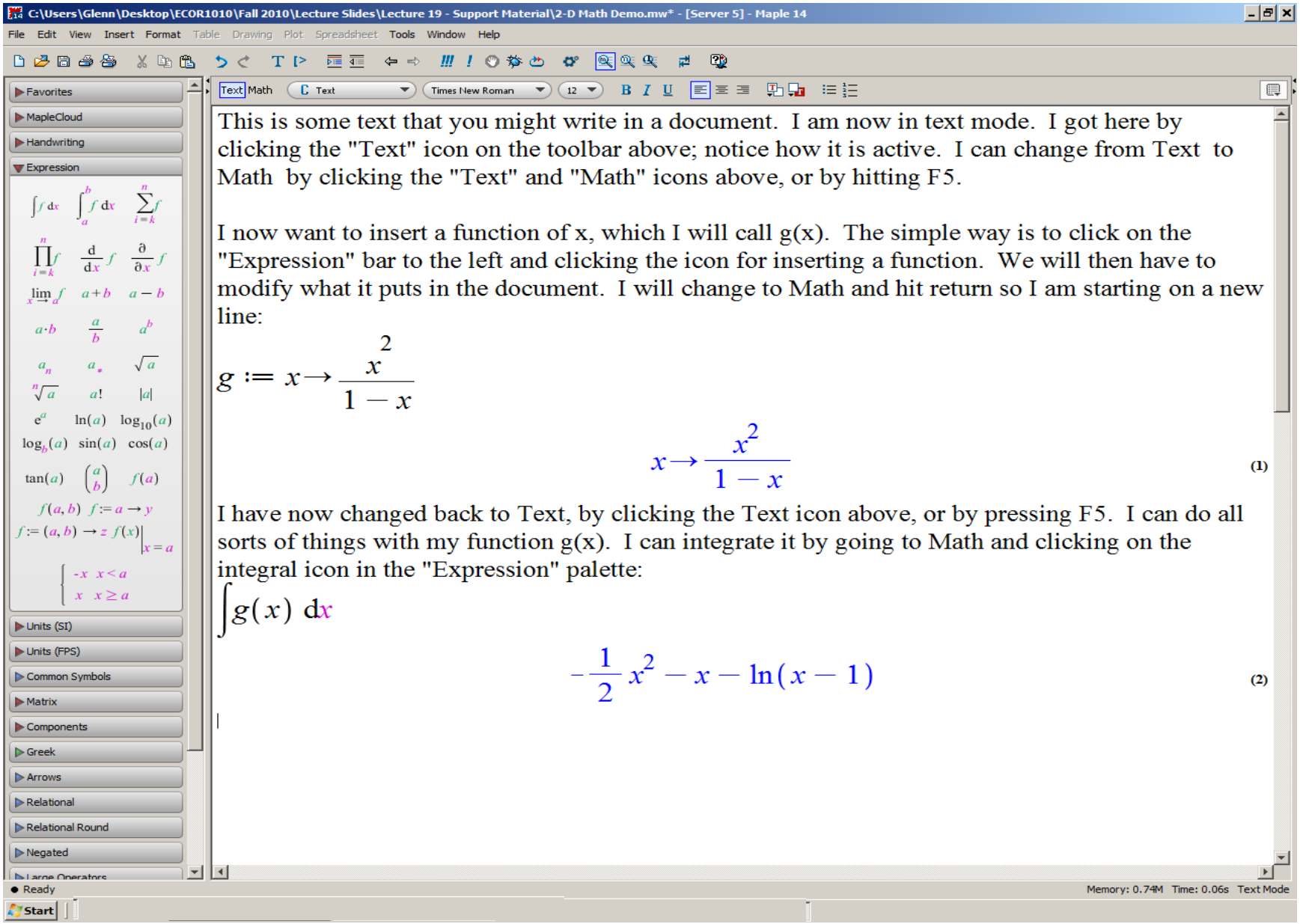
∫ f dx
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
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x → x^2 / (1 − x) (1)
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∫ g(x) dx
−(1/2) x^2 − x − ln(x − 1) (2)
Ready
Memory: 0.74M Time: 0.06s Text Mode
Start

G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14

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Relational Round
Negated
Large Operators

Text Math | Text | Times New Roman | 12

This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.

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$$g := x \rightarrow \frac{x^2}{1 - x}$$

$$x \rightarrow \frac{x^2}{1 - x} \quad (1)$$

I have now changed back to Text, by clicking the Text icon above, or by pressing F5. I can do all sorts of things with my function g(x). I can integrate it by going to Math and clicking on the integral icon in the "Expression" palette:

$$\int g(x)\, dx$$

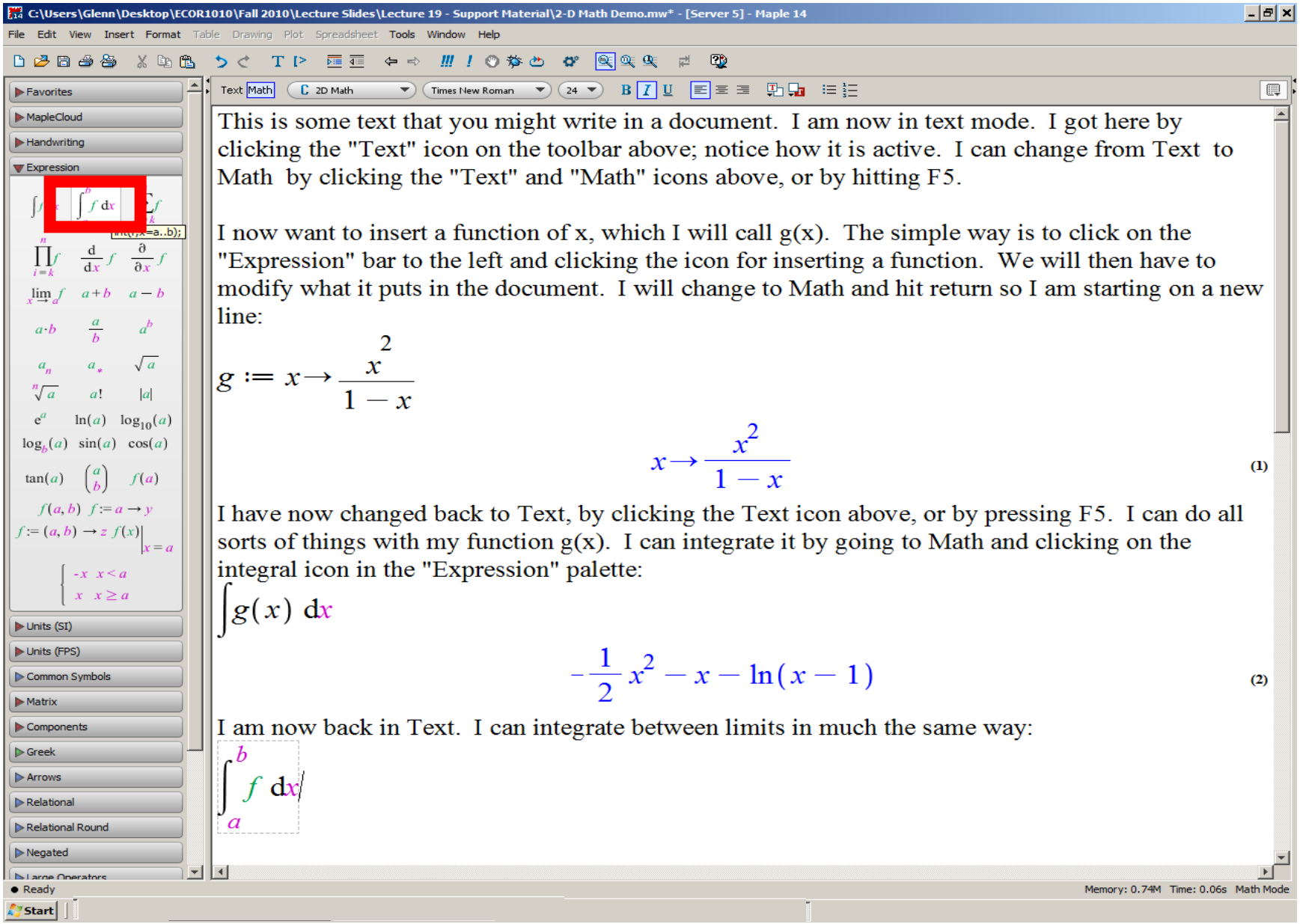
$$-\frac{1}{2}x^2 - x - \ln(x - 1) \quad (2)$$

I am now back in Text. I can integrate between limits in much the same way:

Ready

Memory: 0.74M Time: 0.06s Text Mode

Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14
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Text Math
2D Math
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24
This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
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x → x^2 / (1 − x) (1)
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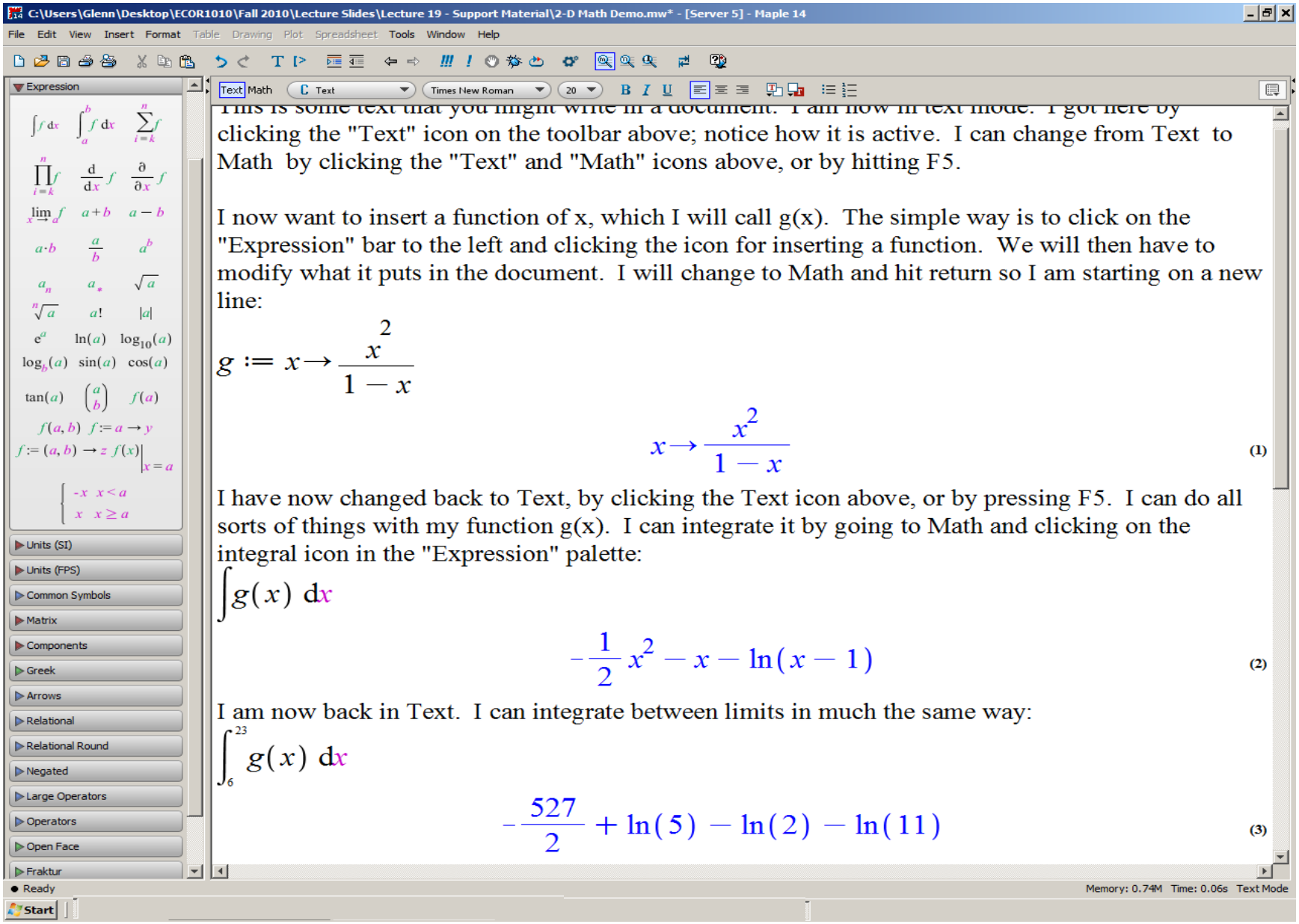
∫ g(x) dx
−(1/2) x^2 − x − ln(x − 1) (2)
I am now back in Text. I can integrate between limits in much the same way:
∫ from a to b of f dx
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start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Text
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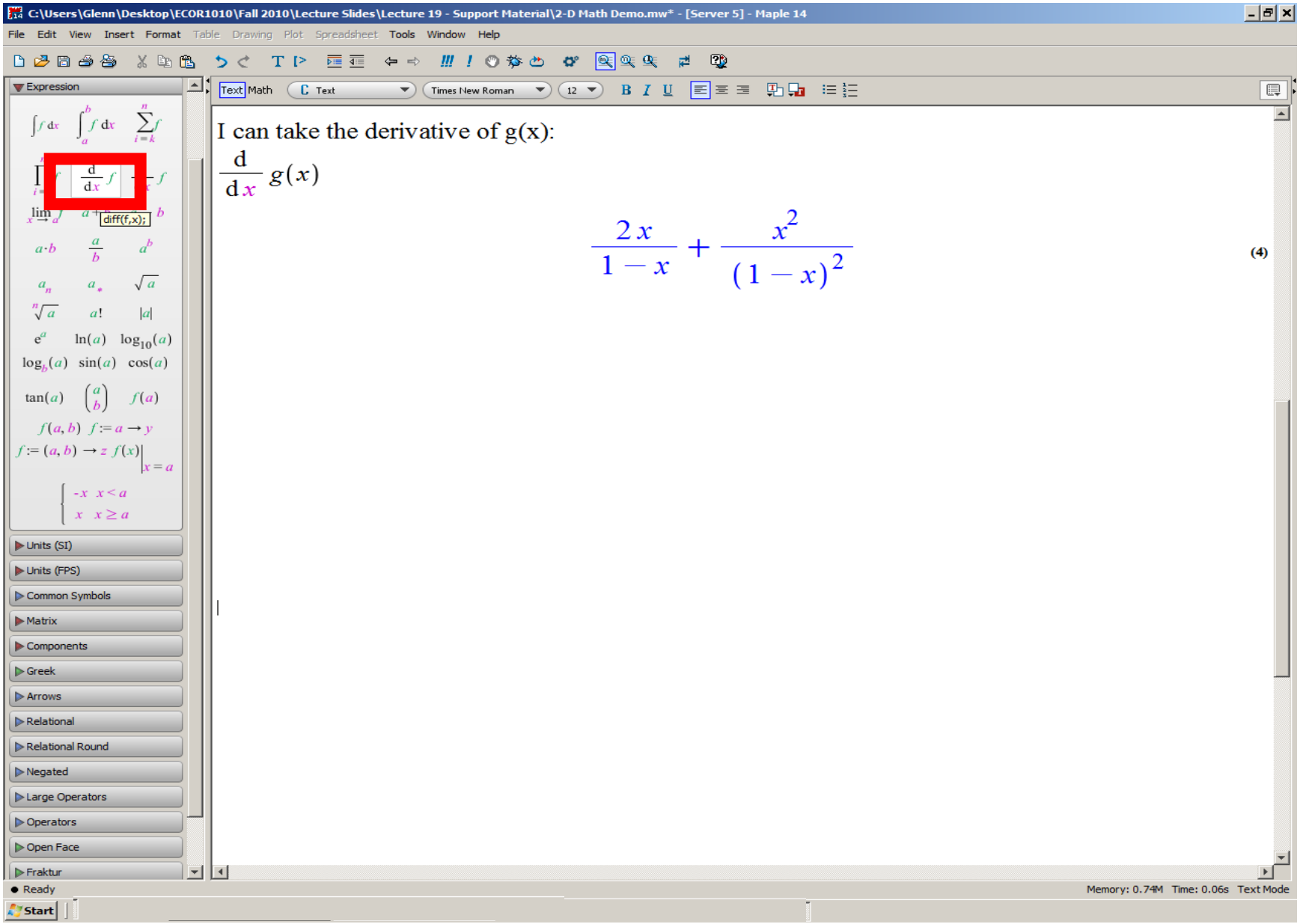
∫ g(x) dx
−(1/2) x^2 − x − ln(x − 1) (2)
I am now back in Text. I can integrate between limits in much the same way:
∫_6^23 g(x) dx
−527/2 + ln(5) − ln(2) − ln(11) (3)
Ready
Memory: 0.74M Time: 0.06s Text Mode
Start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File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Expression
diff(f,x);
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Times New Roman
12
I can take the derivative of g(x):
$\frac{d}{dx} g(x)$
$\frac{2x}{1-x} + \frac{x^2}{(1-x)^2}$
(4)
Ready
Memory: 0.74M Time: 0.06s Text Mode
Start

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Text Math | Text | Times New Roman | 20

I can take the derivative of g(x):

$$\frac{d}{dx} g(x)$$

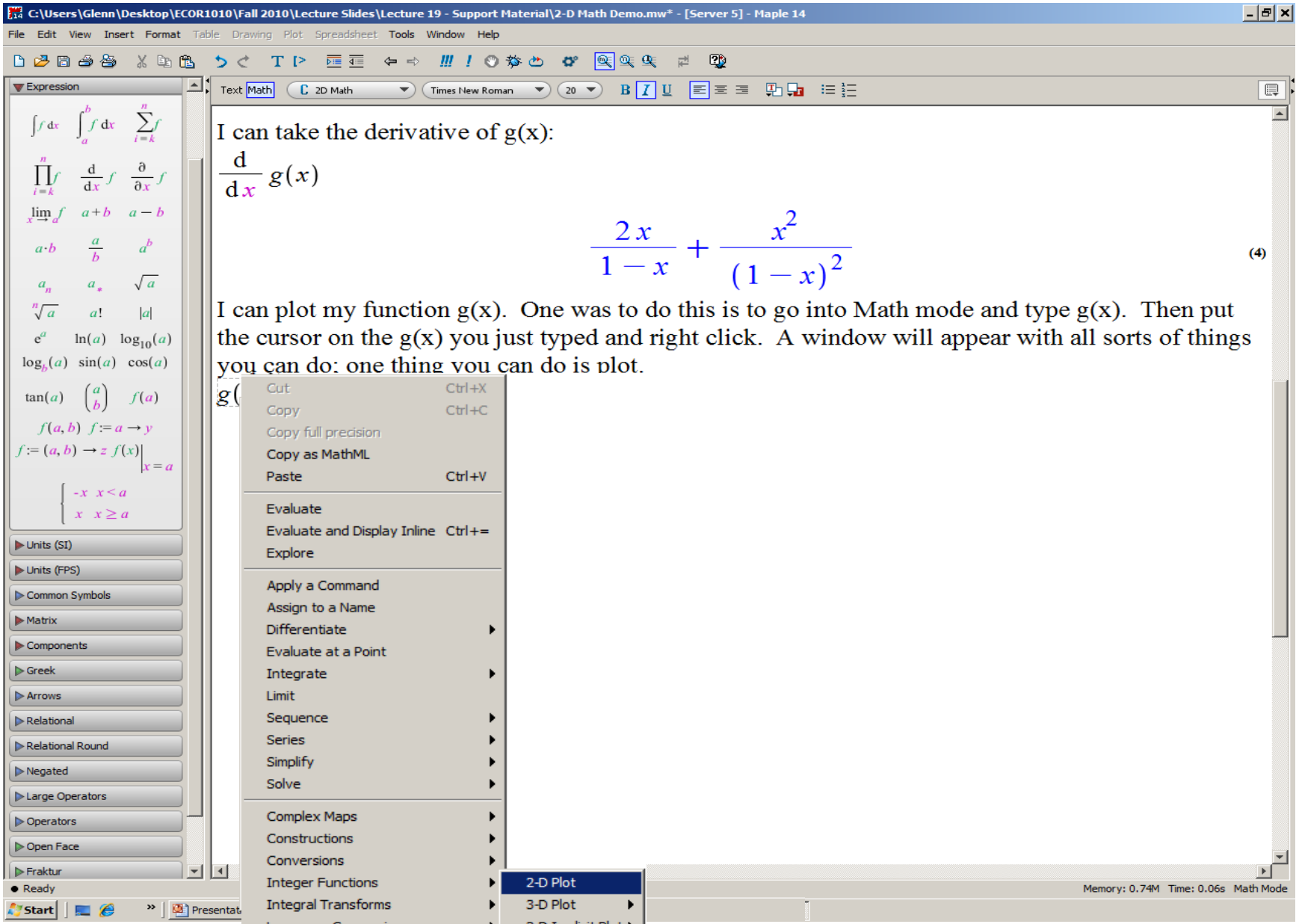
$$\frac{2x}{1-x} + \frac{x^2}{(1-x)^2} \quad (4)$$

I can plot my function g(x). One was to do this is to go into Math mode and type g(x). Then put the cursor on the g(x) you just typed and right click. A window will appear with all sorts of things you can do; one thing you can do is plot.

Ready

Memory: 0.74M Time: 0.06s Text Mode

Start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Cut Ctrl+X
Copy Ctrl+C
Copy full precision
Copy as MathML
Paste Ctrl+V
Evaluate
Evaluate and Display Inline Ctrl+=
Explore
Apply a Command
Assign to a Name
Differentiate
Evaluate at a Point
Integrate
Limit
Sequence
Series
Simplify
Solve
Complex Maps
Constructions
Conversions
Integer Functions
Integral Transforms
Language Conversions
Optimization
Plots
Units
2-D Math
2-D Plot
3-D Plot
2-D Implicit Plot
3-D Implicit Plot
Plot Builder
Ready
Memory: 0.74M Time: 0.06s Math Mode
Start

G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 5] - Maple 14

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Expression

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Text Math | Maple Plot | Times New Roman | 12

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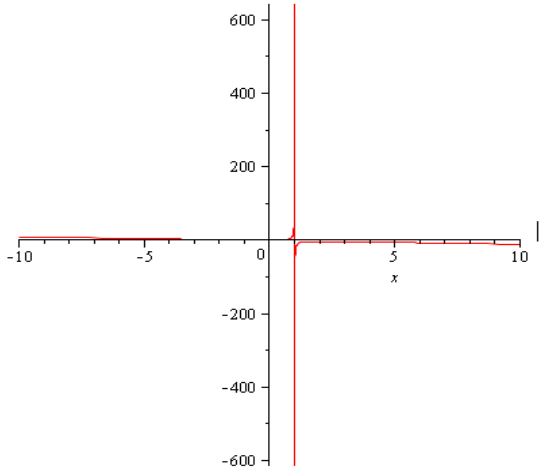
$g(x) \rightarrow$



Ready

Memory: 0.74M Time: 0.06s Text Mode

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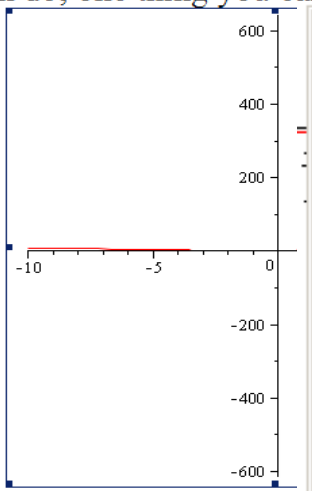
$g(x) \rightarrow$



Cut Ctrl+X
Copy Ctrl+C
Copy full precision
Copy as MathML
Paste Ctrl+V

Style
Symbol
Line
Color
Transparency

Axes
Legend
Title
Scaling Constrained

Manipulator
Probe Info

Export

Normal
Boxed
Framed
None

Properties...

Create second axis

Labels

Toggle Gridlines
Gridlines Properties...

Ready

Memory: 0.74M Time: 0.06s Text Mode

Start

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File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help

Expression

Units (SI)
Units (FPS)
Common Symbols
Matrix
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I can take the derivative of g(x):

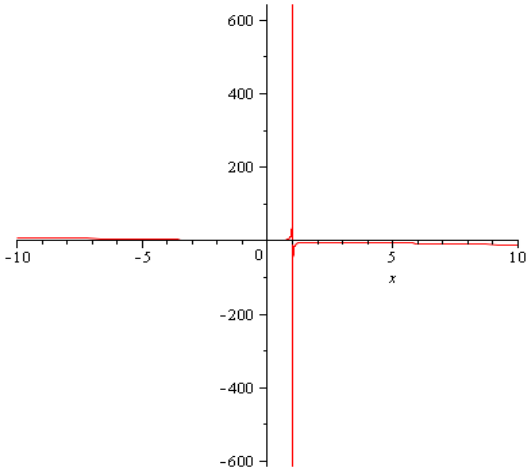
$$\frac{d}{dx} g(x)$$

$$\frac{2x}{1-x} +$$

(4)

I can plot my function g(x). One was to do th ...g(x). Then put the cursor on the g(x) you just typed and right ...ll sorts of things you can do; one thing you can do is plot.

$g(x) \rightarrow$



Axis Properties

Horizontal | Vertical

Log mode
Use data extents
Range min: -612.626
Range max: 643.05
Let renderer choose tickmarks
Number of tickmarks: 5
Custom Spacing: 1.0
Offset: 0.0
Multiply by Pi
Use default subticks
Number of subticks 0
Color...

Apply Reset
OK Cancel

Ready

Memory: 0.74M Time: - Text Mode

Start

G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 11] - Maple 14

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Expression

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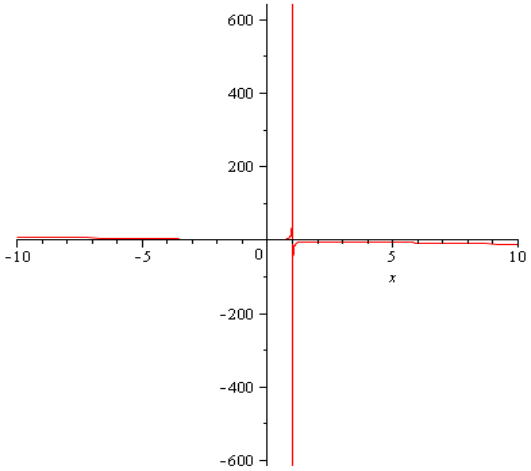
$g(x) \rightarrow$



Axis Properties

Horizontal Vertical

Log mode
Use data extents
Range min: -10
Range max: 10
Let renderer choose tickmarks
Number of tickmarks: 5
Custom Spacing: 1.0
Offset: 0.0
Multiply by Pi
Use default subticks
Number of subticks 0
Color...

Apply Reset
OK Cancel

Ready

Memory: 0.74M Time: - Text Mode

Start

G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 11] - Maple 14

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Text Math | Maple Plot | Times New Roman | 12

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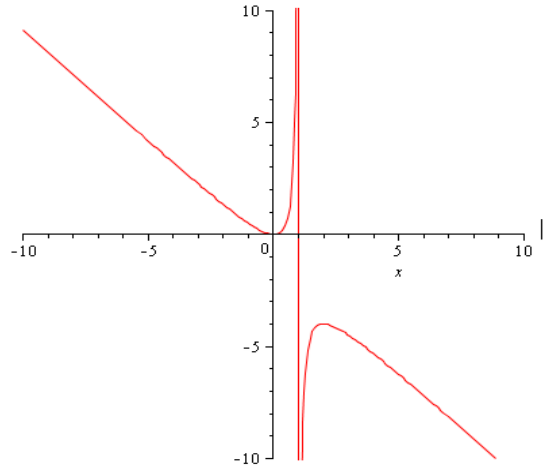

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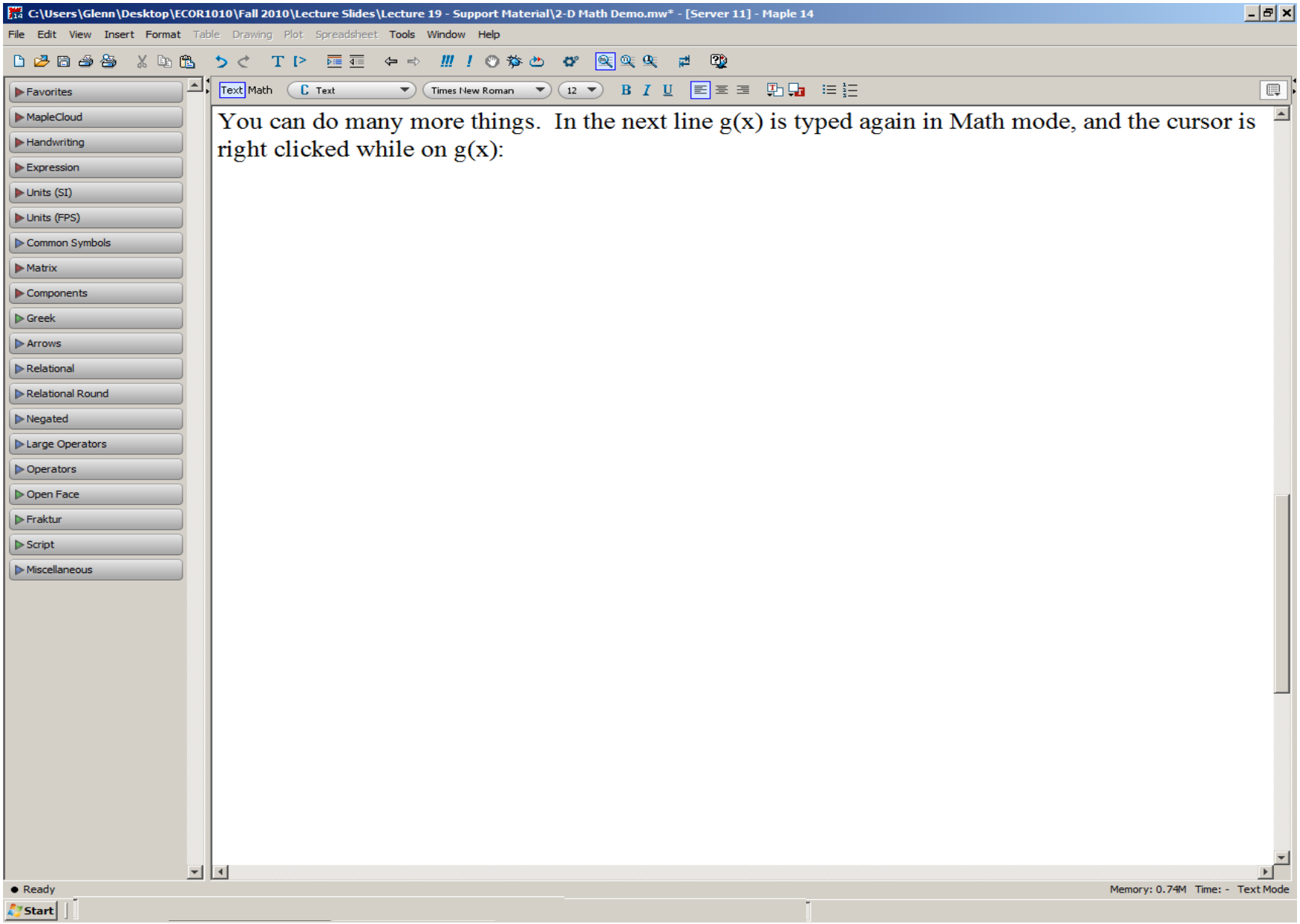
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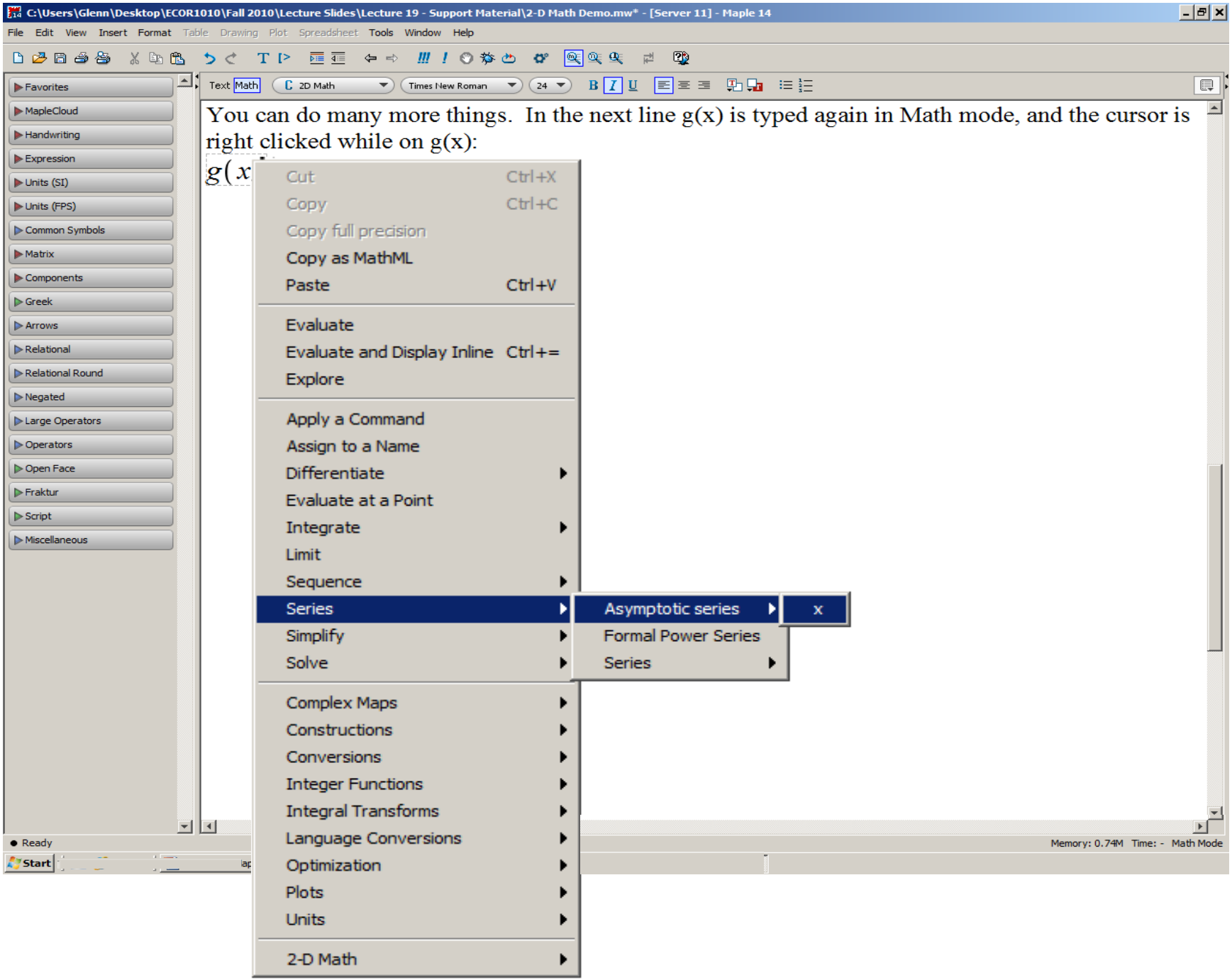
Negated
Large Operators
Operators
Open Face
Fraktur
Script
Miscellaneous
Text Math
Text
Times New Roman
12
You can do many more things. In the next line g(x) is typed again in Math mode, and the cursor is right clicked while on g(x):
Ready
Memory: 0.74M Time: - Text Mode
Start


G:\Users\Glenn\Desktop\ECOR1010\Fall 2010\Lecture Slides\Lecture 19 - Support Material\2-D Math Demo.mw* - [Server 11] - Maple 14
File Edit View Insert Format Table Drawing Plot Spreadsheet Tools Window Help
Text Math 2D Math Times New Roman 24
Favorites
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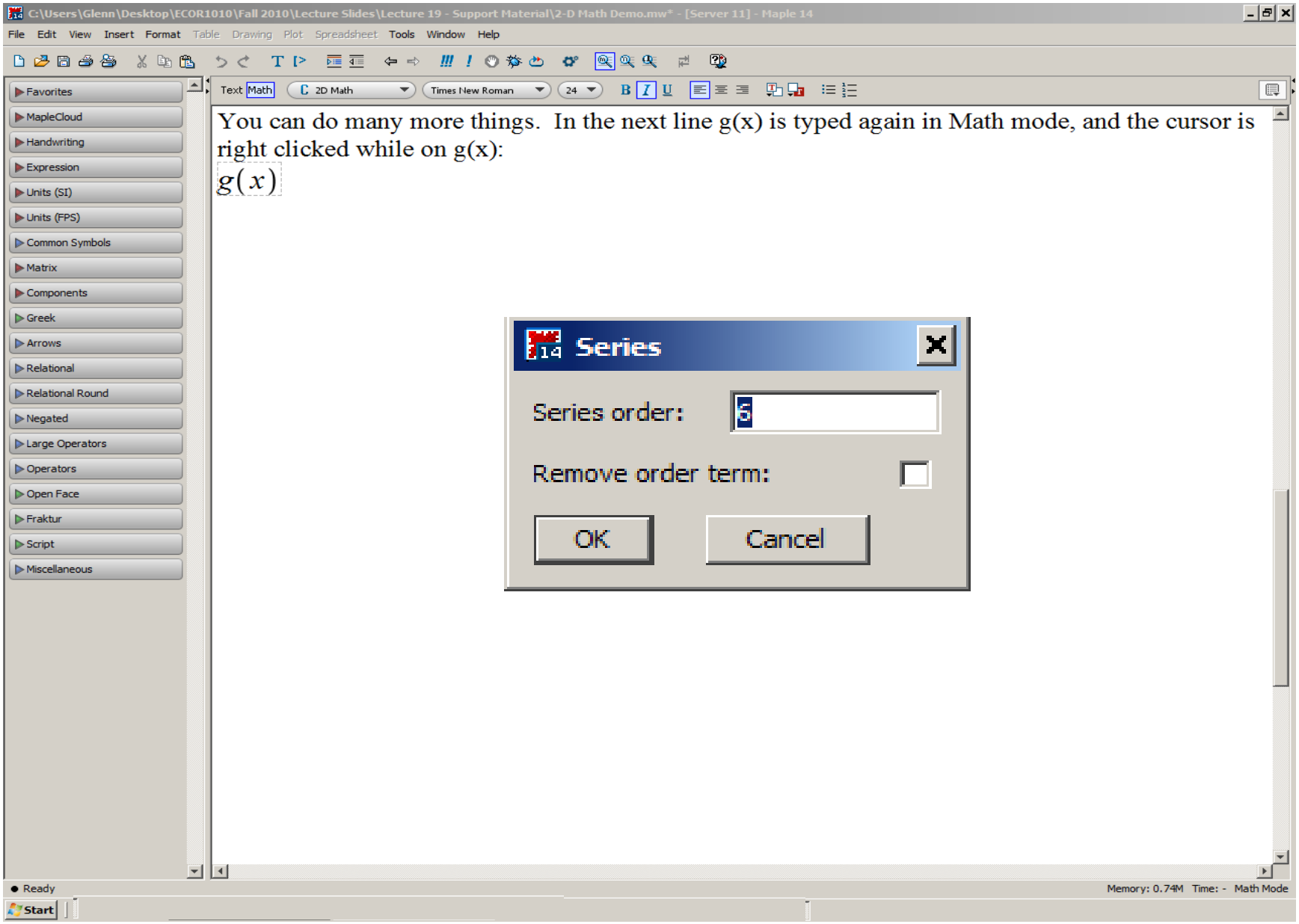
g(x
Cut Ctrl+X
Copy Ctrl+C
Copy full precision
Copy as MathML
Paste Ctrl+V
Evaluate
Evaluate and Display Inline Ctrl+=
Explore
Apply a Command
Assign to a Name
Differentiate
Evaluate at a Point
Integrate
Limit
Sequence
Series
Simplify
Solve
Complex Maps
Constructions
Conversions
Integer Functions
Integral Transforms
Language Conversions
Optimization
Plots
Units
2-D Math
Asymptotic series
Formal Power Series
Series
x
Ready
Memory: 0.74M Time: - Math Mode
Start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Miscellaneous
Text Math
2D Math
Times New Roman
24
You can do many more things. In the next line g(x) is typed again in Math mode, and the cursor is right clicked while on g(x):
g(x)
Series
Series order:
6
Remove order term:
OK
Cancel
Ready
Memory: 0.74M Time: - Math Mode
Start

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Miscellaneous

Text Math | Text | Times New Roman | 12

You can do many more things. In the next line g(x) is typed again in Math mode, and the cursor is right clicked while on g(x):

$$g(x) \xrightarrow{\text{asymptotic series in x}} -x - 1 - \frac{1}{x} - \frac{1}{x^2} - \frac{1}{x^3} - \frac{1}{x^4} - \frac{1}{x^5} + O\left(\frac{1}{x^6}\right)$$

Ready

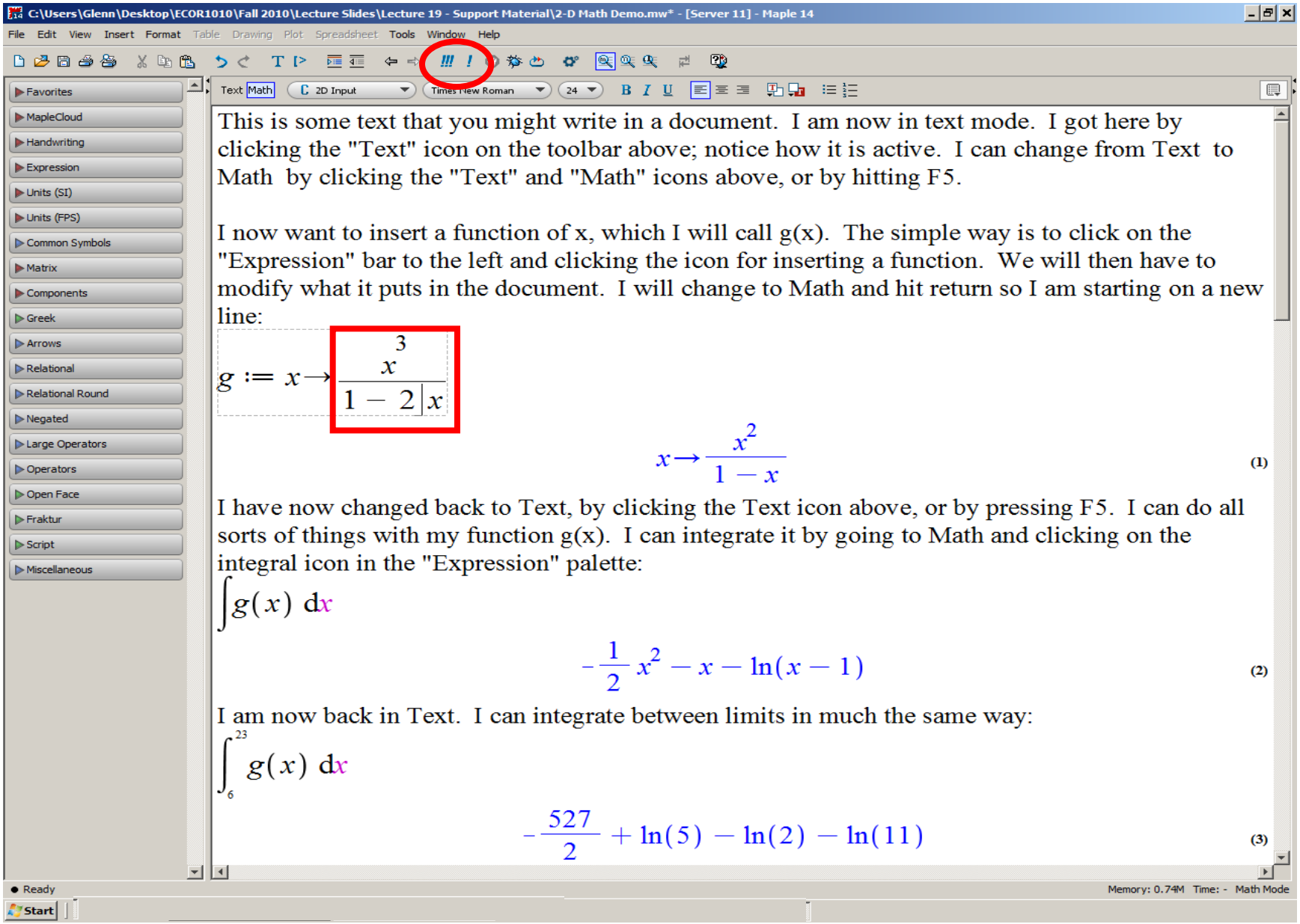
Memory: 0.74M Time: - Text Mode

Start

User controlled update

- We can go back and change the function and everything is updated if we click *!!!*
- If you only want to update a small ‘selected’ portion of the work then click *!*

➢ *see the icons circled in red at the top of the next slide*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This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.
I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:
g := x → x^3 / (1 − 2|x)
x → x^2 / (1 − x) (1)
I have now changed back to Text, by clicking the Text icon above, or by pressing F5. I can do all sorts of things with my function g(x). I can integrate it by going to Math and clicking on the integral icon in the "Expression" palette:
∫ g(x) dx
−(1/2) x^2 − x − ln(x − 1) (2)
I am now back in Text. I can integrate between limits in much the same way:
∫ from 6 to 23 g(x) dx
−527/2 + ln(5) − ln(2) − ln(11) (3)
Ready
Memory: 0.74M Time: - Math Mode
Start

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Text Math | 2D Input | Times New Roman | 24

This is some text that you might write in a document. I am now in text mode. I got here by clicking the "Text" icon on the toolbar above; notice how it is active. I can change from Text to Math by clicking the "Text" and "Math" icons above, or by hitting F5.

I now want to insert a function of x, which I will call g(x). The simple way is to click on the "Expression" bar to the left and clicking the icon for inserting a function. We will then have to modify what it puts in the document. I will change to Math and hit return so I am starting on a new line:

$$g := x \to \frac{x^3}{1 - 2x}$$

$$x \to \frac{x^3}{1 - 2x} \quad (1)$$

I have now changed back to Text, by clicking the Text icon above, or by pressing F5. I can do all sorts of things with my function g(x). I can integrate it by going to Math and clicking on the integral icon in the "Expression" palette:

$$\int g(x)\, dx$$

$$-\frac{1}{6}x^3 - \frac{1}{8}x^2 - \frac{1}{8}x - \frac{1}{16}\ln(-1 + 2x) \quad (2)$$

I am now back in Text. I can integrate between limits in much the same way:

$$\int_6^{23} g(x)\, dx$$

$$-\frac{24667}{12} + \frac{1}{16}\ln(11) - \frac{1}{8}\ln(3) - \frac{1}{16}\ln(5) \quad (3)$$

Ready

Memory: 0.74M Time: - Math Mode

Start

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Text Math | Maple Plot | Times New Roman | 12

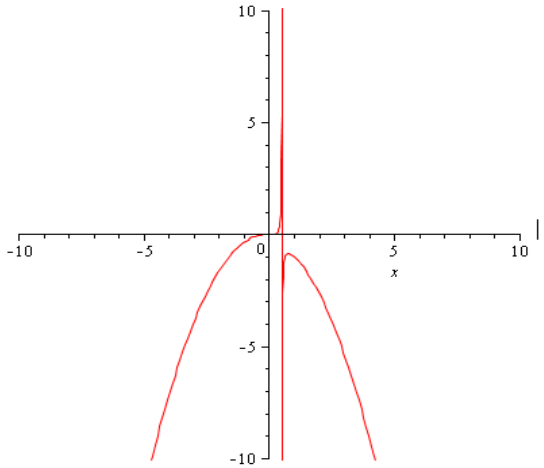
I can take the derivative of g(x):

$$\frac{\mathrm{d}}{\mathrm{d}x} g(x)$$

$$\frac{3x^2}{1-2x} + \frac{2x^3}{(1-2x)^2} \qquad (4)$$

I can plot my function g(x). One was to do this is to go into Math mode and type g(x). Then put the cursor on the g(x) you just typed and right click. A window will appear with all sorts of things you can do; one thing you can do is plot.

$g(x) \rightarrow$



You can do many more things. In the next line g(x) is typed again in Math mode, and the cursor is right clicked while on g(x):

$g(x) \xrightarrow{\text{asymptotic series in x}} -\frac{1}{2}x^2 - \frac{1}{4}x - \frac{1}{8} - \frac{1}{16x} - \frac{1}{32x^2} - \frac{1}{64x^3} - \frac{1}{128x^4} - \frac{1}{256x^5} + O\left(\frac{1}{x^6}\right)$

Ready

Memory: 0.74M Time: - Text Mode

Start

You can output your Maple file to:

- Rich text format (Word)
- LaTeX
- Adobe pdf
- .txt Text file
- .zip
- html, htm

- Hitting ‹ENTER› executes the input given. In “document” mode
- Hitting ‹CNTR›+‹=› executes an inline expression and displays the result inline (without linebreak).
- You can hit ‹SHIFT›+‹ENTER› for a new line while postponing the execution of the input. (Don’t forget the semicolon in this case.)
- In a “worksheet” or “document” you can go back, change lines and re-execute them by hitting enter.

- In a “worksheet” or “document” you can enter normal (formated) text which is not executed. ‹F5› switches between entering text and math.
- ‹ESC› shows a list of possible completions. The right mouse button displays a list of sensible operations on the object. Executing such might write something in text and math mode.
- Everything following **#** is a comment and will not be interpreted.
- **%** is a placeholder for the previous expression entered. **%%** and **%%%** are placeholders for the second and third last expression.

There are two basic ways of displaying and entering math in Maple.

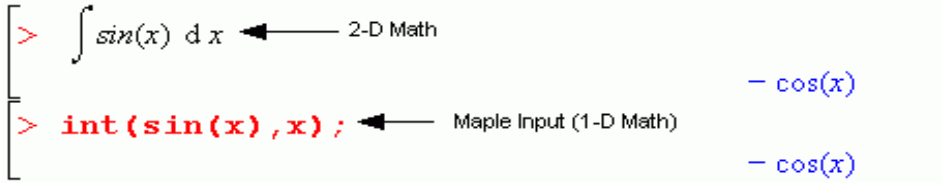
- "1-D Math" (also called "Maple Notation") is in plain ascii text form. Input must be terminated by either **;** (displays the result) or **:** (does **not** display the result).
- "2-D Math" is a more graphical way of entering and displaying math notation.
  - Everything so far has been 2-D Math

ASCII stands for American Standard Code for Information Interchange. ASCII code is the numerical representation of a character such as 'a' or '@' or an action of some sort.

2-D Math

2-D math is the *default* setting in **Worksheet Mode** and **Document Mode**. It is executable standard math notation displayed in a format similar to that found in business and education documents.

Maple Input is executable (1-D math) Maple notation, usually a mathematical expression that Maple can evaluate.



Basic Usage: 2-D Math and 1-D Math Input

2-D Math	*Default setting*. Executable standard math notation. > $\int \sin(x)\,dx$ You do *not* require a semicolon or colon to terminate the command or expression. Access from the **Insert>2-D Math** menu. To switch between 1-D and 2-D math, press the **F5** key or click the **Math** mode icon. When using 2-D math, the **Math** mode icon is highlighted in the toolbar. In **Worksheet** and **Document** modes with 2-D math, the cursor appears with a gray underbar and the input font is **black**. To change the appearance of 2-D math, modify the character styles **2D Input** (for Worksheet mode) and **2D Math** (for Document mode).
1-D Math	Executable Maple notation. Usually an expression that Maple can evaluate. `> factor(x^2 + 2*x + 1);` $(x+1)^2$ **Important**: All 1-D commands must terminate with a semicolon or colon. Access from the **Insert>Maple Input** menu. To switch between 1-D and 2-D math , press the **F5** key or click the **Text** mode icon. When entering Maple input and text, the **Text** mode icon is highlighted in the toolbar. In **Worksheet** and **Document** modes with 1-D math, the input font is **red**.

Basic Operations

- Maple uses the same basic operations as in MATLAB (+, −, *, /)
- Also, factorial ! and exponents ^

In 1-D Math mode:

```
> 3*4-(20*log(3.23)):
> 3*4-(20*log(3.23));
```

$$-11.44964274 \quad (1)$$

```
> 23!;
```

$$25852016738884976640000 \quad (2)$$

```
> 4!
Warning, inserted missing semicolon at end of statement
```

$$24 \quad (3)$$

Some Basic Maple Functions

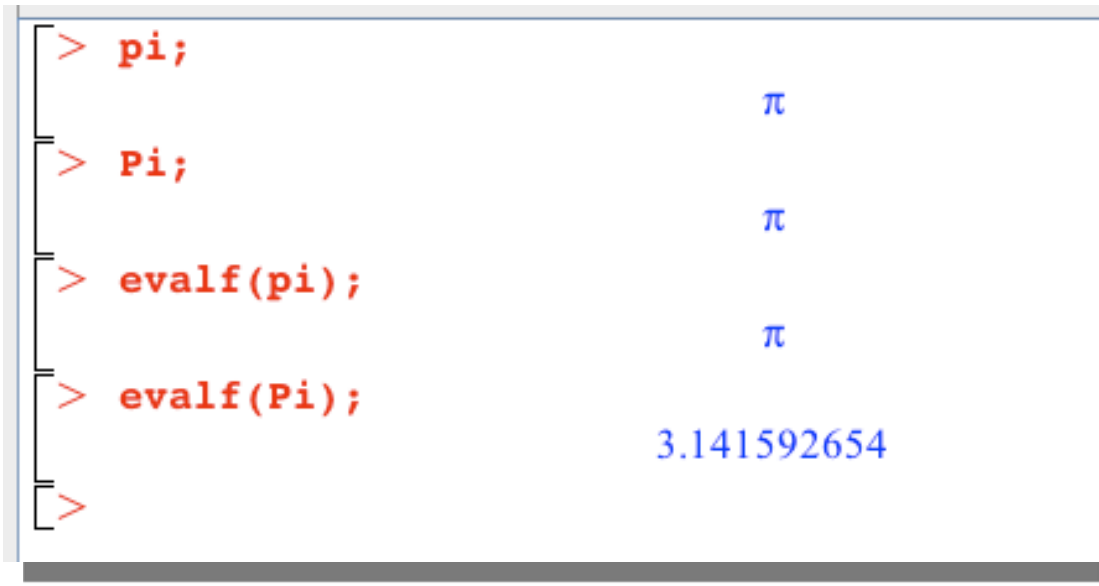
Description	Maple Name
Absolute value, |-2|	`abs(-2)`
Square root	`sqrt(2)`
Exponential function	`exp(x)`
Natural logarithm	`ln(x), log(x)`
Base 10 logarithm	`log[10](x)`

Trigonometric functions	`sin(x), cos(x),`
	`tan(x), csc(x),`
	`sec(x), cot(x)`

Inverse trigonometric functions	`arcsin(x), arccos(x),`
	`arctan(x), arccsc(x),`
	`arcsec(x), arccot(x)`

Special Characters

- Spell out Greek letters to use them in Maple
  - To get θ type theta
  - To get π type pi
  - To use the numerical value of π type Pi
  - Use evalf to find the numerical value



Assignment Operator

- Assign equations and values to a variable, use the := operator
- Value on the left of := is assigned to the value on the right
- The = and := operators ar not the same
- You **cannot** perform recursive assignments

  a := a + 1;

```
> y := diff(x^3+exp(3*x),x);
```

$$y := 3x^2 + 3e^{3x}$$

```
> solve(p^2+q^2-4=0,p);
```

$$\sqrt{-q^2+4}, -\sqrt{-q^2+4}$$

```
>
```

Using the % Operator

- Allows you to use the output from the last command % in the next command

```
> y := diff(x^3+exp(3*x),x);
```

$$y := 3x^2 + 3e^{3x}$$

```
> int(%,x);
```

$$x^3 + e^{3x}$$

```
>
```

Evaluating Expressions

- Maple does not automatically evaluate the numerical value of results
- Use the eval and evalf commands:
  - Expression goes in the argument: see below
  - Or use evalf(expression,n) for evaluation to n significant digits

$$> \; y := 3 \cdot x + 1 :$$

$$> \; eval(y, x = 4);$$

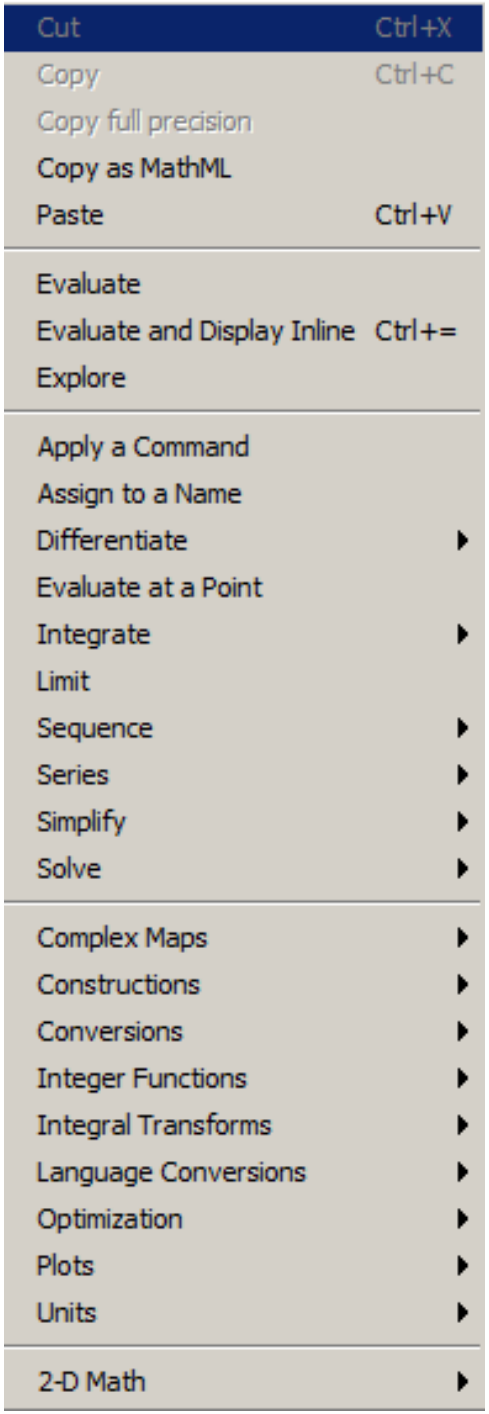
$$13$$

$$> \; evalf\left(\frac{1}{2}\sin\left(\frac{\mathrm{Pi}}{2} \right) + \frac{1}{3}\cos\left(\frac{n\ \mathrm{Pi}}{2} \right), 3 \right);$$

$$0.500 + 0.333\cos(1.57\,n)$$

What can Maple do with Equations?

- Factor
- Expand
- Differentiate
- Integrate
- Limits
- Solve
- Plot



Factoring

- Maple can factor
- Use the factor(expression) command
  - If it can't factor it, it will just return the expression
- Use expand(expression) to expand a factored expression

Factor & Expand Examples

```
> eqn1:=x^2-4;
```

$$eqn1 := x^2 - 4$$

```
> factor(eqn1);
```

$$(x-2)\,(x+2)$$

```
> factor(x^2-5*x+6);
```

$$(x-2)\,(x-3)$$

```
> expand(%);
```

$$x^2 - 5\,x + 6$$

```
> factor(x^3-2*x^2+x+6);
```

$$x^3 - 2\,x^2 + x + 6$$

```
>
```

Solving an Equation

- Use solve(expr,var)
- If you do not specifiy an equation, it sets the expression to zero and solves

Solving a System of Equations

- Use the following syntax

  > solve({expr1,expr2,..},{var1,var2,…})

- Can return parametric solutions for the case where infinite solutions exist

Solve Examples

```
> solve(4*x^2-3*x-5);
```

$$\frac{3}{8} + \frac{1}{8}\sqrt{89}, \frac{3}{8} - \frac{1}{8}\sqrt{89}$$

```
> eqn1 := x^2 = 81;
```

$$eqn1 := x^2 = 81$$

```
> solve(eqn1,x);
```

$$9, -9$$

```
> eqn2 := y = 4/3*x + 3;
```

$$eqn2 := y = \frac{4}{3}x + 3$$

```
> solve(eqn2,x);
```

$$\frac{3}{4}y - \frac{9}{4}$$

```
> eval(%,y=4);
```

$$\frac{3}{4}$$

```
>
```

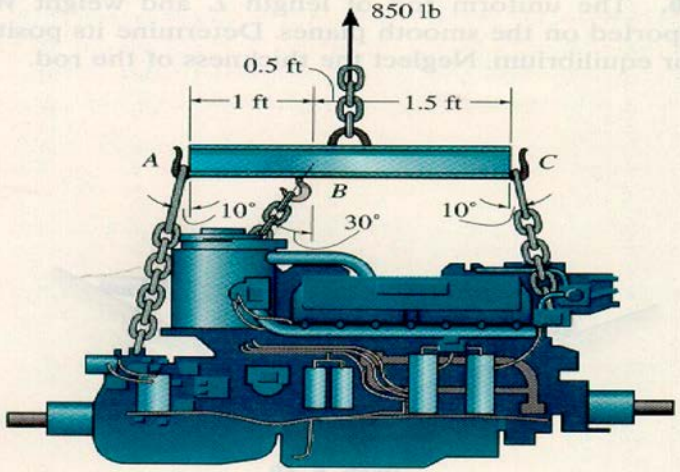
Three Equations, Three Unknowns

$$\sum F_x = 0$$

$$\sum F_y = 0$$

$$\sum M_b = 0$$

5-47. The motor has a weight of 850 lb. Determine the force that each of the chains exerts on the supporting hooks at A, B, and C. Neglect the size of the hooks and the thickness of the beam.



$$-F_A \sin 10 - F_B \sin 30 + F_C \sin 10 = 0$$

$$-F_A \cos 10 - F_B \cos 30 + 850 - F_C \cos 10 = 0$$

$$(1)F_A \cos 10 + 850(0.5) - (2)F_C \cos 10 = 0$$

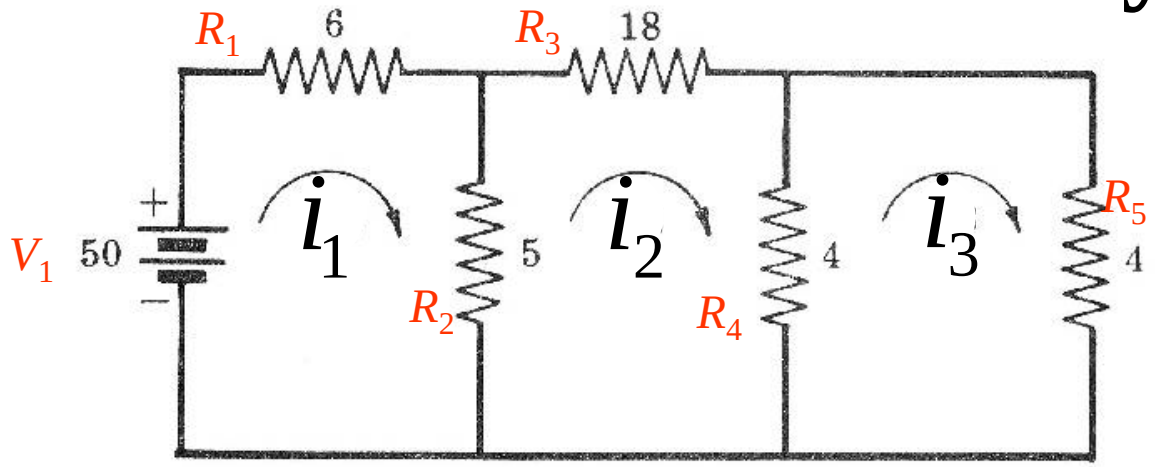
Solve Using Maple

```
> c:=Pi/180:
> SumFx:=-FA*sin(10*c)-FB*sin(30*c)+FC*sin(10*c):
> SumFy:=-FA*cos(10*c)-FB*cos(30*c)+850-FC*cos(10*c):
> SumMB:=FA*cos(10*c)+850*0.5-2*FC*cos(10*c):
> solve({SumFx,SumFy,SumMB},{FA,FB,FC});
```

$$\{FB = -1.3\ 10^{-11},\ FA = 431.5563101,\ FC = 431.5563101\}$$

$$\begin{aligned} -F_A \sin 10 - F_B \sin 30 + F_C \sin 10 &= 0 \\ -F_A \cos 10 - F_B \cos 30 + 850 - F_C \cos 10 &= 0 \\ (1)F_A \cos 10 + 850(0.5) - (2)F_C \cos 10 &= 0 \end{aligned}$$

Mesh Current Network Analysis



- Kirchhoff's voltage law: the sum of the voltage drops around any closed loop is equal to the sum of the voltage rises. (Recall Ohm's Law: V = *i* R)

$R_1 + R_2$ $\quad -R_2$

Loop 1: $i_1(6+5) - i_2 5 + i_3 \times 0 = 50$

$-R_2$ $\quad R_2 + R_3 + R_4$ $\quad -R_4$

Loop 2: $-i_1(5) + i_2(5+18+4) - i_3 \times 4 = 0$

Loop 3: $i_1(0) - i_2 4 + i_3(4+4) = 0$

$-R_4$ $\quad R_4 + R_5$

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Text Math | Text | Times New Roman | 20

In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

Ready

Memory: 0.74M Time: 0.03s Text Mode

Start

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Rows: 3
Columns: 3
Choose...
Type: Custom values
Shape: Any
Data type: Any
Insert Matrix
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In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

$$A := \begin{bmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{bmatrix}$$

Now fill in the numbers

Ready

Memory: 0.74M Time: 0.03s Math Mode

Start

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Matrix
Rows: 3
Columns: 1
Choose...
Type: Custom values
Shape: Any
Data type: Any
Insert Vector[column]
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In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

$$A := \begin{bmatrix} 11 & -5 & 0 \\ -5 & 27 & -4 \\ 0 & -4 & 8 \end{bmatrix}:$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} m_{1,1} \\ m_{2,1} \\ m_{3,1} \end{bmatrix}$$

Now fill in the numbers

Ready

Memory: 0.74M Time: 0.03s Math Mode

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$$A := \begin{bmatrix} 11 & -5 & 0 \\ -5 & 27 & -4 \\ 0 & -4 & 8 \end{bmatrix}:$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} 50 \\ 0 \\ 0 \end{bmatrix}:$$

Ready

Memory: 0.74M Time: 0.03s Text Mode

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$$A := \begin{bmatrix} 11 & -5 & 0 \\ -5 & 27 & -4 \\ 0 & -4 & 8 \end{bmatrix}:$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} 50 \\ 0 \\ 0 \end{bmatrix}:$$

The solution is just the inverse of the A matrix multiplied on the left of the B vector:

$$C := A^{-1} B$$

$$\begin{bmatrix} 5 \\ 1 \\ \frac{1}{2} \end{bmatrix} \quad (1)$$

Ready

Memory: 0.74M Time: 0.03s Math Mode

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In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

$$A := \begin{bmatrix} R1+R2 & -R2 & 0 \\ -R2 & R2+R3+R4 & -R4 \\ 0 & -R4 & R4+R5 \end{bmatrix}:$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} V1 \\ 0 \\ 0 \end{bmatrix}:$$

Symbolic Answer

The solution is just the inverse of the A matrix multiplied on the left of the B vector:

$$C := A^{-1} B$$

$$\begin{bmatrix} \dfrac{(R2\,R4 + R2\,R5 + R3\,R4 + R3\,R5 + R5\,R4)\,V1}{R1\,R2\,R4 + R1\,R2\,R5 + R1\,R3\,R4 + R1\,R3\,R5 + R1\,R5\,R4 + R2\,R3\,R4 + R2\,R3\,R5 + R2\,R5\,R4} \\ \dfrac{R2\,(R4+R5)\,V1}{R1\,R2\,R4 + R1\,R2\,R5 + R1\,R3\,R4 + R1\,R3\,R5 + R1\,R5\,R4 + R2\,R3\,R4 + R2\,R3\,R5 + R2\,R5\,R4} \\ \dfrac{R2\,R4\,V1}{R1\,R2\,R4 + R1\,R2\,R5 + R1\,R3\,R4 + R1\,R3\,R5 + R1\,R5\,R4 + R2\,R3\,R4 + R2\,R3\,R5 + R2\,R5\,R4} \end{bmatrix} \quad (1)$$

Ready

Memory: 0.74M Time: 0.03s Math Mode

Start

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Favorites
MapleCloud
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Open Face
Fraktur
Script
Miscellaneous

Text Math | 2D Output | Times New Roman | 20

In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

$$A := \begin{bmatrix} R1 + R2 & -R2 & 0 \\ -R2 & R2 + R3 + R4 & -R4 \\ 0 & -R4 & R4 + R5 \end{bmatrix} :$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} V1 \\ 0 \\ 0 \end{bmatrix} :$$

The solution is just the inverse of the A matrix multiplied on the left of the B vector:

$$C := A^{-1} B$$

$$\begin{bmatrix} \frac{1}{10} V1 \\ \frac{1}{50} V1 \\ \frac{1}{100} V1 \end{bmatrix} \quad (1)$$

$R1 := 6 :$
$R2 := 5 :$
$R3 := 18 :$
$R4 := 4 :$
$R5 := 4 :$

Ready

Memory: 0.74M Time: 0.03s Math Mode

Start

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Rows: 3
Columns: 1
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Type: Custom values
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Negated
Large Operators
Operators
Open Face
Fraktur
Script
Miscellaneous
Text Math 2D Output Times New Roman 18

In this window we will solve the simple circuit from earlier lectures. First we will construct the A matrix. We will change to Math mode on a new line, type $A:=$ to assign the symbol A to our matrix, and then open up the Matrix Palette and insert a 3x3 matrix:

$$A := \begin{bmatrix} R1+R2 & -R2 & 0 \\ -R2 & R2+R3+R4 & -R4 \\ 0 & -R4 & R4+R5 \end{bmatrix} :$$

Notice the colon, this stops Maple from repeating the assignment. Now define the Voltage vector, called B, in the same way:

$$B := \begin{bmatrix} V1 \\ 0 \\ 0 \end{bmatrix} :$$

The solution is just the inverse of the A matrix multiplied on the left of the B vector:

$$C := A^{-1} B$$

$$\begin{bmatrix} \frac{25}{8} & \frac{92+27\,R5}{57+17\,R5} \\ \frac{125}{8} & \frac{4+R5}{57+17\,R5} \\ & \frac{125}{2\,(57+17\,R5)} \end{bmatrix} \quad (1)$$

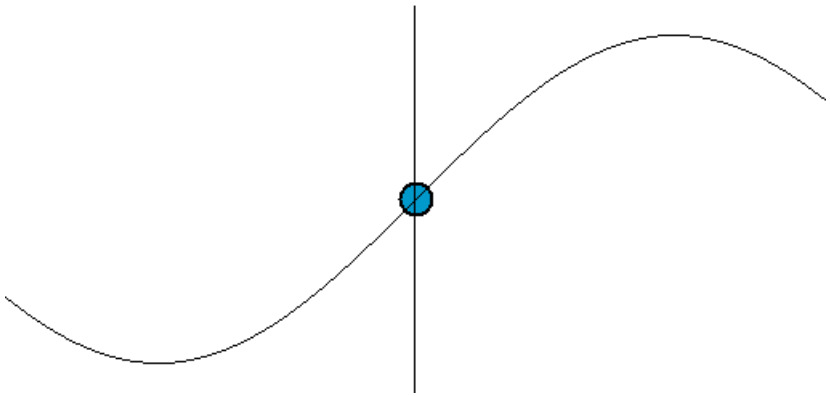
$R1 := 6 :$
$R2 := 5 :$
$R3 := 18 :$
$R4 := 4 :$
$V1 := 50 :$

Ready
Memory: 0.74M Time: 0.03s Math Mode
Start

Harmonic Oscillator

- For a mass moving in the y direction with a linear restoring force:

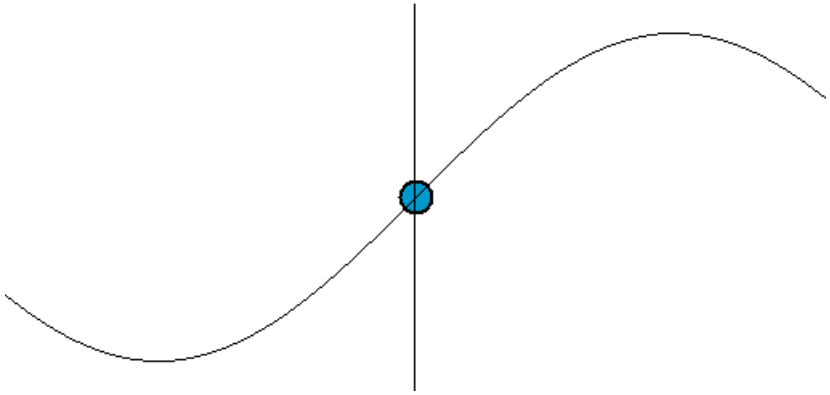
$$F = -ky$$



Harmonic Oscillator

- For a mass moving in the y direction with a linear restoring force:

$$F = ma = m\frac{\mathrm{d}^2 y}{\mathrm{d}^2 t} = -ky$$



- The solution is:

$$y(t) = A\sin(\omega t + \phi)$$

$$\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T}$$

Damped Harmonic Oscillator

- Friction can often be modelled with an additional term proportional to the velocity:

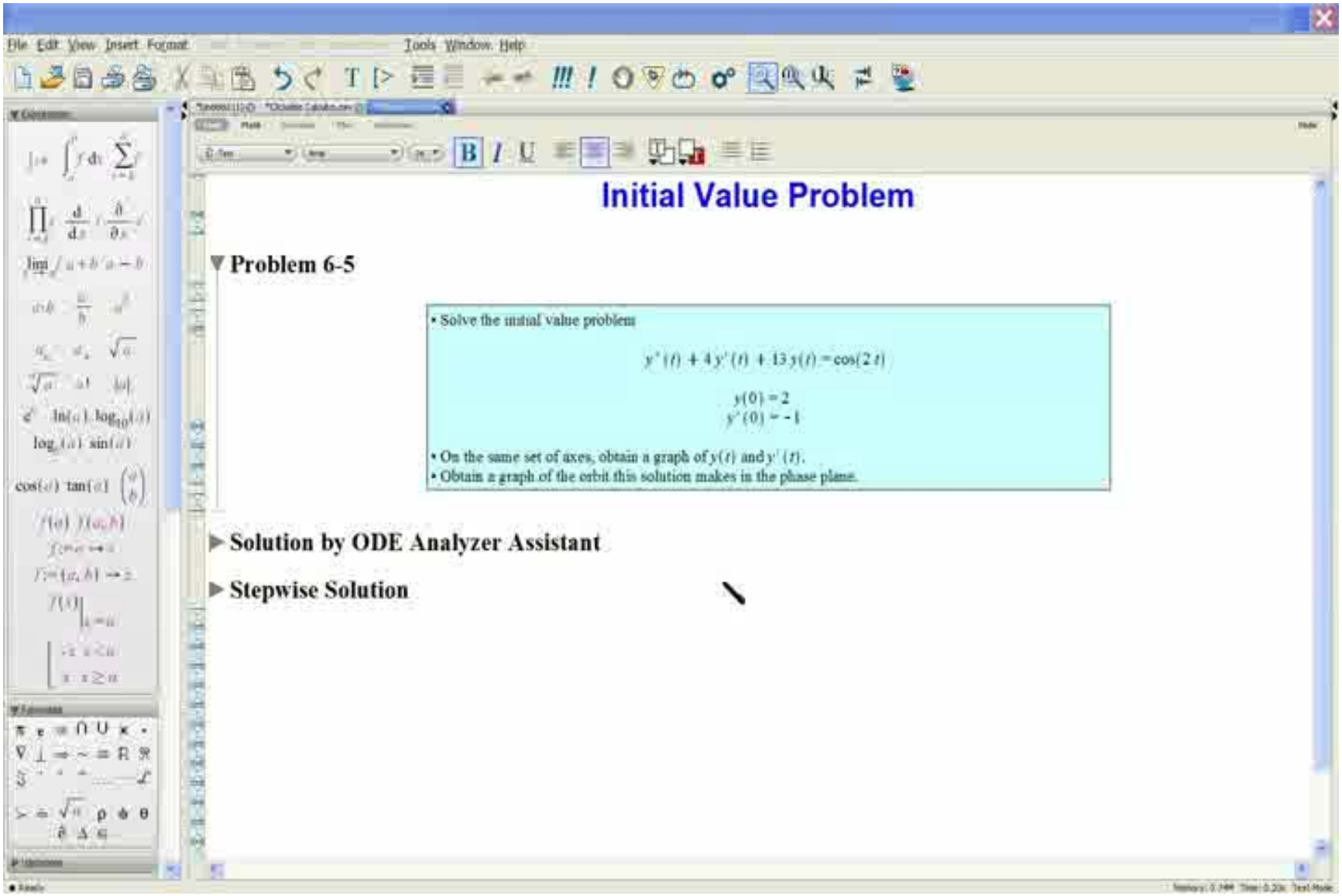
$$F = ma = m\frac{\mathrm{d}^2 y}{\mathrm{d}^2 t} = -ky - c\frac{dy}{dt}$$

Driven Damped Harmonic Oscillator

- We can drive the damped oscillator with an external force, $F(t)$:

$$F = ma = m\frac{\mathrm{d}^2 y}{\mathrm{d}^2 t} = -ky - c\frac{dy}{dt} + F(t)$$

- This is a driven damped harmonic oscillator and the solution is more complicated.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Initial Value Problem
Problem 6-5
• Solve the initial value problem
$$y''(t) + 4y'(t) + 13y(t) = \cos(2t)$$
$$y(0) = 2$$
$$y'(0) = -1$$
• On the same set of axes, obtain a graph of $y(t)$ and $y'(t)$.
• Obtain a graph of the orbit this solution makes in the phase plane.
Solution by ODE Analyzer Assistant
Stepwise Solution

Professional Engineering

ECOR 1010
Lecture 22

Licensed Professions:

Health Care

- Medicine
- Nursing
- Dentistry
- Pharmacy
- Midwifery
- Social Work
- Psychology
- Veterinarians
- Medical Physics
- …

Business

- Law
- Accounting

Design & Technology

- Engineering
- Geo Science
- Architecture

Where else do we see licences?

- We need licences to operate cars, trucks, and airplanes
- What distinguishes people with these licences from licensed professionals?

What is a Profession?

- “A self-selected, self-disciplined group of individuals who hold themselves out to the public as possessing a special skill derived from training and education and are prepared to exercise that skill in the interests of others”

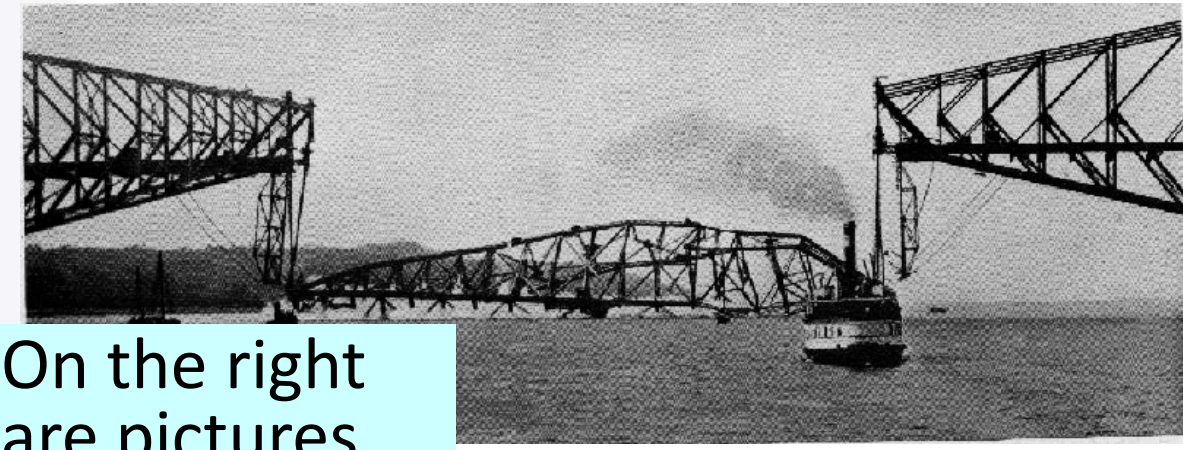
Why do we Licence People?

- To tell clients and customers that these individuals have met standards of education and competence that we as a society deem sufficient to do the job.
  - If you need brain surgery, you want someone who has the right training, and is an honourable person; not some quack who thinks he knows what to do.
  - If you want to build a bridge, you want someone who has mastered the art of bridge building, and is a trustworthy person of good character.
- Licensed Professionals have an exclusive **legal** right to practice
  - No one else can do the job, by law.

Has nothing to do with "looking professional"

Reasons why you might want a professional

Remains after the southern span fell in 1907, killing 75 (courtesy N



- On the right are pictures of the collapse of 1907
- Above is a picture from the collapse of 1916
- To the right is the bridge today.

The twisted steel wreckage of the Quebec Bridge after its collapse 2
August 1907 (courtesy National Archives of Canada).

Theodore Cooper's design and the current bridge …

Professional Organizations

- All recognized professional bodies organize themselves into self-governing professional societies or associations
  - e.g., College of Physicians and Surgeons
  - Professional Engineers Ontario (PEO)
- Major function is to define the duties and responsibilities of their members
  - Code of Ethics
  - Guidelines for Practice
  - Disciplinary Procedures

Legislative Mandate

- Provincial jurisdiction in Canada
  - Professional Engineers Act
  - By state in the USA
- Professional Engineering is defined in the Act
  - “practice of professional engineering” means any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising that requires the application of engineering principles and concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment, or the managing of any such act; New

Legislative Mandate

- Provincial jurisdiction in Canada
  - Professional Engineers Act
  - By state in the USA
- Professional Engineering is defined in the Act
  - "Any act of designing, composing, evaluating, advising, reporting, directing or supervising; wherein the safeguarding of life, health, property or the public welfare is concerned, and that requires the application of engineering principles, but does not include practising as a natural scientist" Old

Professional Engineers Act

- Professional Engineers Ontario (PEO)
  - www.peo.on.ca
  - http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90p28_e.htm
  - http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_900941_ev004.htm

Professional Engineers Act

R.S.O. 1990, CHAPTER P.28

Consolidation Period: From June 22, 2006 to the e-Laws currency date.

Last amendment: 2006, c.19, Sched.B, s.14.

Brand New (Passed into Law October 25, 2010):
http://www.e-laws.gov.on.ca/html/source/statutes/english/2010/elaws_src_s10016_e.htm

Professional Engineering

- Unifying theme is public safety
  - Bridges and buildings
  - Designing vehicles that carry people
    - Planes, trains, and automobiles
  - Software to operate a nuclear reactor
  - Electrical and electronic components
  - Control systems
  - Environmental engineering
  - …

Responsible and Accountable

- Society has granted Professional Engineers the exclusive **legal** right to practice engineering
- In return, Society has expectations:
  - Responsibility
  - Accountability
  - No unreasonable errors or omissions that involve public safety
  - Liability and liability insurance

Professional Engineers Ontario (PEO)

- Licensing and enforcement body in Ontario
- Enforces Professional Engineers Act
- Enforces standards of competence
- Enforces use of the title “Professional Engineer” and “P.Eng.”
- Responsible for public safety

- Does not protect engineers
- Has nothing to do with the “Iron Ring”

Code of Ethics

- All Professional Engineers must follow the "Code of Ethics"
- Part of Regulation 941 of the Professional Engineers Act in Ontario
  - http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_900941_ev004.htm
- The Code of Ethics spells out the duties and responsibilities of a Professional Engineer

Code of Ethics

- Defines the professional engineer's responsibilities to:
  - Society and the environment
  - The engineer's employer and/or clients
  - Fellow engineers
- Other professional obligations arise from:
  - Technical standards and protocols
  - Business and corporate practice
  - International treaties

Code of Ethics

It is your professional duty to understand and abide by the code of ethics to the very best of your ability

Tenets of the Code of Ethics

- **#1: Safety**: Health and Welfare of the Public
- Practitioners are to do work only within their competence
- Practitioners are to conduct themselves with honesty, integrity, fairness and objectivity
- Comply with applicable codes, statutes, regulations, etc.
- Uphold and enhance the honour and dignity of the profession

Code of Ethics and Misconduct

- Definition of Professional Misconduct: Section 72 of Regulations, R.R.O. 1990, Reg. 941, s. 72 (1); O. Reg. 657/00, s. 1 (1):

http://www.peo.on.ca/complaints/definition_misconduct.htm

Definition of Professional Misconduct: Section 72 of Regulations RRO. 941

72. (1) In this section,

"harassment" means engaging in a course of vexatious comment or conduct that is known or ought reasonably to be known as unwelcome and that might reasonably be regarded as interfering in a professional engineering relationship;

"negligence" means an act or an omission in the carrying out of the work of a practitioner that constitutes a failure to maintain the standards that a reasonable and prudent practitioner would maintain in the circumstances. R.R.O. 1990, Reg. 941, s. 72 (1); O. Reg. 657/00, s. 1 (1).

(2) For the purposes of the Act and this Regulation,

"professional misconduct" means,

(a) negligence,

(b) failure to make reasonable provision for the safeguarding of life, health or property of a person who may be affected by the work for which the practitioner is responsible,

(c) failure to act to correct or report a situation that the practitioner believes may endanger the safety or the welfare of the public,

(d) failure to make responsible provision for complying with applicable statutes, regulations, standards, codes, by-laws and rules in connection with work being undertaken by or under the responsibility of the practitioner,

(e) signing or sealing a final drawing, specification, plan, report or other document not actually prepared or checked by the practitioner,

(f) failure of a practitioner to present clearly to the practitioner's employer the consequences to be expected from a deviation proposed in work, if the professional engineering judgment of the practitioner is overruled by non-technical authority in cases where the practitioner is responsible for the technical adequacy of professional engineering work,

(g) breach of the Act or regulations, other than an action that is solely a breach of the code of ethics,

(h) undertaking work the practitioner is not competent to perform by virtue of the practitioner's training and experience,

(i) failure to make prompt, voluntary and complete disclosure of an interest, direct or indirect, that might in any way be, or be construed as, prejudicial to the professional judgment of the practitioner in rendering service to the public, to an employer or to a client, and in particular, without limiting the generality of the foregoing, carrying out any of the following acts without making such a prior disclosure:

1. Accepting compensation in any form for a particular service from more than one party.
2. Submitting a tender or acting as a contractor in respect of work upon which the practitioner may be performing as a professional engineer.
3. Participating in the supply of material or equipment to be used by the employer or client of the practitioner.
4. Contracting in the practitioner's own right to perform professional engineering services for other than the practitioner's employer.

5. Expressing opinions or making statements concerning matters within the practice of professional engineering of public interest where the opinions or statements are inspired or paid for by other interests,

(j) conduct or an act relevant to the practice of professional engineering that, having regard to all the circumstances, would reasonably be regarded by the engineering profession as disgraceful, dishonourable or unprofessional,
(k) failure by a practitioner to abide by the terms, conditions or limitations of the practitioner's licence, limited licence, temporary licence or certificate,
(l) failure to supply documents or information requested by an investigator acting under section 34 of the Act,
(m) permitting, counselling or assisting a person who is not a practitioner to engage in the practice of professional engineering except as provided for in the Act or the regulations,
(n) harassment. R.R.O. 1990, Reg. 941, s. 72 (2); O. Reg. 657/00, s. 1 (2).

Misconduct

- Negligence
  - "**negligence**" means an act or an omission in the carrying out of the work of a practitioner that constitutes a failure to maintain the standards that a reasonable and prudent practitioner would maintain in the circumstances
- Failure to safeguard life, health and property
- Failure to report or correct something that endangers public safety
- Failure to comply with codes, statutes, etc.
- Failure to disclose conflicts of interest clearly to employer

Misconduct

- Breach of the Act
- Undertaking work for which the Practitioner is not qualified
- Disgraceful, dishonorable or unprofessional conduct
- Failure to abide by license

Misconduct

- Failure to cooperate with PEO investigators
- Permitting or assisting a person who is not a practitioner to engage in professional activities
- Harassment
  - "**harassment**" means engaging in a course of vexatious comment or conduct that is known or ought reasonably to be known as unwelcome and that might reasonably be regarded as interfering in a professional engineering relationship

Designation and Seal

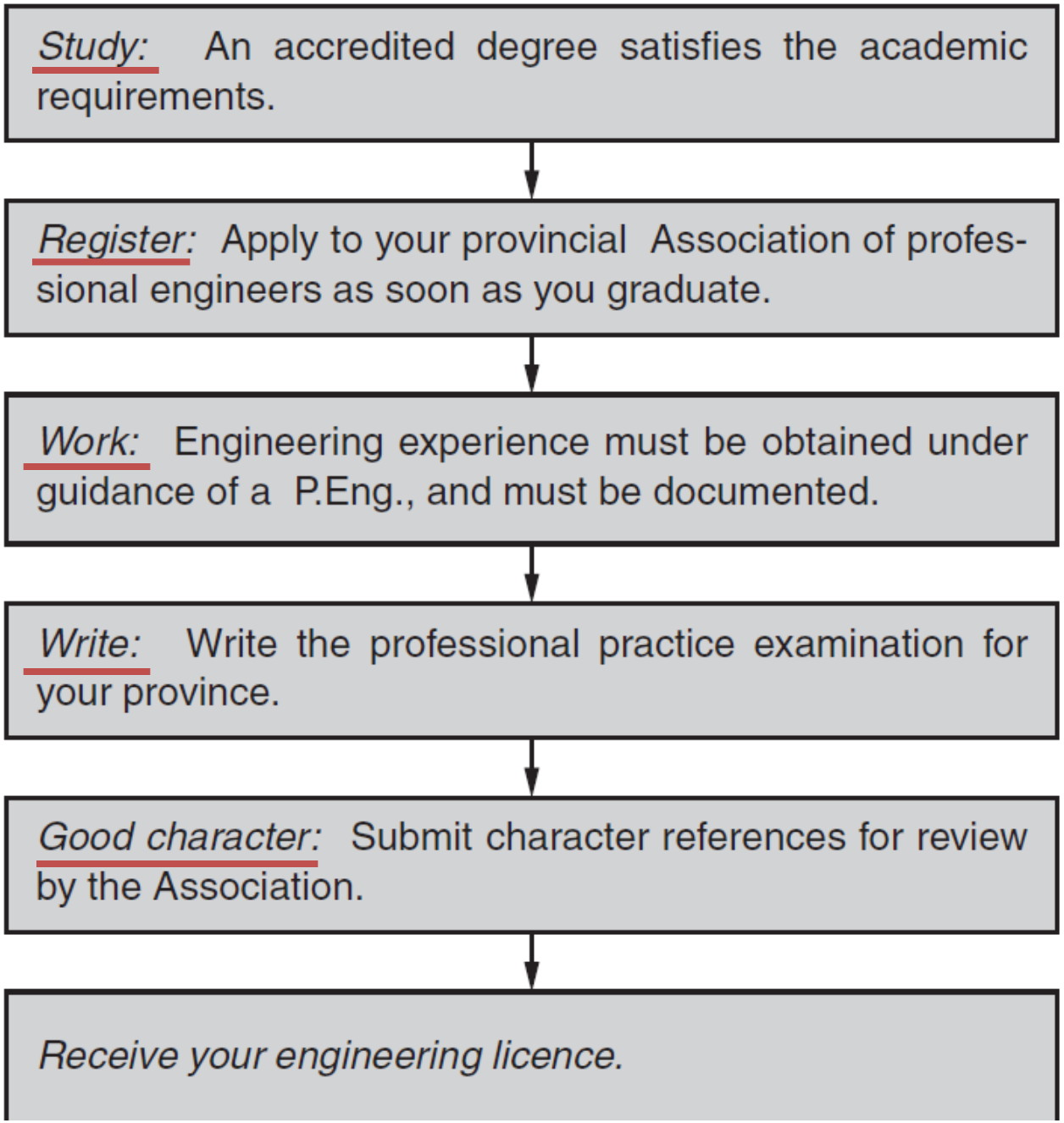
- Your ECOR 1010 professor:
  - G. McRae, P.Eng.

Figure 5.1 A typical professional engineer's seal. On an actual seal, the name of the licensed engineer appears on the crossbar. (Courtesy of Professional Engineers Ontario)

Requirements for Licensing

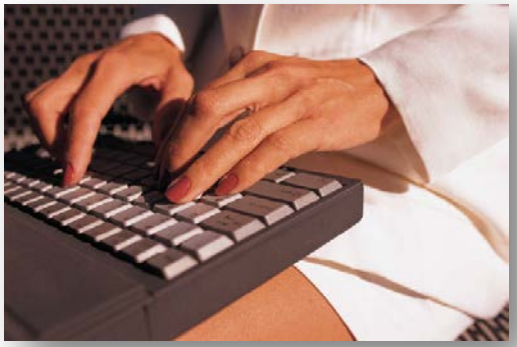
- Be at least 18 years old
- ~~Be a citizen or permanent resident of Canada~~
- Be of good character
- Meet education standards established by PEO
- Pass the professional practice exam (PPE) on engineering law and ethics
- Meet engineering experience requirements
  - Four years of engineering practical experience in Ontario

Steps to becoming a Professional Engineer from an accredited university program



Acceptable Engineering Experience

- Based on five quality-based criteria
  1. Application of Theory
  2. Practical Experience
  3. Management of Engineering
  4. Communication Skills
  5. Social Implications of Engineering



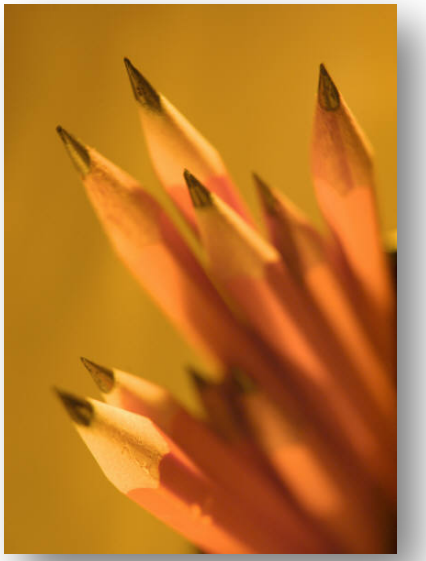
Pre-Graduation Experience

- You can count up to 12 months of experience prior to graduation
- Experience counts only after you have completed 50% of your coursework
  - e.g., after second year
- Assessed on the five criteria in the previous slide

Experience Credit

- Graduate degrees (e.g., M.Eng., M.A.Sc.) can give you up to 12 months of experience credit
  - They must be in the same discipline as your undergraduate engineering degree
- Thesis research can count if it is:
  - Applied engineering in nature
  - Is funded externally
- Total time credit cannot exceed the time required for the degree and thesis research

Academic Requirements



- Mathematics
  - Minimum 1/8 of the program
- Basic sciences
  - About 1/8 of the program
- Engineering sciences (ES)
  - Minimum 1/8 of the program
- Engineering design (ED)
  - Minimum 1/8 of the program
- ES plus ED must be minimum 1/2 of the program
- Complementary studies
  - Minimum 1/8 of the program

Your Engineering Degree at Carleton satisfies these requirements

Additional Academic Requirements

- Complementary studies must include engineering economics
- Environment and sustainable development
- Health and safety
- Ethics and professional practice

Your Engineering Degree at Carleton satisfies these requirements

Example Professional Practice Exam (PPE) Question: Conflict of Interest

You are a Professional Engineer in the mechanical department of a large general contracting firm. You have recently inherited shares of stock in a company that manufactures air handling equipment. You hold this company's products in very high regard and often specify them on projects that your company is building.

Now that you are a shareholder of this company can you ethically continue to specify its products? If you feel that you can, is there any action that you should take to do so ethically?

Conflicts of Interest

- Individual engineers should be aware of the potential for conflicts of interest
- Must be clearly and unambiguously disclosed to the employer and/or client

Other Conflicts

- Can arise from differences of ‘technical’ opinion between engineers, or between an engineer and his/her company
- In such circumstances, engineers are advised to maintain written records, kept in a safe place, of any disagreement and the course of action that was taken

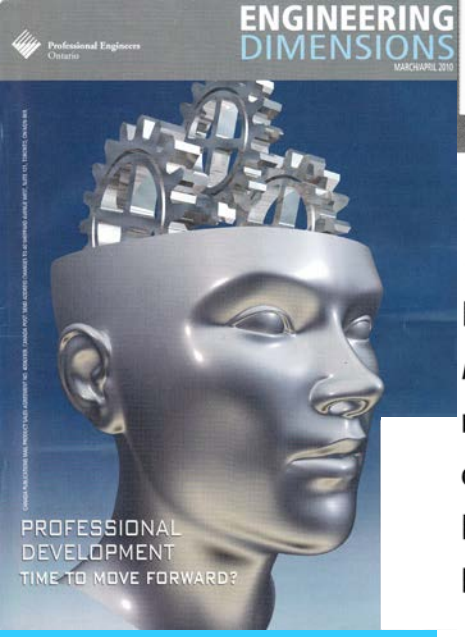
Enforcement of the Act

- Usually starts with complaint
  - PEO also does pro-active investigations
  - Based on Code of Ethics, e.g. a person practicing without a license
- Complaint lodged with Discipline Committee
  - Enacted through PEO Act
- Discipline Committee decides whether formal hearing is warranted

Hearing

- PEO is the prosecutor
- Engineer is defendant
- Complaints committee is judge and jury
- Fines, lifting of license, etc.
- Name and details published for all to see
  - e.g., in the “Engineering Dimensions” publication

You do not want your name in the “blue pages”.



GAZETTE

DECISION AND REASONS

In the matter of a hearing under the *Professional Engineers Act* and in the matter of a complaint regarding the conduct of **Your name ?** , P.ENG., a member of the Association of Professional Engineers of Ontario, and **Your company ?** , a holder of a Certificate of Authorization.

THE ALLEGATIONS

The allegations against **You** , and **Your company** are contained in Exhibit 1, the Notice of Hearing dated June 20, 2007. They allege that **You are** guilty of incompetence, and that **Your company was** guilty of professional misconduct.

In summary, they allege that **You**

(a) provided certifications and opinions that the fire and life safety systems in several new buildings were in compliance with the Ontario Building Code (OBC) and the National Fire Protection Association (NFPA) when they were not;

(b) failed to make adequate provisions to comply with the OBC and NFPA regulations and requirements;

(c) provided certification of fire and life safety installations, which they were not competent or qualified to do;

(d) sealed and signed a certification that they did not conduct or supervise; and

(e) acted in a disgraceful, dishonourable and unprofessional manner.

Non-Engineers

- Practicing without a license
  - PEO goes to public court
- If found guilty:
  - $10,000 fine
  - $50,000 fine for repeat offenders
- Enforcement on www.peo.on.ca

Certificate of Authorization

- If you want to offer services to the public, you need a Certificate of Authorization

"No person shall offer to the public or engage in the business of providing to the public services that are within the practice of professional engineering except under and in accordance with a certificate of authorization."

Certificate of Authorization

- Required anytime a firm or individual offers professional engineering services to the public
- Individual
  - Must be licensed professional engineer
  - Must have five years of licensed practice
  - Must demonstrate competency in C of A area
  - Must be insured
- Engineering Firm
  - Designates an individual P.Eng. as Chief Engineer

PEO Act

- Public safety is central to PEO Act and practice
- The act
  - Regulates behavior of Engineers as employers and employees
  - Regulates Engineers who act as consultants and report on matters of safety

Professional Engineers

- Designs are to be safe (first priority)
  - Central focus of the profession
- Engineers violate the Act (*i.e.,* the Law) if they give advice that put workers in harm's way
  - Engineers have a special obligation because they have been given the responsibility for public safety

Example: Pre-Start Health & Safety Reviews

- Required by Section 7 of Regulation 941 for Industrial Establishments
- For installation of new equipment or hazardous processes
- Consists of report from P. Eng. stating what is required to comply with Regulation

Engineering Safety Reviews

- Safety reviews are required before a piece of equipment, machine or device is:
  - Reconstructed
  - Altered in some way
  - or installed in some way
- Situations where there is toxicity, flammability, temperature, pressure changes, etc.
- Situations where there is the requirement for guards, shields, control devices for safety, etc.

Types of Certification

- Detailed reports stating, for examples:
  - Equipment safe to operate, will not endanger a worker
  - Floor capable of supporting or withstanding applied loads
  - Stresses do not exceed material limits with appropriate safety factor

Letter of Confirmation

- P.Eng. investigates, reports to the owner, and generates a letter of confirmation
  - Certifying that equipment is safe
- Owner uses this in case of legal problems at some point in the future

Professional Engineers are legally responsible for:

- Design work
- Producing reports
- Certifying equipment
- Certifying structures
- Performing Pre-Start Health and Safety Reviews

Bottom Line

- Provide certification/reports under the Occupational Health and Safety Act (OHSA)
- Liable under both OHSA and PEO Act
- Must understand and correctly apply all applicable legislation and standards
- Must not work outside experience/training

Protect the Public and Yourself

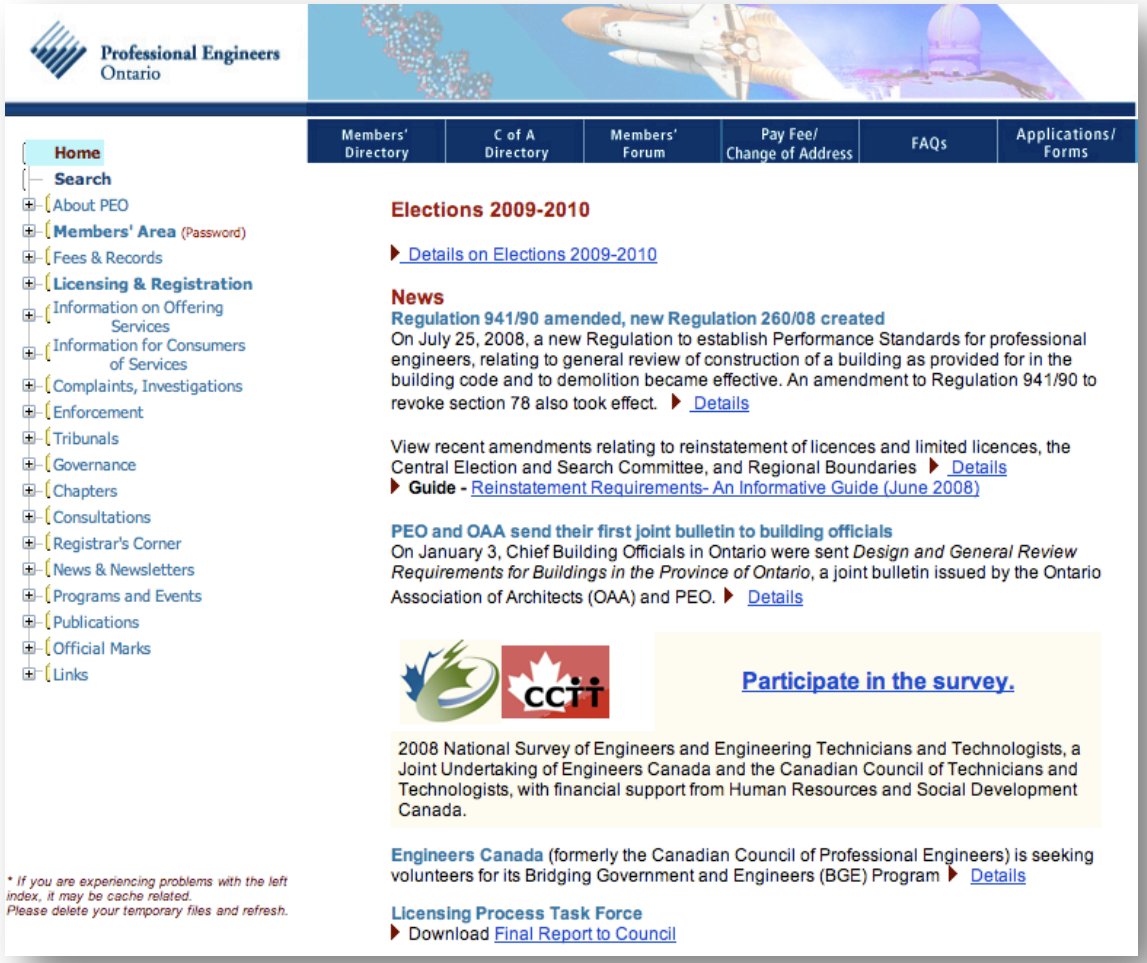
Do

- Work within your competence
- Understand and document scope of work
- Understand and apply national and international standards
- Document all references and assumptions

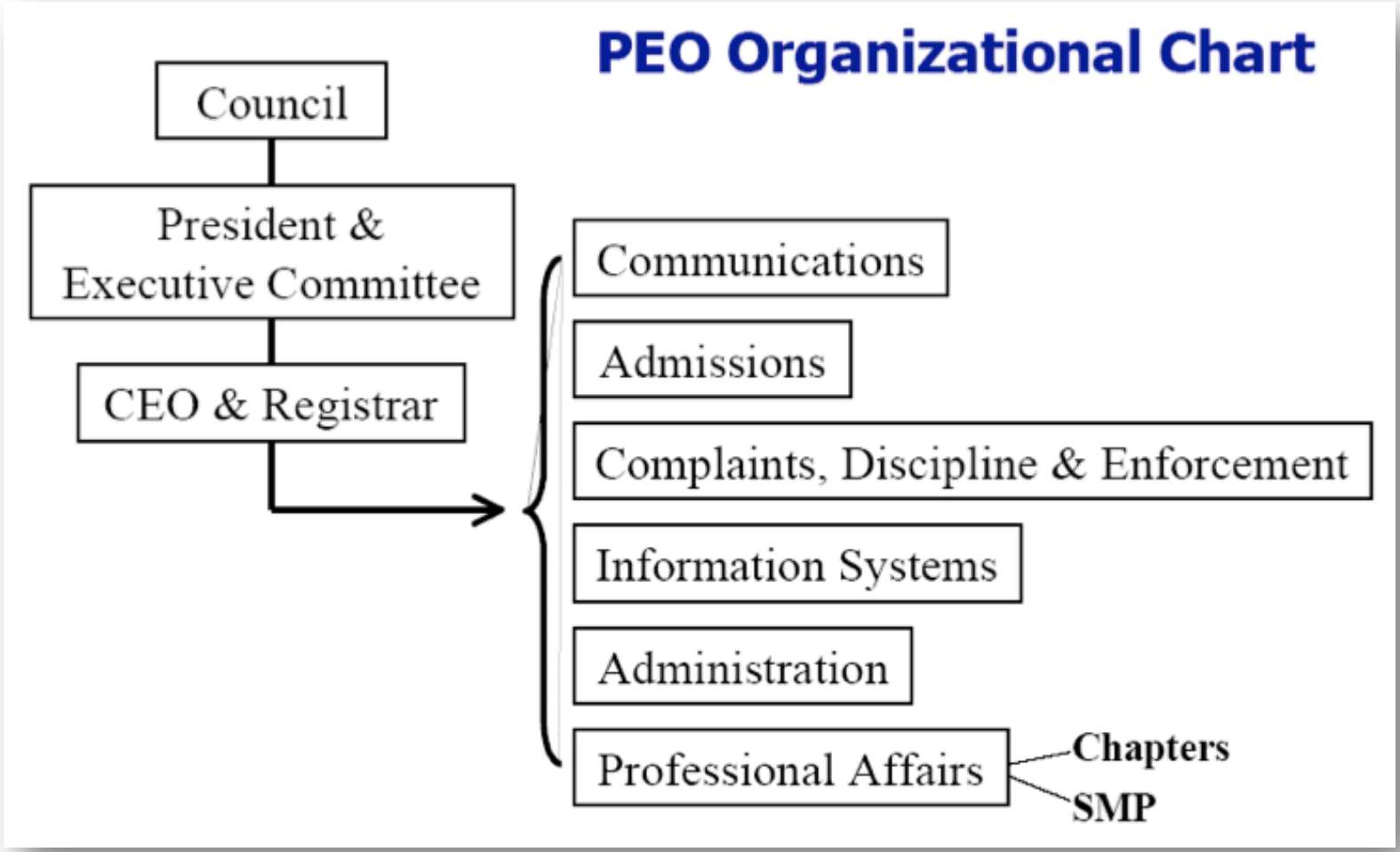
Do Not

- Work outside of your field of knowledge
- Assume that things are “understood” without being documented
- Become overconfident
- Be pressured by employer, client or peers

PEO Online (www.peo.on.ca)



How Does the PEO Work?



PEO Chapters

- Geographically based, chapters are local branches of PEO
  - Activities are organized by volunteer professional engineers living within the chapter
- Chapter boundaries are defined mainly by postal code
- PEO licensees are assigned to the chapter in which they reside

PEO Chapters

- Facilitates the participation of licensees (Professional Engineers) in governing and advancing the engineering profession
- Maintains a local presence for PEO through activities of interest to engineers and of benefit to their communities

PEO Chapters

Eastern
Algonquin
Upper Canada
Kingston
Ottawa
Peterborough
Quinte
Thousand Islands

East
East Toronto
Lake Ontario
Scarborough
Simcoe County
Willowdale/Thornhill
York

North
Algoma
Lakehead
Lake-of-the-Woods/Atikokan
North Bay
North Superior
Porcupine/Kapuskasing
Sudbury
Temiskaming

Western
Windsor-Essex
Grand River
Georgian Bay
Hamilton
Chatham-Kent County
Lambton
London
Niagara
Brantford

West Central
Brampton
Etobicoke
Kingsway
Mississauga
North Toronto
Oakville
Toronto Dufferin
Toronto Humber

Canadian Council of Professional Engineers (CCPE)

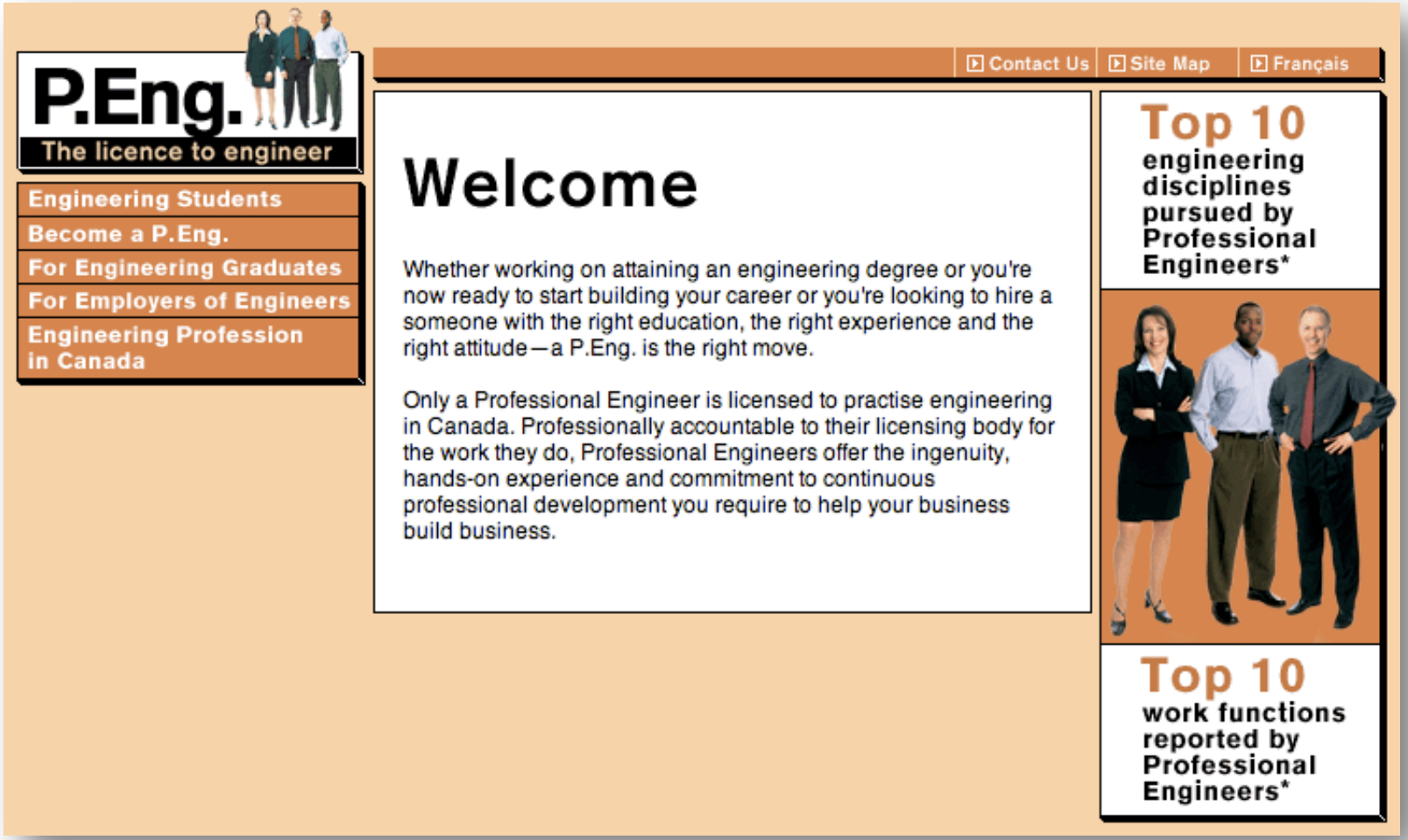
- A federation of the 13 provincial and territorial licensing bodies
- Consists of over 160,000 licensed engineers
- Coordinates high national standards in engineering education, practice, professional qualifications and ethics

engineerscanada

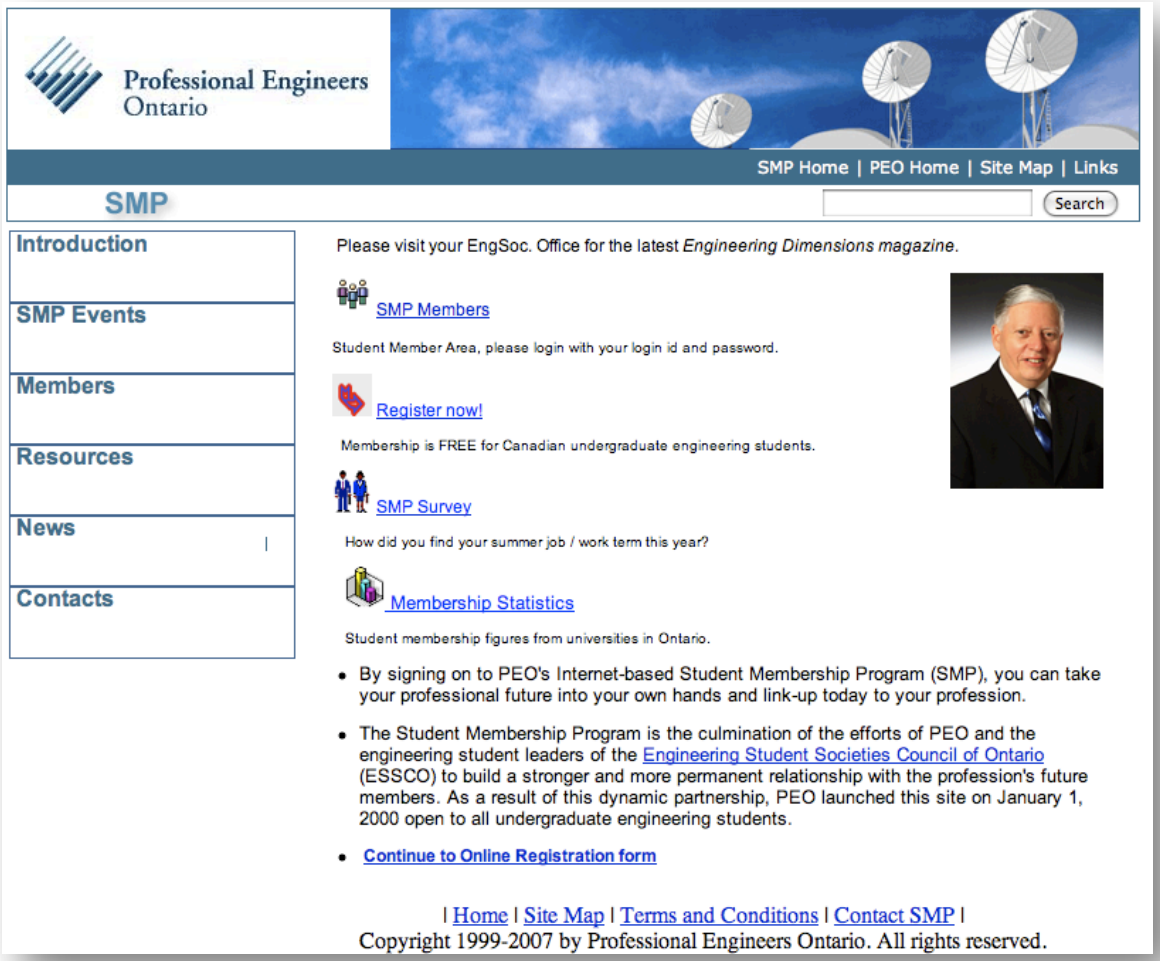
Canadian Engineering Accreditation Board (CEAB)

- A committee of the CCPE
- Accredits Canadian undergraduate engineering programs
- Programs approved by CEAB fulfill PEO's educational requirement for licensing
- All engineering programs in Carleton are fully accredited by CEAB

www.peng.ca


P.Eng.
The licence to engineer
Contact Us
Site Map
Français
Engineering Students
Become a P.Eng.
For Engineering Graduates
For Employers of Engineers
Engineering Profession in Canada
Welcome
Whether working on attaining an engineering degree or you're now ready to start building your career or you're looking to hire a someone with the right education, the right experience and the right attitude—a P.Eng. is the right move.
Only a Professional Engineer is licensed to practise engineering in Canada. Professionally accountable to their licensing body for the work they do, Professional Engineers offer the ingenuity, hands-on experience and commitment to continuous professional development you require to help your business build business.
Top 10
engineering disciplines pursued by Professional Engineers*
Top 10
work functions reported by Professional Engineers*

PEO Student Membership Program (www.engineeringstudents.peo.on.ca)



SMP Objectives

- Raise your level of professional knowledge
- Promote better communication between students and the engineering community
- Standardize the delivery of PEO's programs and activities to students
- Seamless transition from student to P.Eng.

Useful Websites

- SMP (Student Membership Program)
  - www.engineeringstudents.peo.on.ca
- PEO (Professional Engineers Ontario)
  - www.peo.on.ca
- OSPE (Ontario Society of Professional Engineers)
  - www.ospe.on.ca
- CCPE (Canadian Council of Professional Engineers)
  - www.ccpe.ca / www.peng.ca
- ESSCO (Engineering Student Socities Council of Ontario)
  - www.essco.ca

Reading Assignment

- Chapters 4 and 5

Occupational Heath and Safety

ECOR 1010
Lecture 23

The acronym is pronounced like gosh, but without the g, so people say: “osh”

Safety and Professional Engineering

- Safety is the unifying theme of professional engineering
  - You will become a leader in your organization
  - You have professional obligations
- Occupational Heath and Safety Act (OHSA)
- Ministry of Labour (Ontario)
  - Enforces the OHSA
  - Audits workplaces for compliance
  - Investigates accident and prosecutes for contravention

Occupational Heath and Safety Act

- Intended for the protection of workers against health and safety hazards on the job
- Sets out the framework for making Ontario's workplaces healthy and safe
  - Similar acts in all provinces of Canada
- Defines the rights and duties of all parties in the workplace
- Establishes procedures for dealing with workplace hazards

OHSA Online

- http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90o01_e.htm

Occupational Health and Safety Act

R.S.O. 1990, CHAPTER O.1

Consolidation Period: From August 20, 2007 to the e-Laws currency date.

Last amendment: 2007, c. 8, s. 221.

Workplace Responsibilities

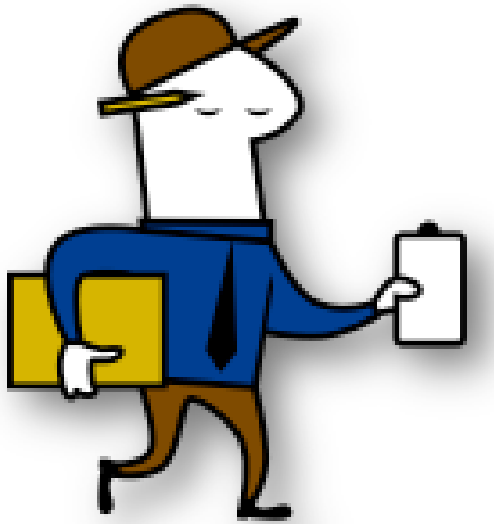
- Workers, supervisors, employers, engineers are all responsible for OHSA implementation
  - Called the Internal Responsibility System (IRS)
  - Often a company committee is formed to do so, called a Joint Heath and Safety Committee
    - Organizations with more than 20 employees
    - Composition split between workers and management
  - Identify, discuss, investigate, educate, and recommend changes to workplace practices

Duties of Workers

- Work in compliance with OHS Act and regulations
- Use protective equipment, devices or clothing that is required by the employer
- Report any defects in equipment
- Report contraventions and hazards
- Do not bypass any safety device
- Do not operate equipment that may endanger the safety of any worker
- Do not remove or make ineffective any protective device required by the employer or by the regulations

Rights of Workers

- There are four basic rights under the OHSA
  1. Right to participate
  2. Right to know
  3. Right to refuse work
  4. Right to stop work



Rights of Workers

Right to Participate

- Right to be part of the process of identifying and resolving workplace health and safety concerns

Right to Know

- Right to know about any potential dangers to which the they may be exposed
- Right to be trained and to have information on machinery, equipment and hazardous substances
  - e.g., WHIMIS

Rights of Workers

Right to Refuse Work

- Can refuse any work where unreasonable safety risks are apparent
  - There are exceptions: police officers, for example
- Must report refusal to employer/supervisor
- Refusal must be investigated
- Worker must remain at workstation if safe to do so

Right to Stop Work

- In certain circumstances, certified members of a joint health and safety committee have the right to stop work that is dangerous to any worker

Duties of the Supervisor

- Ensure workers follow safe procedures
- Ensure workers wear appropriate safety clothing or devices
- Must advise workers of hazardous situations
- Must take every reasonable precaution to ensure worker safety

Duties of the Employer

- Ensure OHSA provisions followed
  - Develop and implement a health and safety program and policy
  - Post a copy of OHSA in the workplace
- Provide training
- Supply and maintain protective equipment
- Must take every reasonable precaution to ensure safe workplace

Your Duties as an Engineer

- Ensure safety of public
- Report or correct any hazardous situation
- Maintain competence
- Do not perform work outside area of expertise (gained by training and experience)
- Apply applicable national and international codes and standards

WHIMIS

- Workplace Hazardous Materials Information System (WHMIS)
  - Cautionary labelling of containers of WHMIS "controlled products"
  - Provision of material safety data sheets (MSDS)
  - Worker education programs

Enforcement and Penalties

- Enforced internally and by the Ministry of Labour (authority to enforce the law)
- Section 31(2) of the OHSA:
  - "… a professional engineer as defined in the Professional Engineers Act contravenes this Act if, as a result of his or her advice that is given or his or her certification required under this Act that is made negligently or incompetently, a worker is endangered"

Penalties

- Section 66. (1) of the OHSA:
  - "Every person who contravenes or fails to comply with, (a) a provision of this Act or the regulations ;(b) an order or requirement of an inspector or a Director; or (c) an order of the Minister, is guilty of an offence …"
  - OHSA refers to the person not the employer!
  - Offenders are personally liable
  - Fines from $25,000 to $500,000

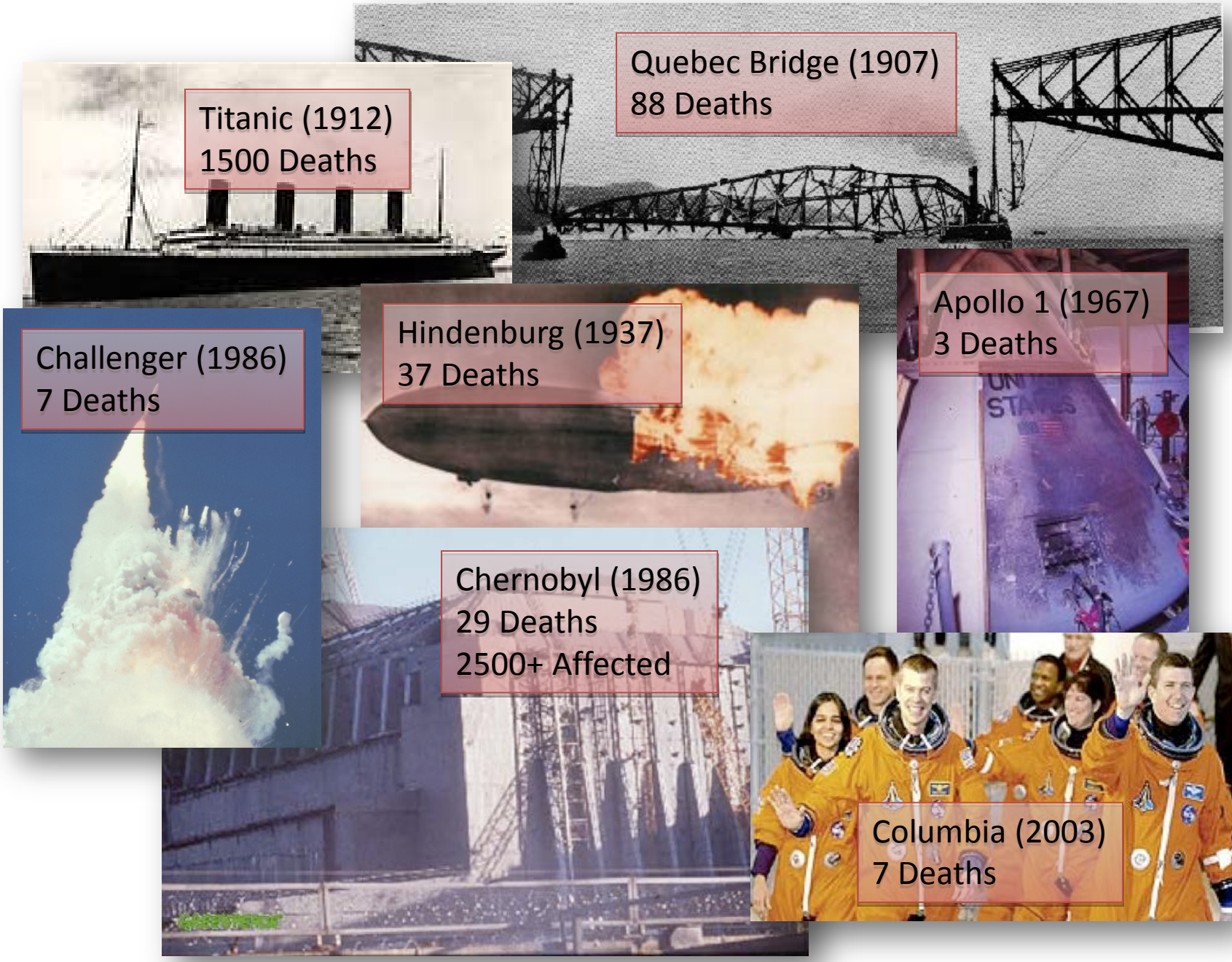
Engineering Successes and Disasters

Some Major Engineering Successes

- Pyramids in Egypt, Mexico, and South America
- Ancient Roman aqua ducts (some still in use)
- Magnetic compass
- Steam engine
- Powered flight
- Space travel
- Nuclear energy
- Wired and wireless communications
- Transistors and the microcomputer
- The Internet

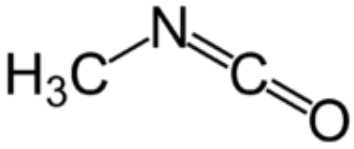
Engineering Disasters

- **Major Process Plant Accidents**
- **Management Controls and Major Accident Root Causes**


Titanic (1912)
1500 Deaths
Quebec Bridge (1907)
88 Deaths
Challenger (1986)
7 Deaths
Hindenburg (1937)
37 Deaths
Apollo 1 (1967)
3 Deaths
Chernobyl (1986)
29 Deaths
2500+ Affected
Columbia (2003)
7 Deaths

Major Process Plant Accidents

Bhopal, India 1984



- **Union Carbide pesticide manufacture.**
- **Release of 40 tonnes of heavier-than-air very toxic methyl isocyanate (MIC).**
- **Possibly the greatest industrial disaster in history.**
- **15,000 killed, 500,000 severely injured.**
- **Maintenance management problems.**
- **No safety analysis report on facility.**
- **Staff not qualified or knowledgeable with hazards.**
- **No operational safety review process.**
- **Poorly-defined line management responsibilities.**

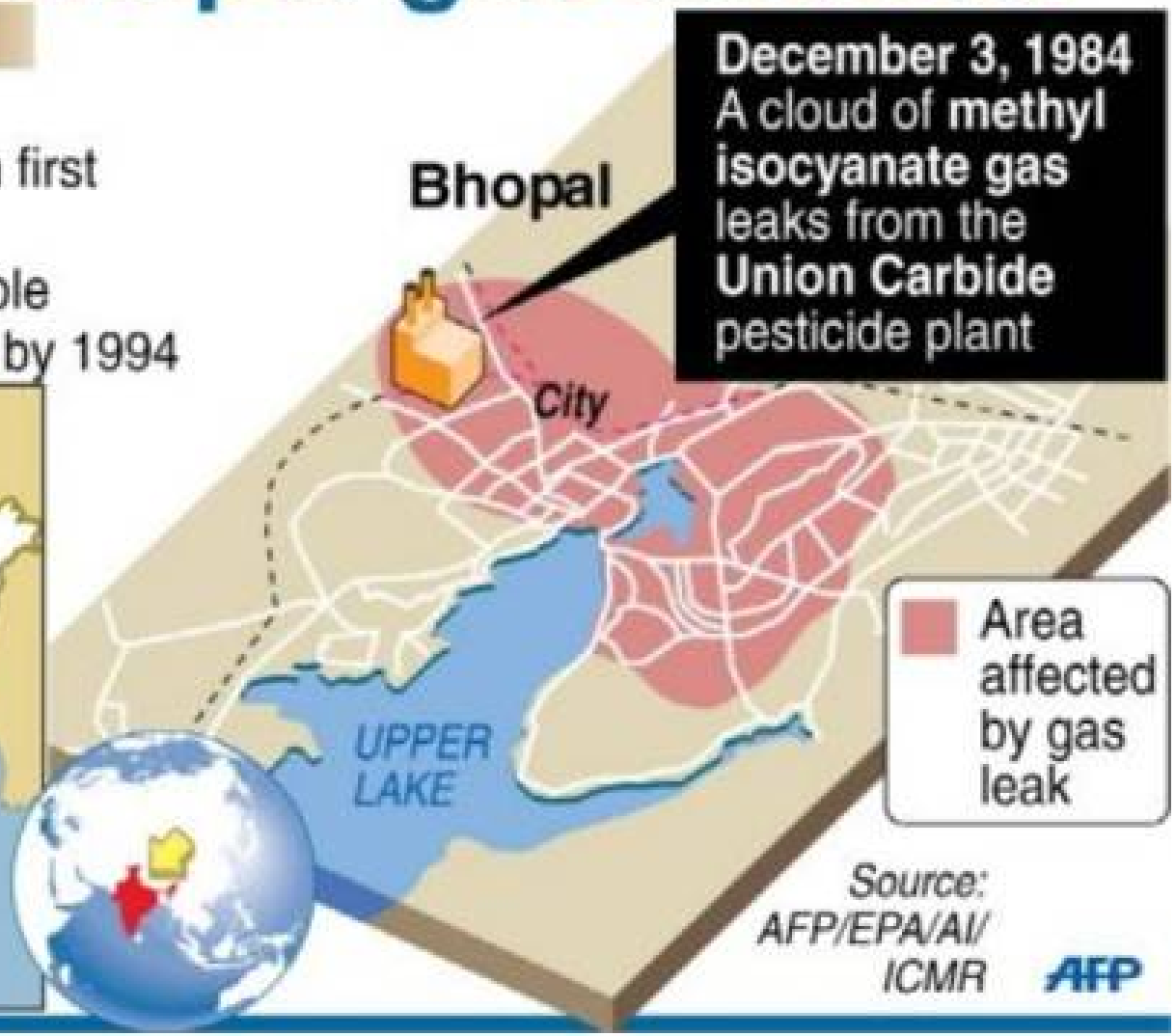
On June 7, 2010 eight UCIL executives including former chairman Keshub Mahindra were convicted of criminal negligence and sentenced to two years in jail. The sentences are under appeal.

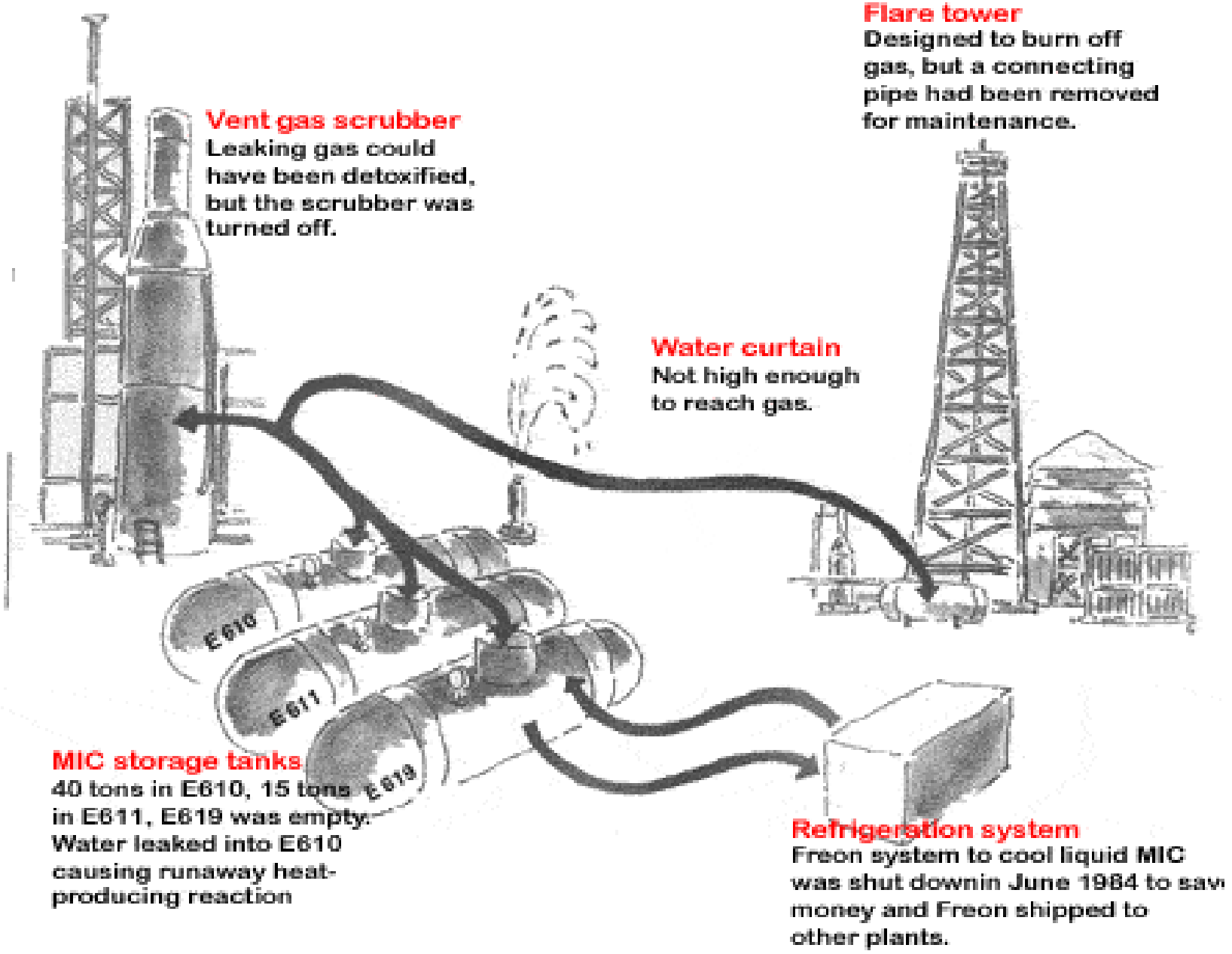
The 1984 Bhopal gas disaster

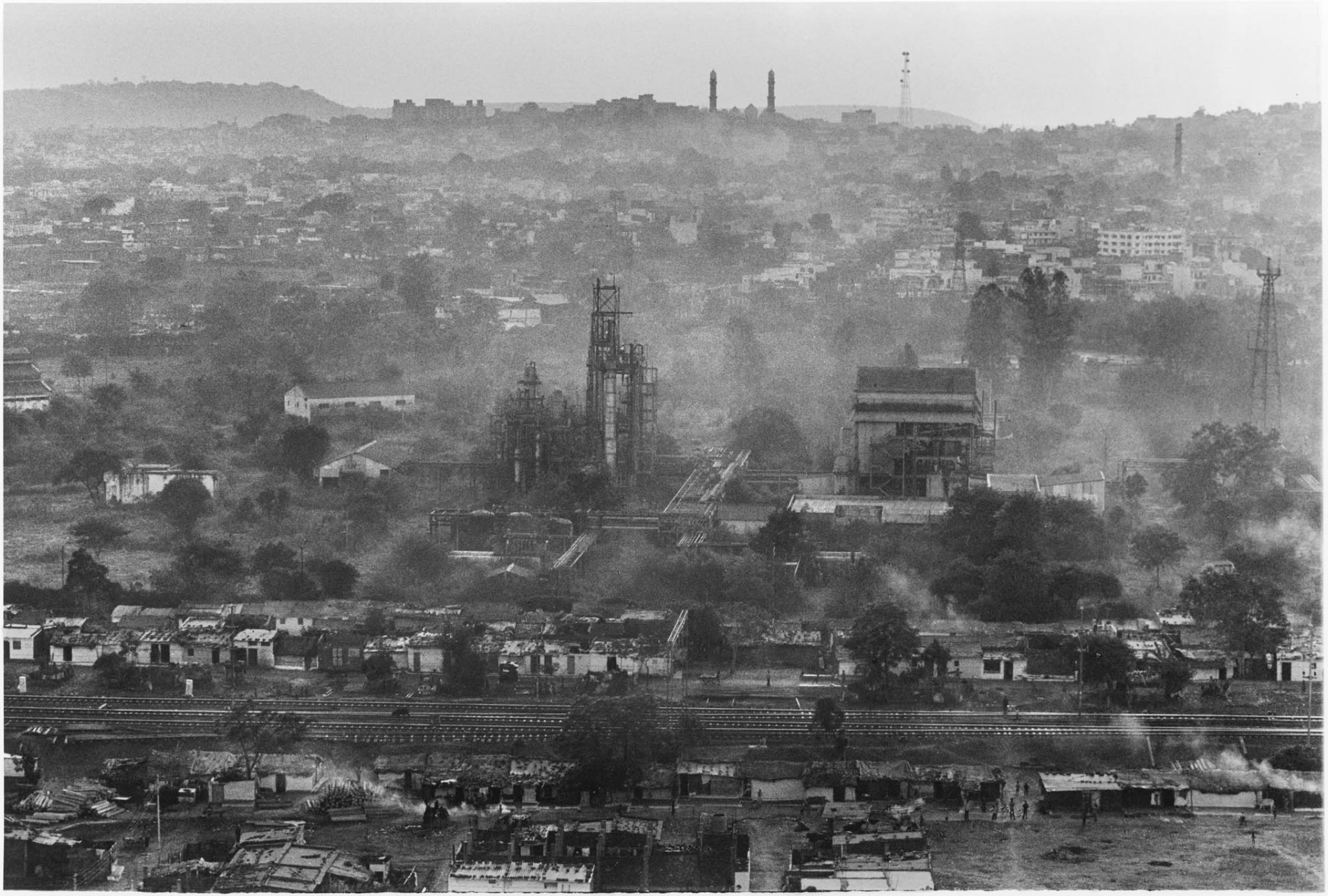
The human cost

(estimates)

- Up to 10,000 deaths in first three days
- Additional 25,000 people died of related injuries by 1994



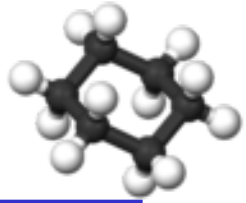

Flare tower
Designed to burn off gas, but a connecting pipe had been removed for maintenance.
Vent gas scrubber
Leaking gas could have been detoxified, but the scrubber was turned off.
Water curtain
Not high enough to reach gas.
E 610
E 611
E 619
MIC storage tanks
40 tons in E610, 15 tons in E611, E619 was empty. Water leaked into E610 causing runaway heat-producing reaction
Refrigeration system
Freon system to cool liquid MIC was shut downin June 1984 to sav money and Freon shipped to other plants.



TIME
INDIA'S DISASTER
THE NIGHT OF DEATH
A GLOBAL WORRY
TERROR ON THE TARMAC
A Murderous Skyjacking

BHOPAL DISASTER 1984 TO?
THE SUFFERING CONTINUES,
SO DOES THE STRUGGLE.

SCIENCEphotoLIBRARY

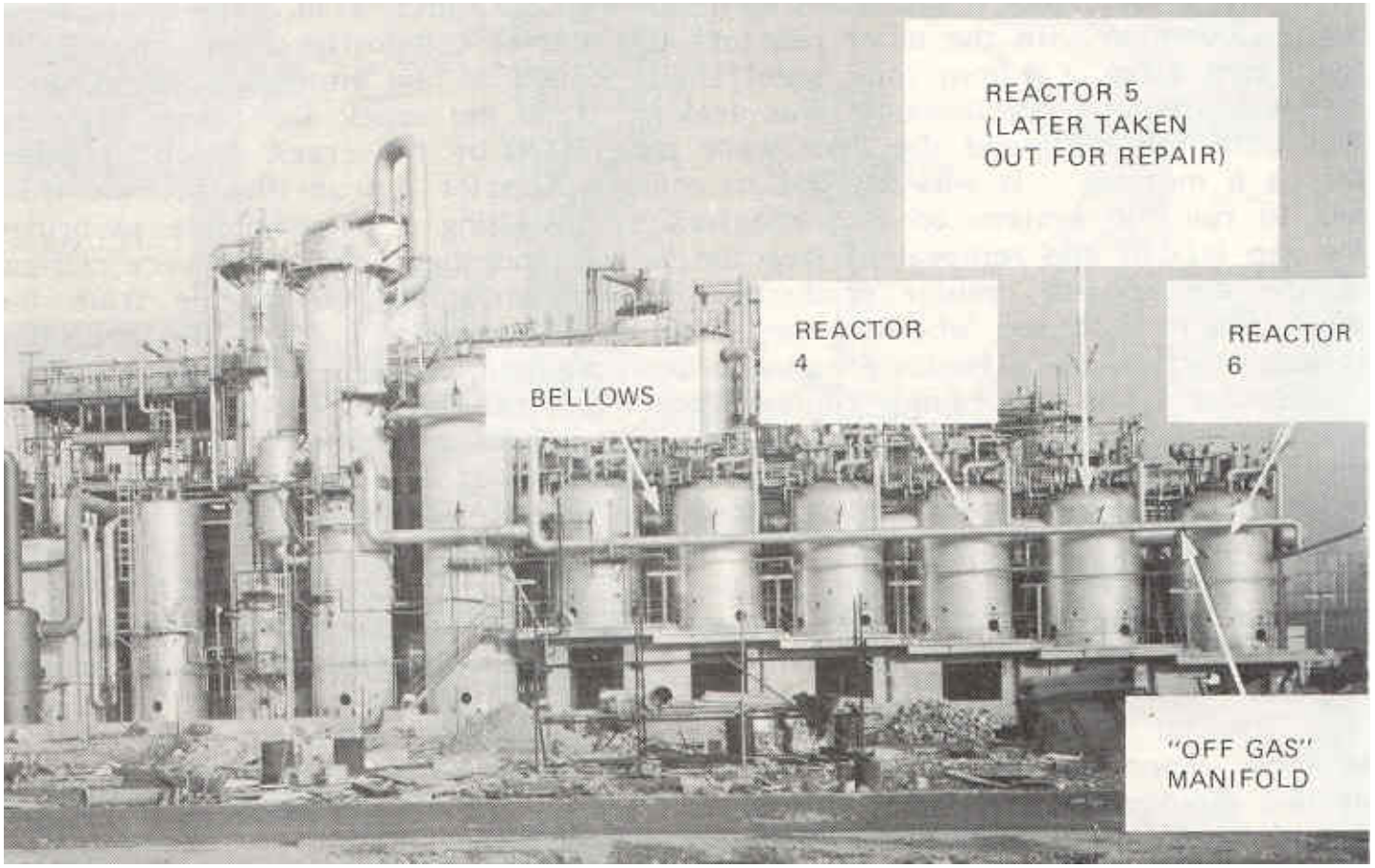


Flixborough, Cyclohexane Oxidation Plant, UK 1974

- **Vapour-cloud explosion.**
- **Largest-ever peacetime explosion in the UK.**
- **Plant Destroyed, 28 fatalities, 36 injuries on site, 53 offsite.**
- **Resources lacked a qualified Mechanical Engineer.**
- **Production pressures.**
- **Lack of safety review process for design changes.**

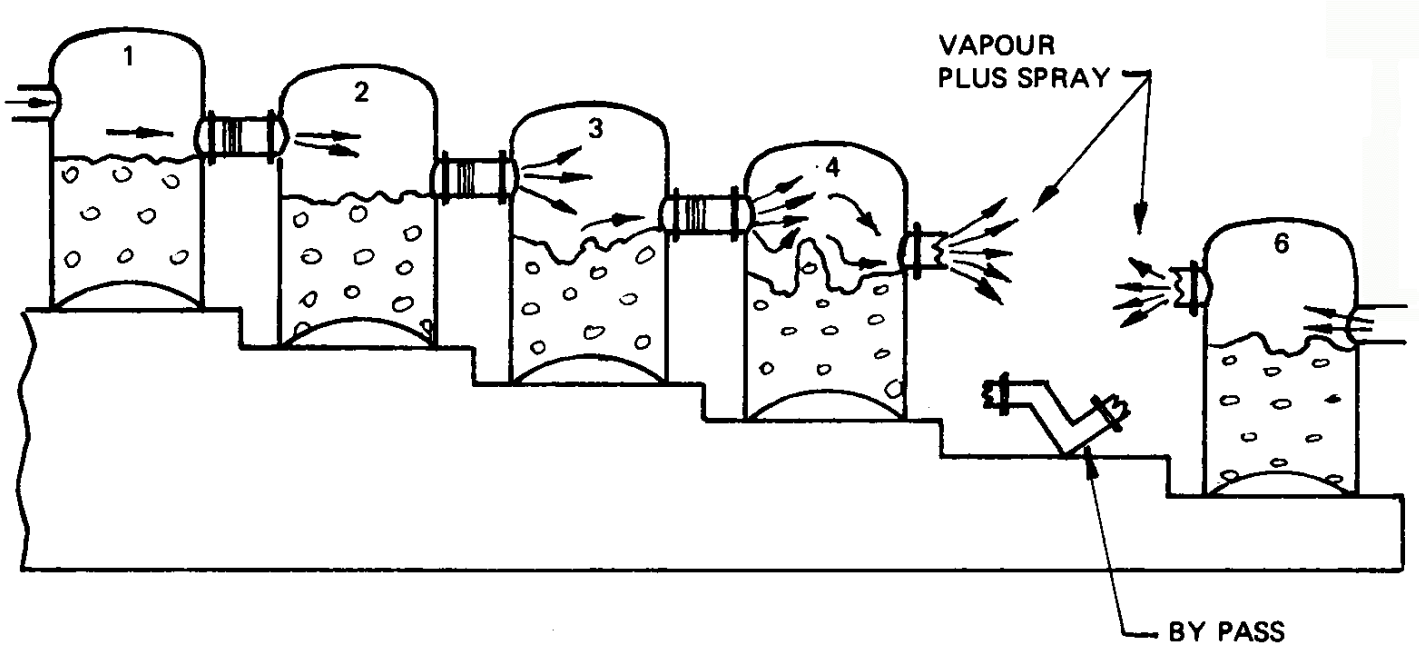
Flixborough Explosion

REACTOR CONFIGURATION



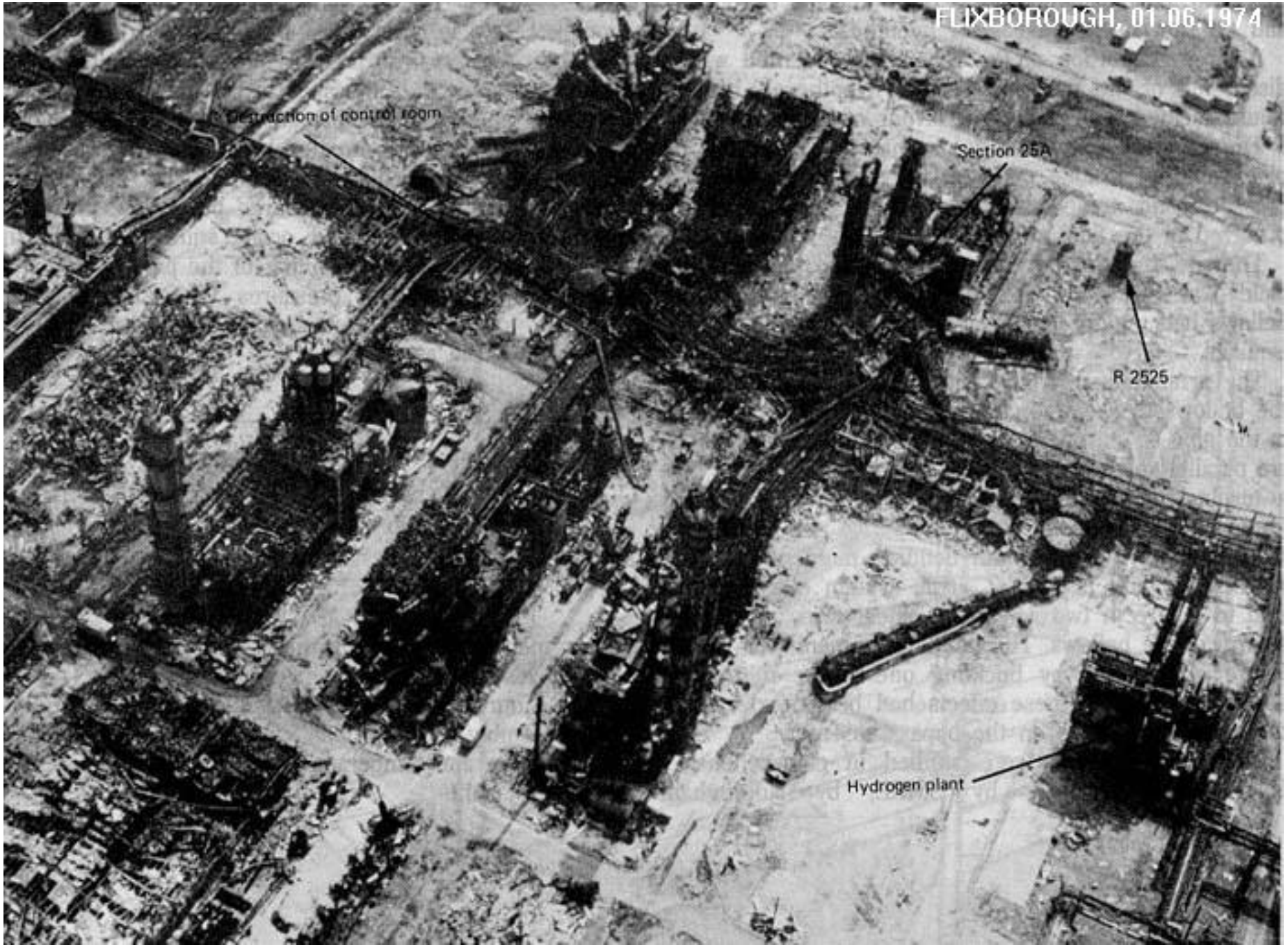
- Two months prior to the explosion, a crack was discovered in the number 5 reactor.

- It was decided to install a temporary 20” pipe to bypass the leaking reactor to allow continued operation of the plant while repairs were made.



The bypass pipe failed because of lateral stresses in the pipe during a pressure surge

- The bypass had been designed by personnel who were not experienced in high-pressure pipework,
- no plans or calculations had been produced,
- the pipe was not pressure-tested, was mounted on temporary scaffolding poles that allowed the pipe to twist under pressure
- The by-pass pipe was a smaller diameter (20") than the reactor flanges (24"). To align the flanges, short sections of steel bellows were added at each end of the by-pass →under pressure such bellows tend to squirm or twist.
- **The bypass had not been reviewed by appropriate chartered engineers.**


FLIXBOROUGH, 01.06.1974
Destruction of control room
Section 25A
R 2525
Hydrogen plant

FILXBOROUGH, 01.06.1974,
UK

Management and Organizational Systems Controls

Purpose:

- **To provide and maintain protection in particular for institutions which use technology with potential for high consequence, low frequency accidents and also to achieve process loss prevention.**

Features:

- **Do not belong exclusively to engineered systems or human factors regimes but are a complex interaction between technical and social aspects of an organization.**

Why The Interest?

- **Analysis of major accidents demonstrates that inadequate organization and management systems performance can usually be traced to management practices and policies.**

- **Organizations have no memory**

We Can Classify Major Accident Causes into 5 Categories of "Failure“:

1. **Dominating production imperatives.**
2. **Failure to allocate appropriate or adequate resources.**
3. **Failure to recognize deteriorating safety situation.**
4. **Lack of appreciation of the safety envelope.**
5. **Failure to define / assign safety responsibility clearly.**

Improving the Corporate Memory

- Include past accidents / near misses for education of undergraduates, new employees.
- Explain reasons for standards, rules & instructions.
- Lecture and discuss old accidents and incidents for employee training, at all levels.
- Implement a system to document and review incidents and feedback lessons learned.

Learning from the Past

"Decay is inherent in all component things."

The Pali Canon, Suttapitaka, Mahaparinibbana, Ch2, c. 500-250 B.C.

"History repeats itself."

from *Thucydides: History I, c. 410 B.C.*

"I am not one who is born with the possession of knowledge; I am one who is fond of antiquity, and earnest in seeking it there."

The Confucian Analects, c. 400 B.C.

"Peoples and government have never learned anything from history, or acted on principles deducible from it."

G.W.F. Hegel, *The Philosophy of History, 1832*

"We cannot escape history."

Lincoln, *2nd Annual Message to the Congress, 1862*

"If you do not learn from history you are doomed to repeat it."

George Santayana reference to US involvement in Viet Nam War

"The only thing new in the world is the history you don't know."

H.S. Truman, c. 1970.

"The four most expensive words in any language are 'This time it's different'."

Sir John Templeton, contemporary investor.

Incentives:

- The desired lifetime of bridges, sewer systems, buildings, nuclear plants is being extended to longer than their original design lifetime.

- Decreasing the costs of inspection is now a priority for owners. This objective is being supported by questionable probabilistic methods and by unproven assumptions of material properties.

- Excessive reliance of present engineers on handbooks and computer models with no insight into the reasons for past failures.

- New designs, as used in advanced plants now being proposed, are always prone to failures owing to lack of prior testing.

Incentives:

- Assertions by suppliers that problems of the past have been solved despite the lack of adequate longer term data.
- Laboratory studies have identified modes of failure of advanced materials that have not been observed in service but should be expected.
- Most of the experienced people who built the present infrastructure have retired or have passed away.
- New engineers, while well educated, are unfamiliar with the mechanical and chemical fragilities of materials.

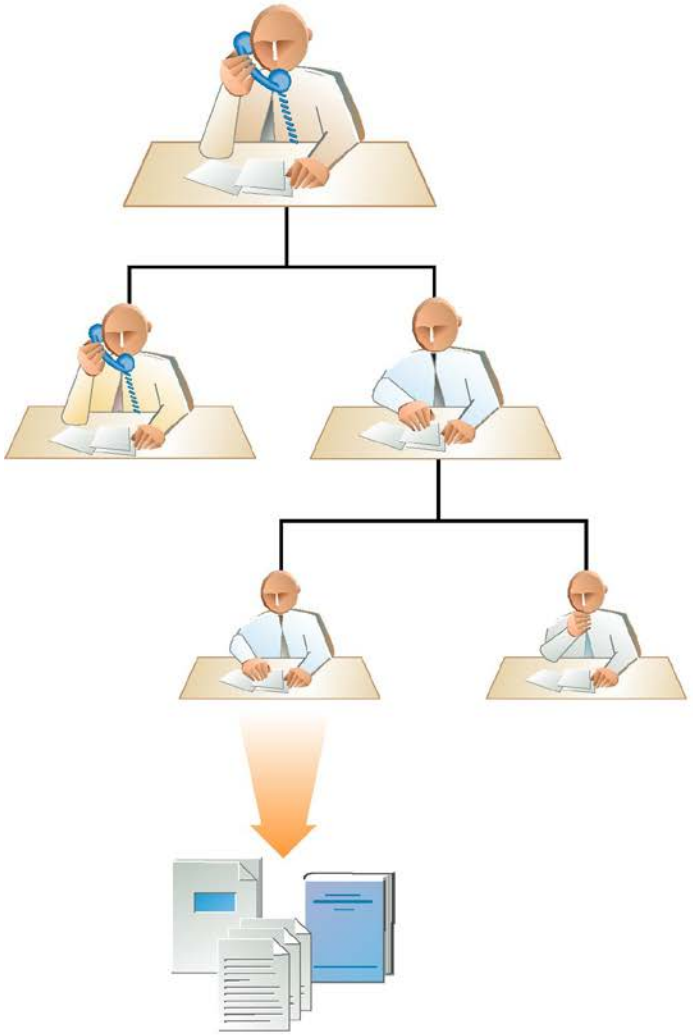
Major Failures to date have been knowable and predictable

Nominally responsible people:

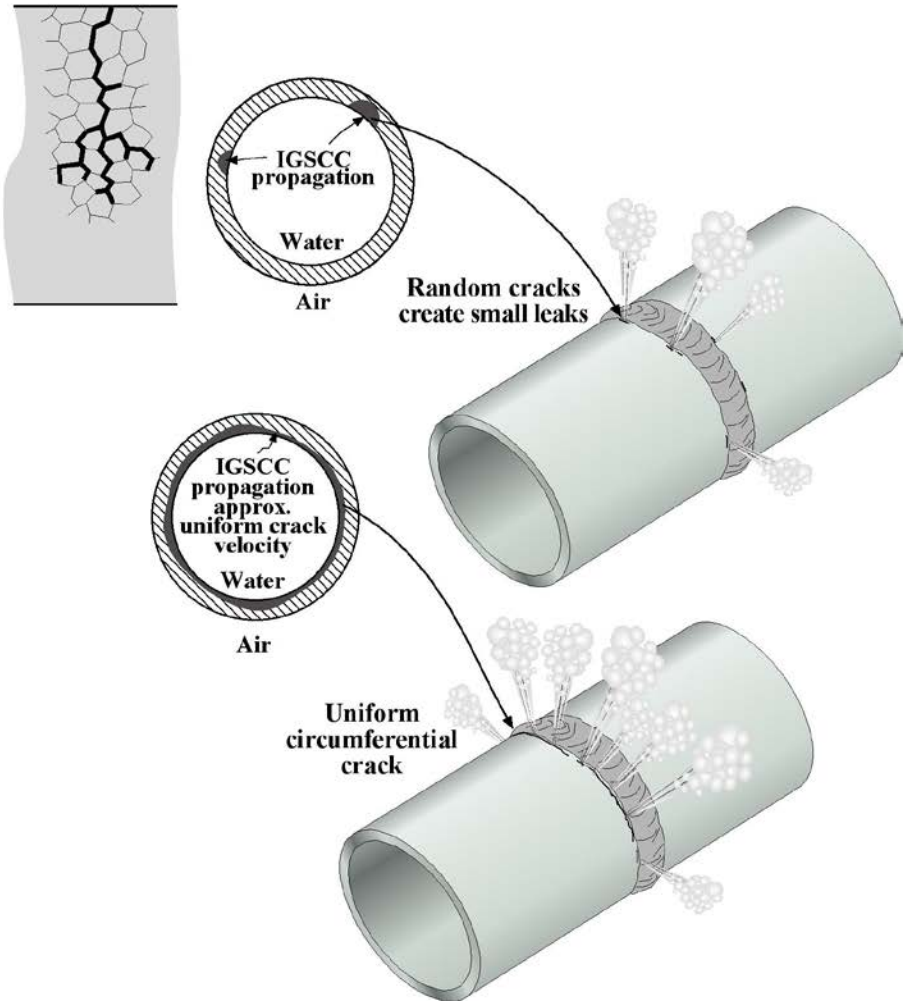
- Do not study and analyze the literature
- Assume that failure will happen on someone else's watch
- Do not involve knowledgeable experts
- Are unaware of the fragility of materials

The difference between cause and mode

Cause + **Mode**



IGSCC Inter granular stress corrosion cracking



Root Cause

- Failures are not caused by physical atomistic processes; in the example SCC is the path – the mode – of the failure
- Failures are caused by the decisions (actions) of managers – or the lack of decisions (actions) of managers
- Generally, there are no surprises; only people who have not studied the background; managers in perpetual denial

An opinion: Disconnect

- Major Failures are associated with Major Projects & Companies, which have lots of details, which usually means many levels of managers
- The people at the top are not always the most technically savvy, but even if they are, you cannot expect senior management to understand all the details
- Top-level managers have many conflicting constraints all demanding their attention: profits, shareholders, marketing, , safety.
- When you have many levels of management there comes a point where the top levels becomes *disconnected* with lower levels,
- Yet, the top level managers make the decisions

How do we deal with this?

- Failures are minimized with a management strategy to re-connect top-level managers with those at the “human-machine interface”.
- Failure Modes are studied to give Managers options → Research
- Tools, such as Non-Destructive Evaluation / Testing (NDE, NDT), are used to identify premature failure modes and careless oversights.

Reading Assignment

- Chapters 7 and 8

ECOR 1010 – ELEC 1908

Technology, Society & Environment
Lecture 1

What Will You Do to Help Society ?

Why Technology, Society & Environment ?

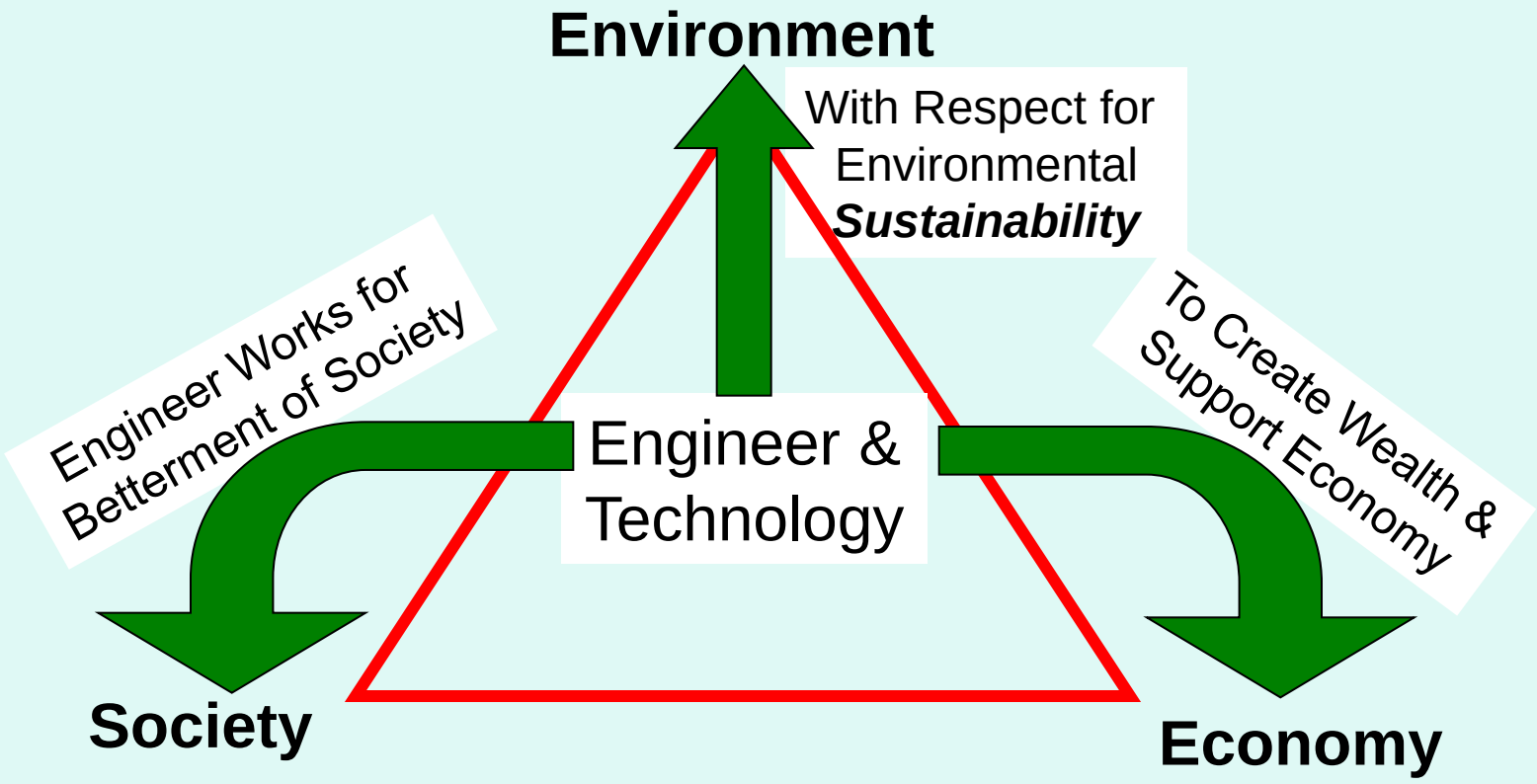
Engineer's Attributes:	**Curriculum Component:**
• First rate ***technical*** knowledge	← – – – – – – – → engineering, science & math
• Create what has not been	← – – – – – – – – – → innovation & design skills
• Not only do things right, but know what to do	← → critical thinking & problem solving
• Connect ethical, political, international ***environmental***, economic factors	← – – – → humanities / complementary studies

Allows Engineers To:

- Put ***technical*** knowledge to work for ***society***
- Catalyze private sector to create wealth

Aim of Engineering Profession

Application of Engineer's Technical Knowledge

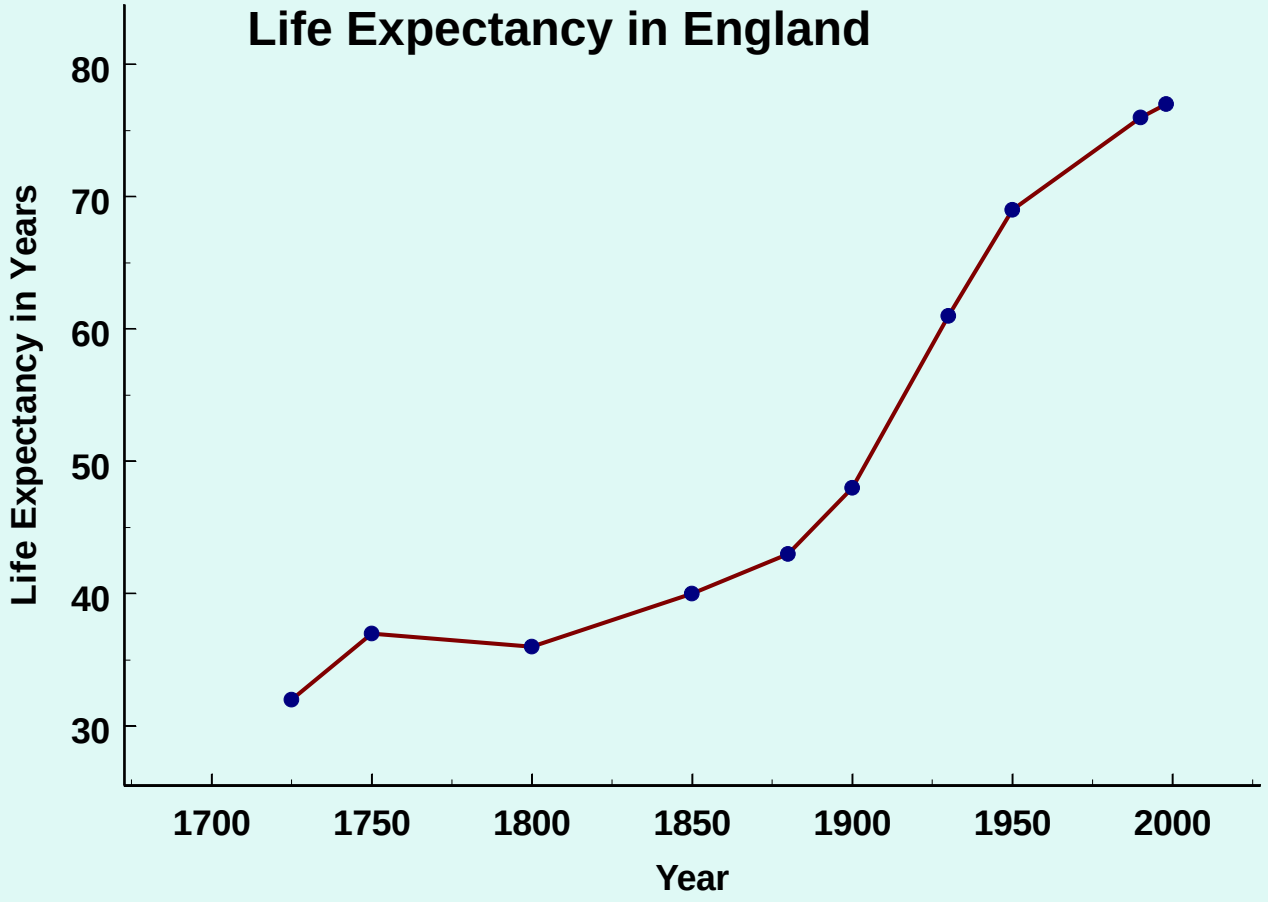


Interface between Society-Economy-Environment

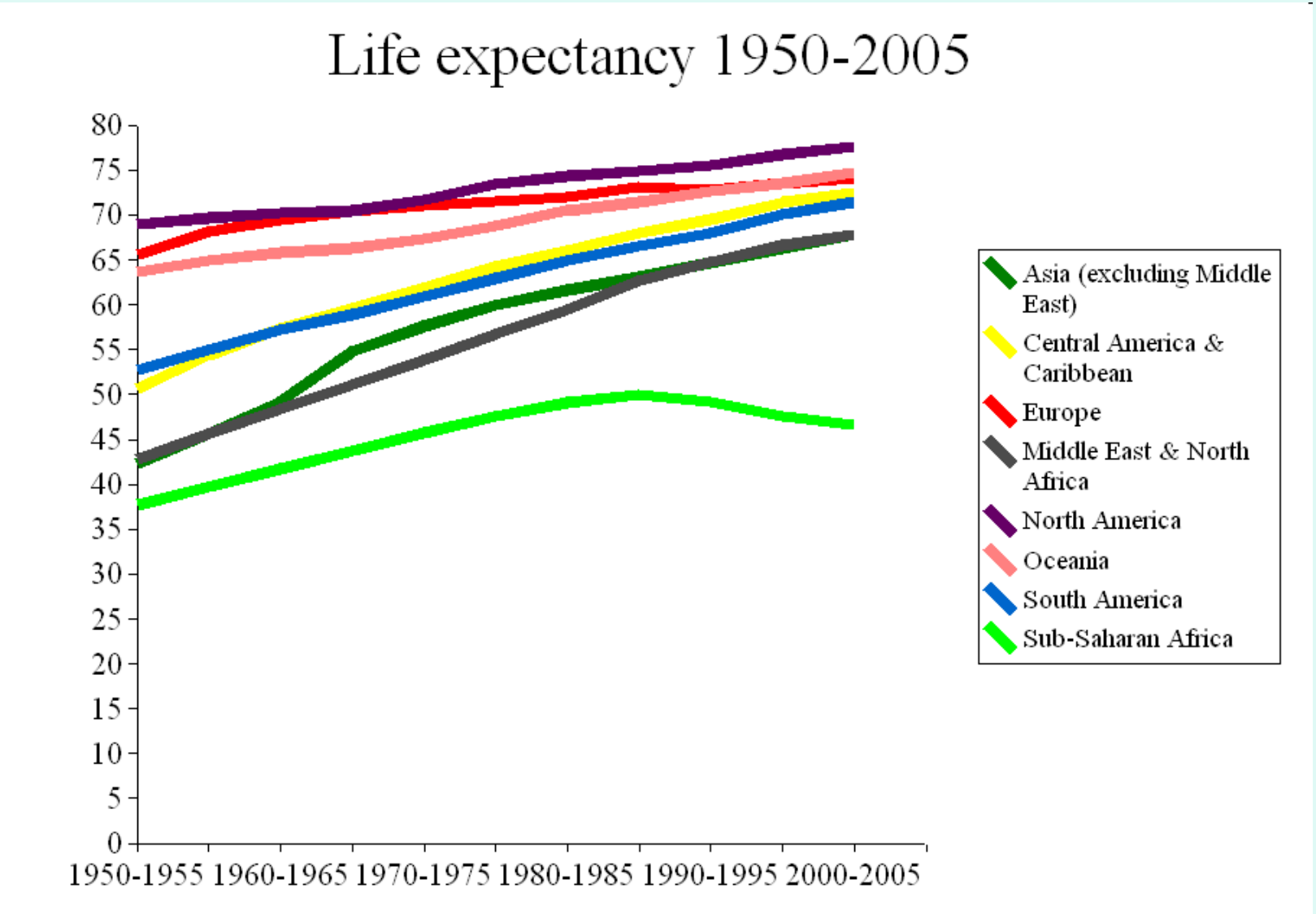
Difficult task to balance all three

Requires Substantial '*Engineering Skill & Judgement*'

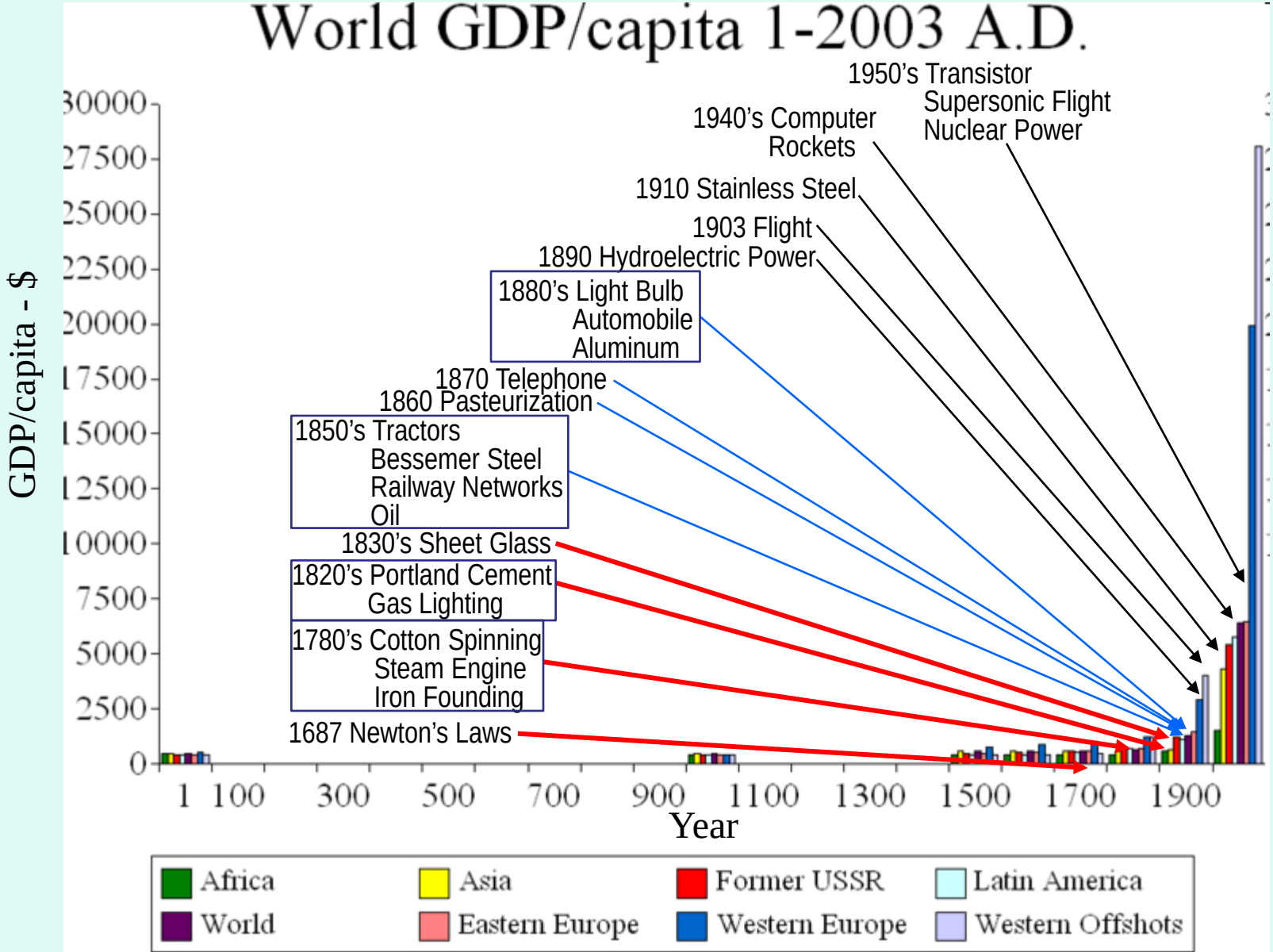
Are Engineers & Technology Making a Difference ? - 1



Are Engineers & Technology Making a Difference ? - 2



Are Engineers & Technology Making a Difference ? - 3



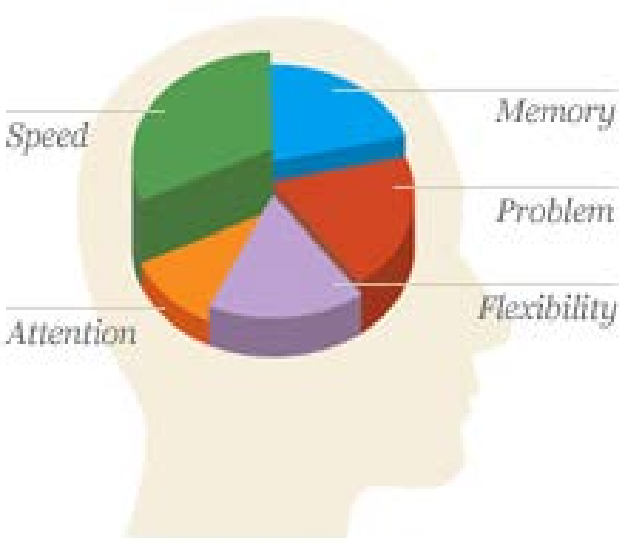
How Are You Going to Make a Difference ?

How Do You Plan to Contribute to Aims of Engineering Profession ?

- Put ***technical*** knowledge to work for ***society***
- Catalyze ***economy*** to create wealth for the benefit of ***society***

- What is your plan ?
- No plan yet ? … That's Okay … It's only the first few days of 1st Year !!
- But watch this TED talk:

http://www.ted.com/talks/bertrand_piccard_s_solar_powered_adventure.html



Time Management

The Key to Success in C Eng

and

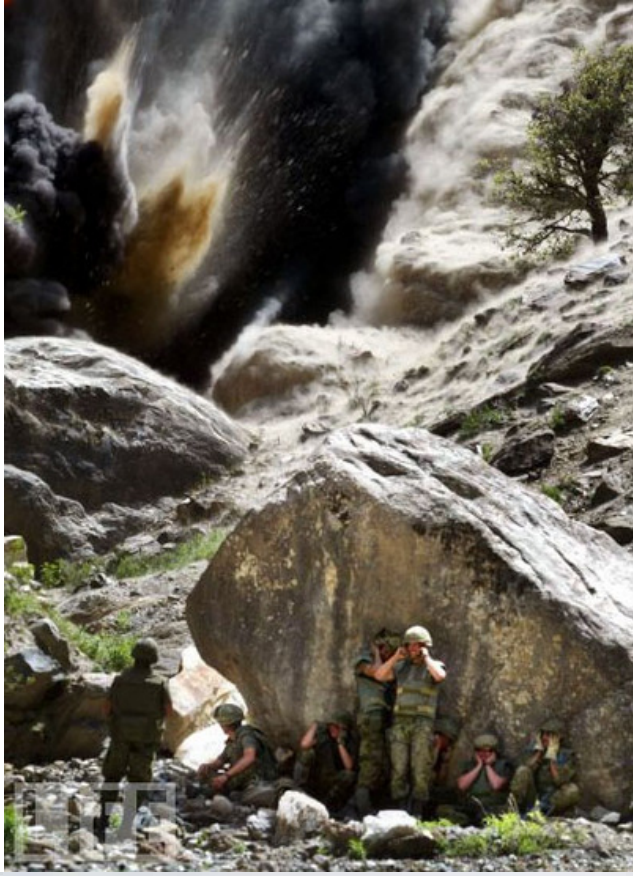
Beyond

CARLETON STUDENT ENGINEERING SOCIETY
ENG
OPTIONS

Carleton UNIVERSITY

Who I Am

- Brian Laughton
  - Academic Support Officer
  - Mechanical Engineer 7T8
  - B Ed 96
  - Retired Lieutenant-Colonel Military Engineer
  - Husband
  - Father
  - Coach, Scout Leader, Church Worker, Landlord, Tourist …..



SOLAR IMPULSE - AROUND THE WORLD IN A SOLAR ...

Page Safety Tools

SOLARIMPULSE AROUND THE WORLD IN A SOLAR AIRPLANE

SOLVAY OMEGA Schindler

VISION | CHALLENGE | TEAM | PARTNERS | MEDIA | SOLARIMPULSE&YOU

Solar Impulse back in Switzerland

Solar Impulse HB-SIA landed in Payerne on July 3 2011 following a flight powered exclusively by solar energy. This flight marks the end of the European solar flights campaign, initiated on May 13, 2011 and that took Solar Impulse' team to Brussels and Paris.

Detailed information are available on Solar Impulse' blog and via the Smartphone app "Solar Impulse Inventing the Future", available free on **Appstore** and **Androïd Market** .

POST A COMMENT SOLAR ON TWITTER

>Stephen from Florida: Bravo! Now this is true human accomplishment!
2011-07-13 12:29:09

>YanLu: FELiCiDADES, Bertrand! Must have been awful to see that plane soar by, with feet on the ground! ABRAZOS desde México!
2011-07-12 18:23:25

>Andre Bernet: Petite vidéo de l'atterrissage à Payerne! http://www.youtube.com/watch?v=M5isukzEq4Y
2011-07-11 14:44:54

>Jean Durin, Landes, France.: Bravo à toutes et à tous pour votre opiniâtreté pour mener à son terme ce très beau projet. Bravo également pour la conception du site qui nous a réellement immergé dans le suivi en temps réel de Solar Impulse. Chapeau bas à toute l'équipe !

BLOG

Bertrand takes the controls of HB-SIA

Yet another extraordinary emotionally charged moment at Solar Impulse: Bertrand has made his first flight with HB-SIA and has done it with flying colours. After spending some time getting the feel of the plane yesterday morning, Bertrand took off ...
Continue Reading

Follow us on

SUPPORTERS PROGRAM

Join supporters program

PHOTOS / VIDEOS

Bertrand Piccard's First Flight

MORE VIDEOS MORE PHOTOS

"All that is impossible remains to be achieved."
JULES VERNE

FOUNDERS

Two men, both pioneers and innovators, both pilots, are driving force behind Solar Impulse. Bertrand Piccard, psychatrist and aeronaut, who made the first non-stop round-the-world balloon flight, is the initiator and chairman. André Borschberg, an engineer and graduate in management science, a fighter pilot and a professional airplane and helicopter pilot, is the CEO. The former's avant-gardist vision and the latter's entrepreneurial and managerial experience are an ideal combination.

ANDRÉ BORSCHBERG
CEO AND PROJECT CO-FOUNDER

VISION
CHALLENGE
TEAM
FOUNDERS
CONFIGURATION & STRUCTURE
ENERGY & PROPULSION
PRODUCTION / WORKSHOP
PROJECT SUPPORT
FLIGHT TEST
FLIGHT MISSION
TAKE OFF TEAM
PARTNERS
MEDIA
SOLAR IMPULSE & YOU

CONFIGURATION & STRUCTURE

Mechanical engineers, aeronautical engineers, physicists, specialists in structures and aerodynamics, in design and calculating tools, leading-edge specialists in composite materials, pilots with a passion for renewable energy. From the drawing board to the complicated calculations necessary. All have joined forces to finalise the solar airplane's structure and turn a dream into reality.

"All that is impossible rer

VISION
CHALLENGE
TEAM
FOUNDERS
CONFIGURATION & STRUCTURE
ENERGY & PROPULSION
PRODUCTION / WORKSHOP
PROJECT SUPPORT
FLIGHT TEST
FLIGHT MISSION
TAKE OFF TEAM
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ENERGY & PROPULSION

To manage, transform, store and regulate the power supplied by the photovoltaic cells, to develop high-performance engines batteries, the Solar Impulse electrical engineers have challenged technology bounds in their quest for maximum efficiency, minimum weight and high reliability. And at the heart of the solar plane, a central computer is there to monitor operations and ensure optimal energy use.

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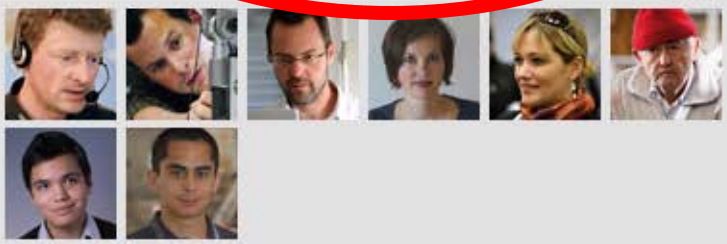
PROJECT SUPPORT

Defining the plane's configuration, its size, the number of engines, its form – this is all the job of engineers with degrees in aeronautics and mechanical engineering, mathematicians and specialists in the algorithms used in modelling and simulation. They are all multi-disciplinary, with know-how in leading-edge construction techniques, aerodynamics, thermodynamics, project and systems management and computer simulation.



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FLIGHT TEST

The solar plane is going to have to be put through a whole series of trials before setting out on its 36-hour flight, the project's initial highlight. In this test phase, pilots will be joining up with the engineers, taking charge of the ground tests and then the test flights. The engineers' knowledge of performance and flight dynamics will be paired with the talent and skills of the pilots.

Here are six terrific truths about time:

First: *Nobody can manage time*. But you can manage those things that take up your time.

Second: *Time is expensive*. As a matter of fact, 80 percent of our day is spent on those things or those people that only bring us two percent of our results.

Third: *Time is perishable*. It cannot be saved for later use.

Fourth: *Time is measurable*. Everybody has the same amount of time...pauper or king. It is not how much time you have; it is how much you use.

Fifth: *Time is irreplaceable*. We never make back time once it is gone.

Sixth: *Time is a priority*. You have enough time for anything in the world, so long as it ranks high enough among your priorities.

Chapter 3

Advice on Studying, Exams, and Learning

Studying to be an engineer is not a spectator sport—success requires participation. Even if you were at the top of your class in high school, you are in a new league now, with classmates who know how to set priorities, schedule their time, take notes, and organize their studies. This chapter will help you to excel academically, but for best results, you must "read it before you need it." That is, you should read this chapter early in the academic year and apply these skills regularly. This chapter tells you:

- how much time you should expect to spend studying,
- how to organize yourself to study effectively,
- how to prepare for examinations and write them,
- what to do if things should go wrong in your studies.

SECTIONS

3.1 The Good and Bad News About University Studies
3.2 How Much Study Time is Required?
3.3 Managing Your Time
3.4 Preparing for the Start of Lectures
3.5 Developing a Note-Taking Strategy
3.6 A Checklist of Good Study Skills
3.7 Collaborating on Assignments
3.8 Preparing for Examinations
3.9 Writing Examinations
3.10 When Things Go Wrong
3.11 Your Professional Career and Lifelong Learning
3.12 Further Study
3.13 References

Section 3.3 Managing Your Time

- Term calendar: First, you need a general plan of the term. This is simply a calendar showing the dates of key events during your academic term.
- Weekly timetable: Second, you need a weekly timetable. Your classes are usually scheduled weekly, so this is a key document. Most importantly, it can be used to calculate your free time.
- “To do” list: Third, you need a master “to do” list of tasks to be done, and their deadlines, so that you can set priorities for your work.
- Synchronizing: Finally, you must synchronize these documents, usually every few days, to avoid conflicts, to set priorities, and to allocate your free time effectively.

10 Common Time Management Mistakes

http://www.mindtools.com/pages/article/time-management-mistakes.htm

- Mistake #1. Failing to Keep a To-Do List
- Mistake #2. Not Setting Personal Goals
- Mistake #3. Not Prioritizing
- Mistake #4. Failing to Manage Distractions
- Mistake #5. Procrastination
- Mistake #6. Taking on too Much
- Mistake #7. Thriving on "Busy“
- Mistake #8. Multitasking
- Mistake #9. Not Taking Breaks
- Mistake #10. Ineffectively Scheduling Tasks

Top 10 Ways of Wasting Time in University

http://collegelife.about.com/od/TimeManagement/a/Top-10-Ways-Of-Wasting-Time-In-College.htm

- **1. Social media (think Facebook, Twitter, etc.).**
- **2. People.**
- **3. The World Wide Web.**
- **4. The Party Scene.**
- **5. Drama.**
- **6. Email.**
- **7. Cell Phone.**
- **8. Movies and You Tube.**
- **9. Video games.**
- **10. Not getting enough sleep.**

Effective Scheduling

Planning to Make the Best Use of Your Time

http://www.mindtools.com/pages/article/newHTE_07.htm

- Scheduling is the process by which you look at the time available to you, and plan how you will use it to achieve the goals you have identified. By using a schedule properly, you can:
  - Understand what you realistically can achieve with your time.
  - Plan to make the best use of the time available.
  - Leave enough time for things you absolutely must do.
  - Preserve contingency time to handle 'the unexpected'.
  - Minimize stress by avoiding over-commitment to yourself and others.

Five Step Scheduling Process

http://www.mindtools.com/pages/article/newHTE_07.htm

Scheduling is then a five-step process:

- Step 1. Identify the time you have available.
- Step 2. Block in the essential tasks you must carry out to succeed in your job.
- Step 3. Schedule in high priority urgent tasks and vital "house-keeping" activities.
- Step 4. Block in appropriate contingency time to handle unpredictable interruptions.
- Step 5. In the time that remains, schedule the activities that address your priorities and personal goals.

If you have little or no discretionary time left by the time you reach step five, then revisit the assumptions you have made in steps one to four.

Some Time Management Web-Pages

- http://www.mindtools.com/pages/main/newMN_HTE.htm
- http://collegelife.about.com/od/academiclife/a/timemanagement.htm
- http://collegelife.about.com/od/TimeManagement/a/Guide-To-Time-Management-For-Students.htm
- http://collegelife.about.com/lr/time_management_skills/1438236/1/
- http://www.effective-time-management-strategies.com/student-time-management.html

Good Luck to You All!!

ECOR 1010 – ELEC 1908

Technology, Society & Environment
Lecture 2

Energy & Sustainability

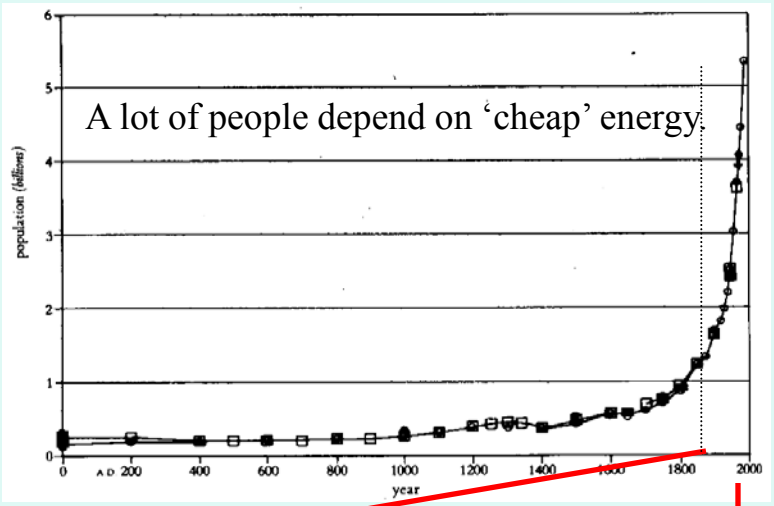
The Unique Role of Exo-Somatic* Energy in Modern Civilization

- Energy is the key to everything else. Without energy, nothing can happen.
- No factor has played a greater role in the recent explosive growth of the human enterprise than abundant cheap energy (fossil fuels).
- In addition, no other resource has changed the structure of economies, the nature of technologies, the balance of geopolitics, and the quality of human life as much as petroleum.

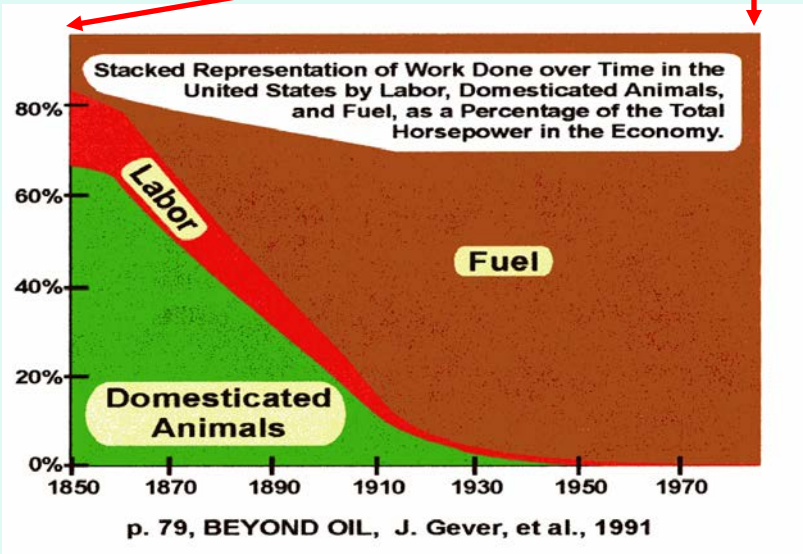
* Outside the body; extragenetic

Technology Rules: Two Great (Energetic) Leaps Forward

- The adoption of agriculture ten millennia ago led to a 13-fold increase in average human population growth compared to the previous 10 millennia.

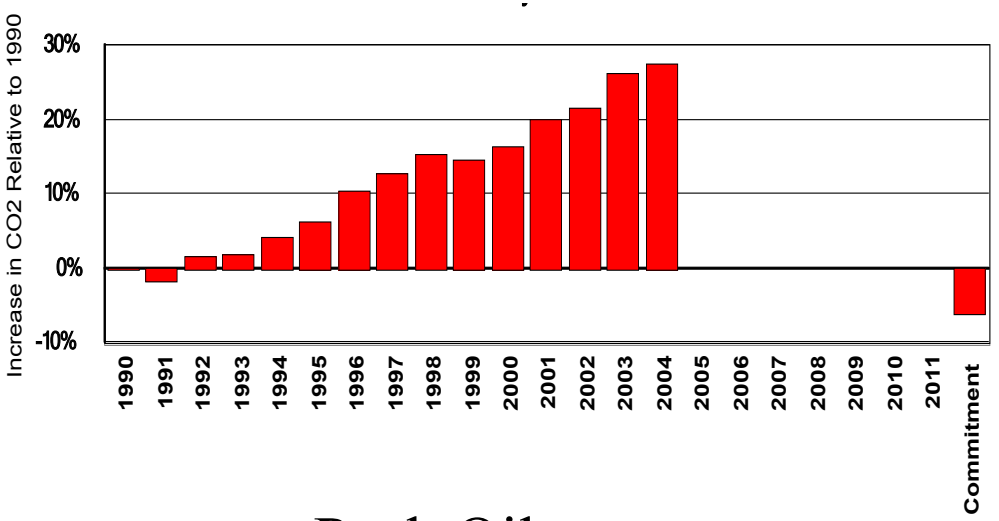


- The discovery and widespread use of fossil fuels, particularly petroleum, is the major physical factor behind the four-fold expansion of the human population (and every other measure of humanity) in just the past 150 years.

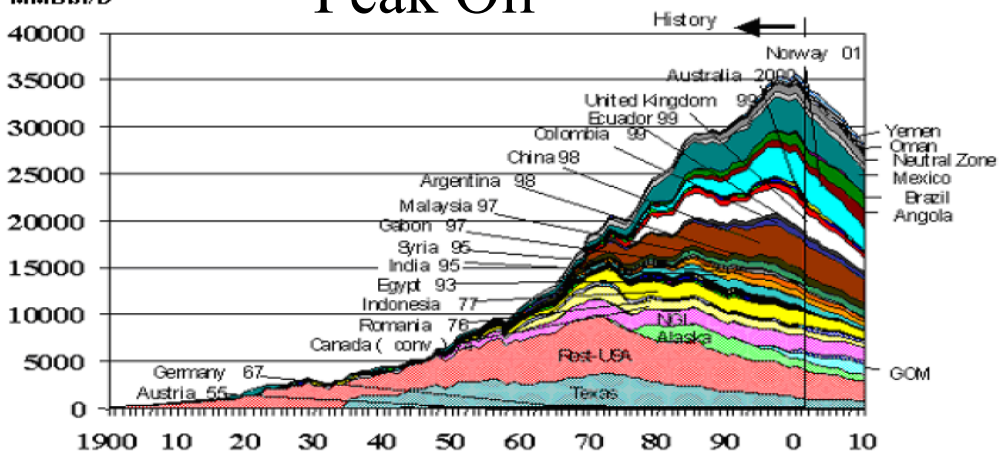


Two Reasons for Moving Beyond Fire and Fossil Fuels:

- Most people know that we may be forced to use less fossil fuel to avoid risk of serious climate change. Indeed, that's what the Kyoto debate is all about. However…
- Fewer people are aware that we may soon have less fossil fuel to burn because the inexpensive, easily accessible stocks are being depleted.



Peak Oil



Sustainable Energy Consumption – Oil ?

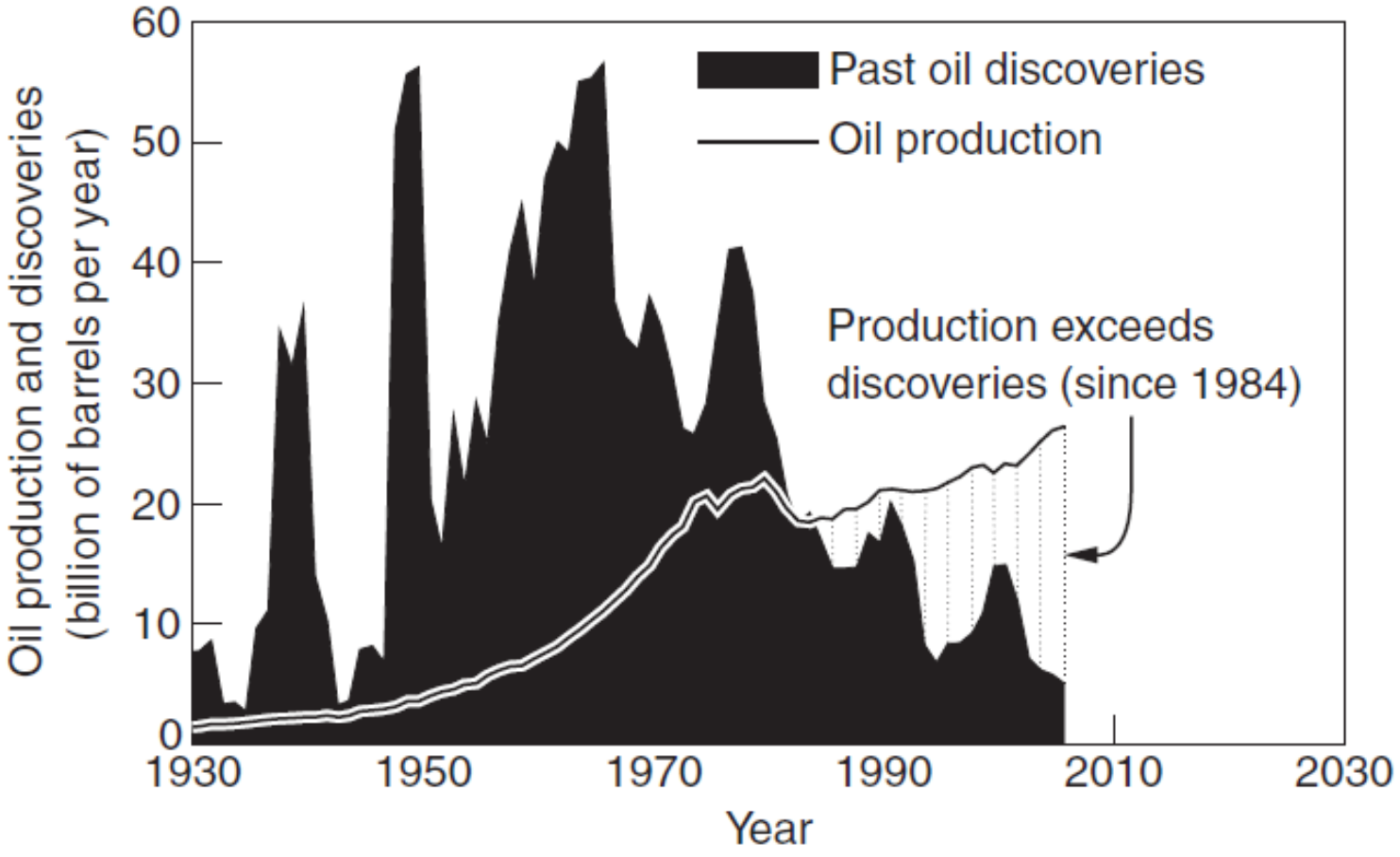


Figure 9.6 The growing gap between world oil production and discoveries [27].

Oil & Gas Consumption Not Sustainable

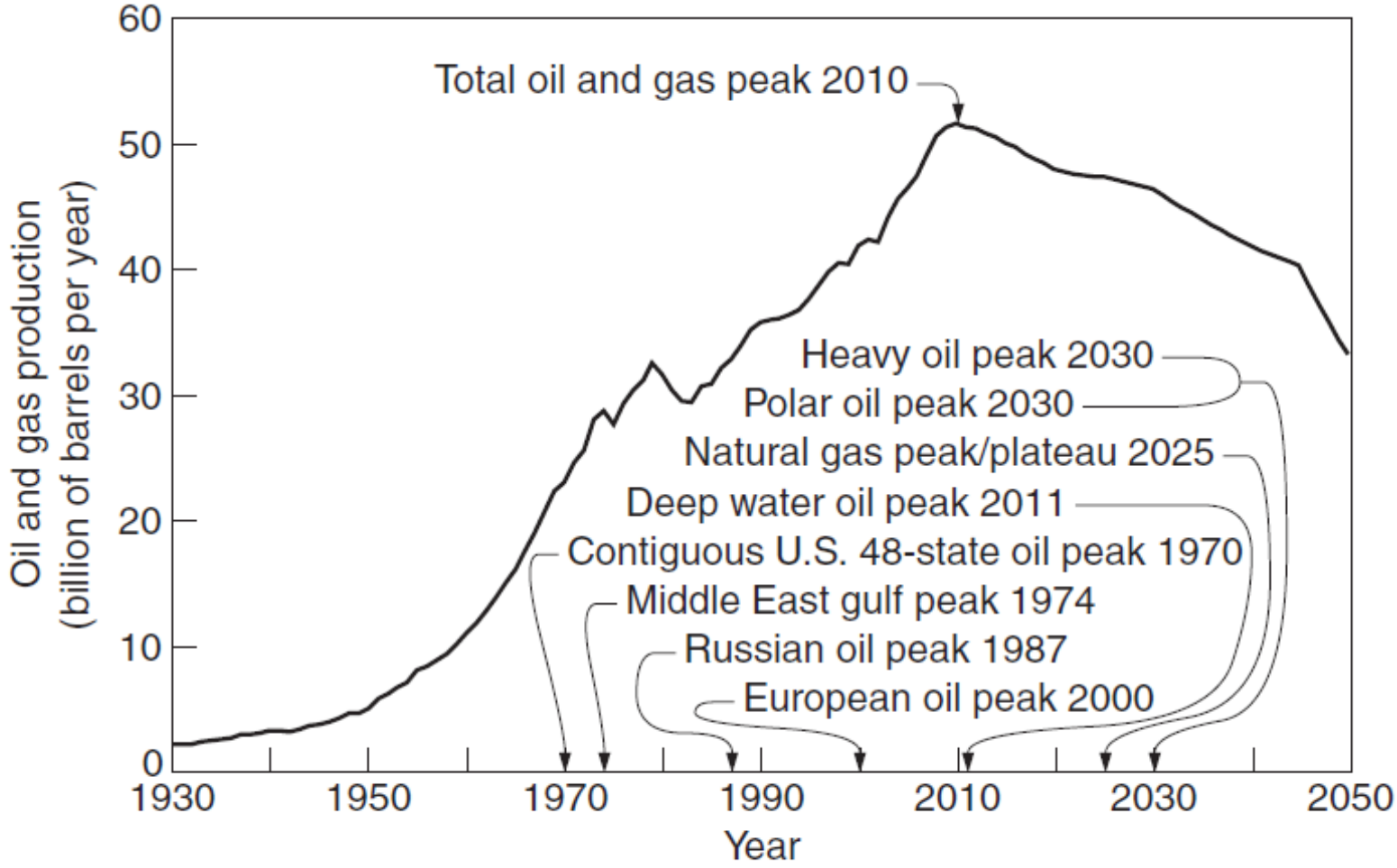


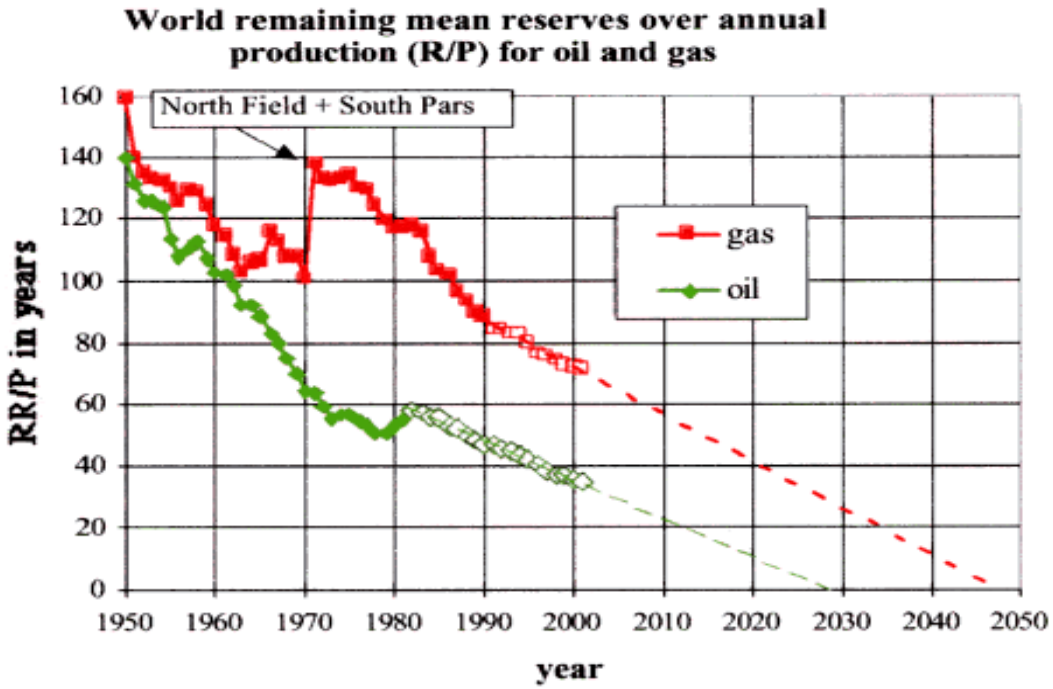
Figure 9.5 Campbell's 2006 total oil and gas production forecast [26, 27].

Is This Good or Bad ?

The Problem with Accessibly:

Coal resources are available in almost every country worldwide. At current production levels, proven coal reserves are estimated to last 164 years (World Coal Institute). In contrast, proven oil and gas reserves will be depleted this century. Over 68% of oil and 67% of gas reserves are concentrated in the Middle East and Russia.

Oil is gone before 2030 and gas is just 20 years behind (Laherrere 2003)



The Next 100 Years ?

Year		**2000**	**2050**	**2100**
Population (POP)	billions	6	9.5	10.5
GDP (in 2000 $)	$US trillion	32	80	230
GDP/POP	$US/capita	5,300	8,400	22,000
Energy (E)	EJ*	429	770	1,390
Coal		100	220	650
Oil		163	160	110
Natural Gas		95	200	160
Nuclear		9	20	90
Hydropower		9	20	30
Trad. Biomass		45	70	90
Modern Biomass		7	50	120
Wind		<<1	20	90
Other Renewables		<<1	10	50
E/GDP	MJ/$US	13.6	9.6	6
E/POP	GJ/capita	71.4	81	132

*1 EJ = 10^{18} Joules

(from: Jaccard, Sustainable Fossil Fuels)

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Population (POP)	billions	6	9.5	10.5
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Wind		<<1		90
Other Renewables		<<1	10	50
E/GDP	MJ/$US	13.6		6
E/POP	GJ/capita	71.4		132

Population ×1.75
per capita wealth ×4.15

Population ×1.75
Energy Use ×3.24

from <¼ to nearly ½

reduced oil

Increases ×10
≈6% of total

Increases ×100
≈6% of total

More Energy Efficient Wealth Creation

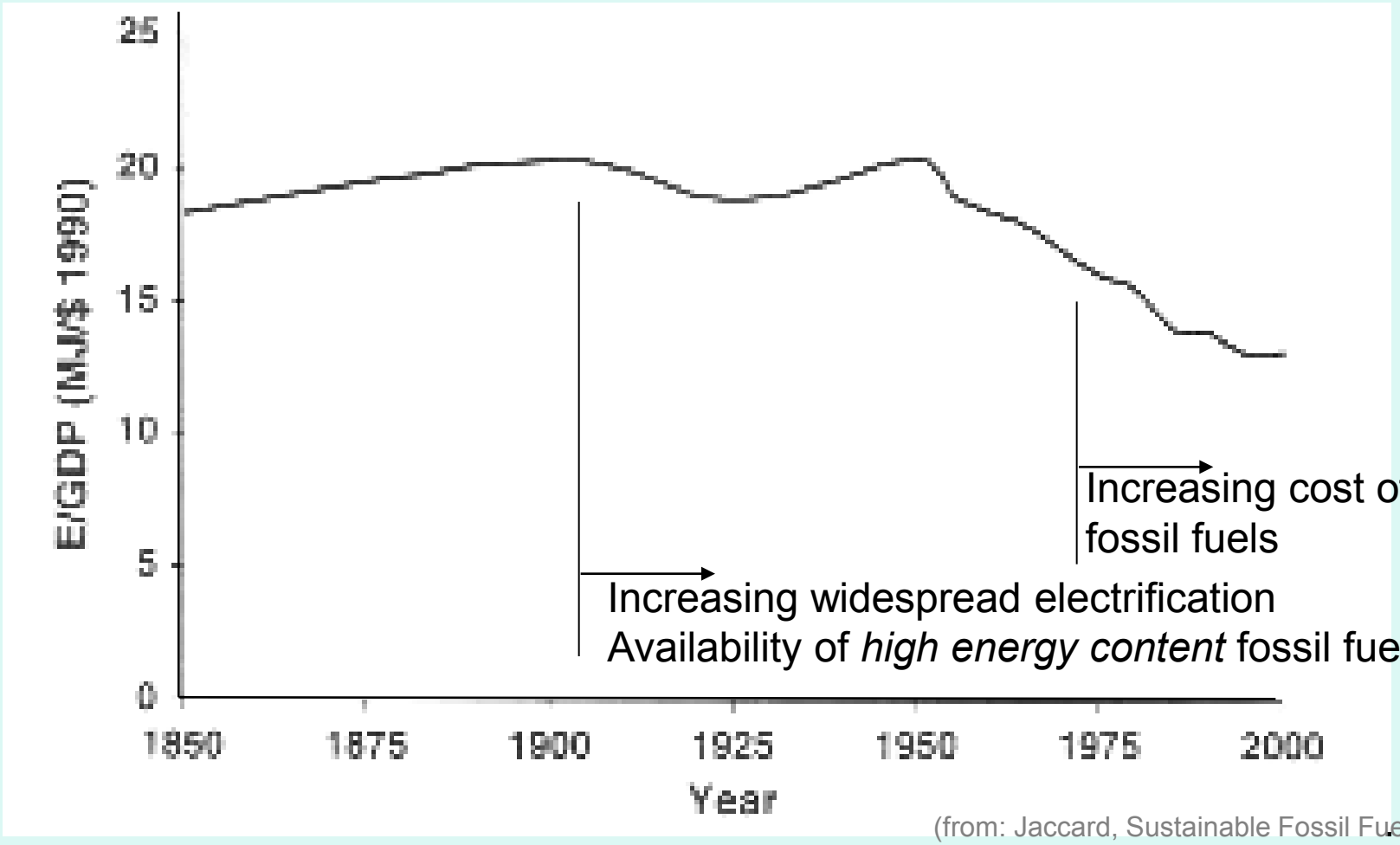
But, more wealthy people

*1 EJ = 10^{18} Joules

(from: Jaccard, Sustainable Fossil Fuels)

What will this mean for the environment?

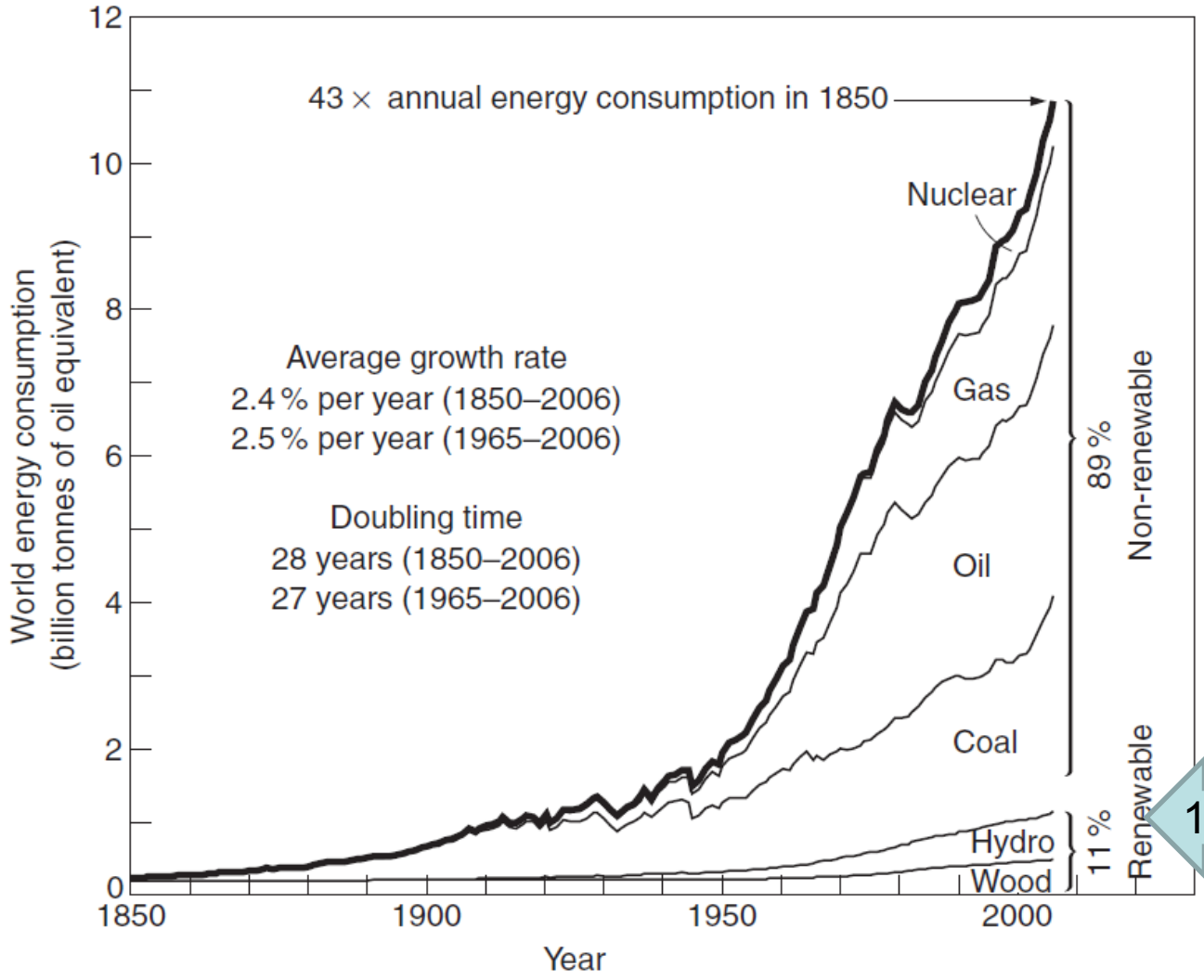
Global History
Energy Consumption / Wealth (GDP)



(from: Jaccard, Sustainable Fossil Fuels)

More Energy Efficient Wealth Creation →

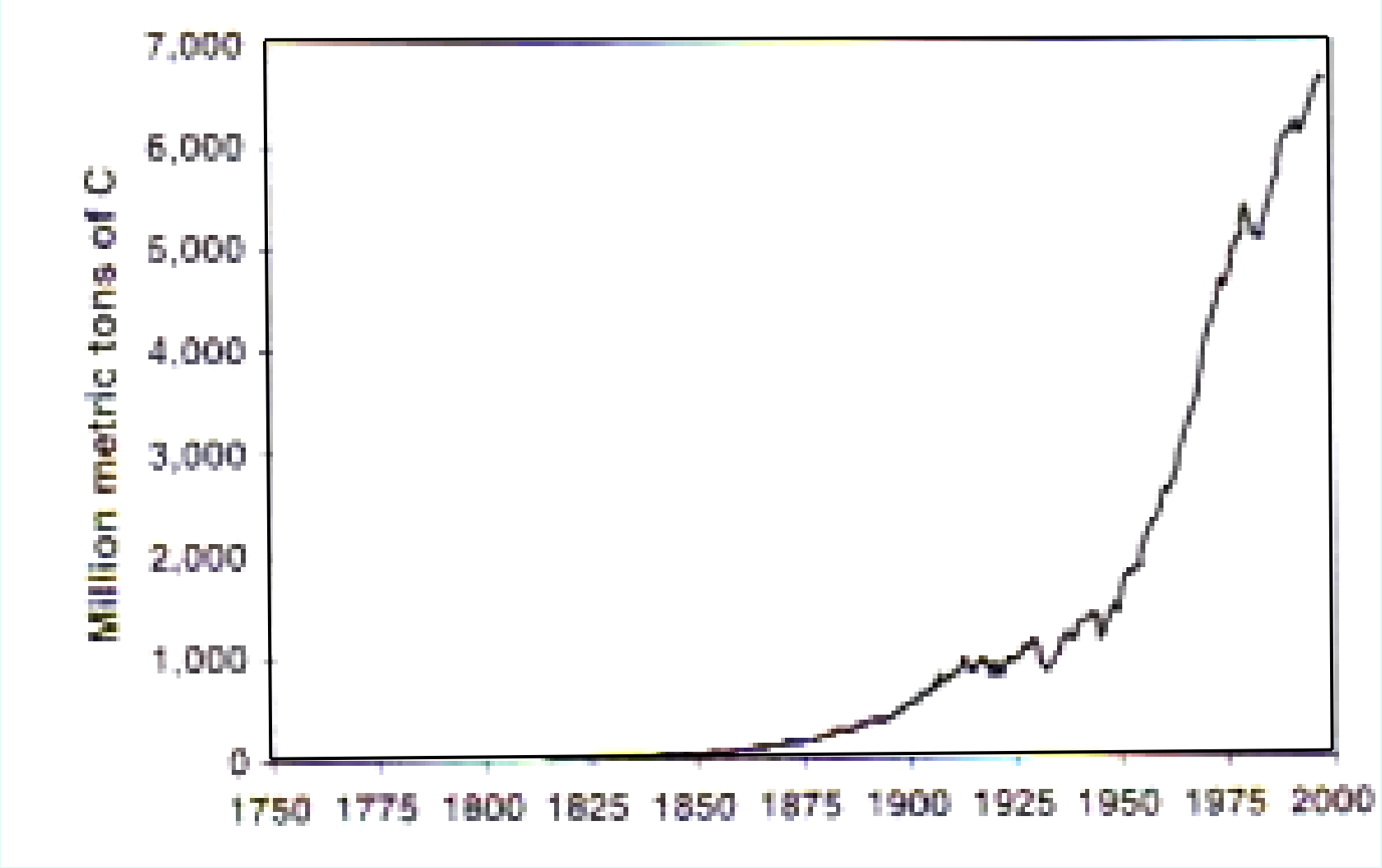
Global Energy Consumption



11% renewables

Figure 9.4 Primary annual world energy consumption 1850 to 2006 [22–24]. A tonne of oil equivalent equals 42 gigajoules (GJ) or 12 megawatt-hours (MWh) of thermal energy.

Global CO_2 Emissions



(from: Jaccard, Sustainable Fossil Fuels)

Canada's GDP, Energy Consumption and CO_2 Emissions

We can cut emissions and still grow the economy!

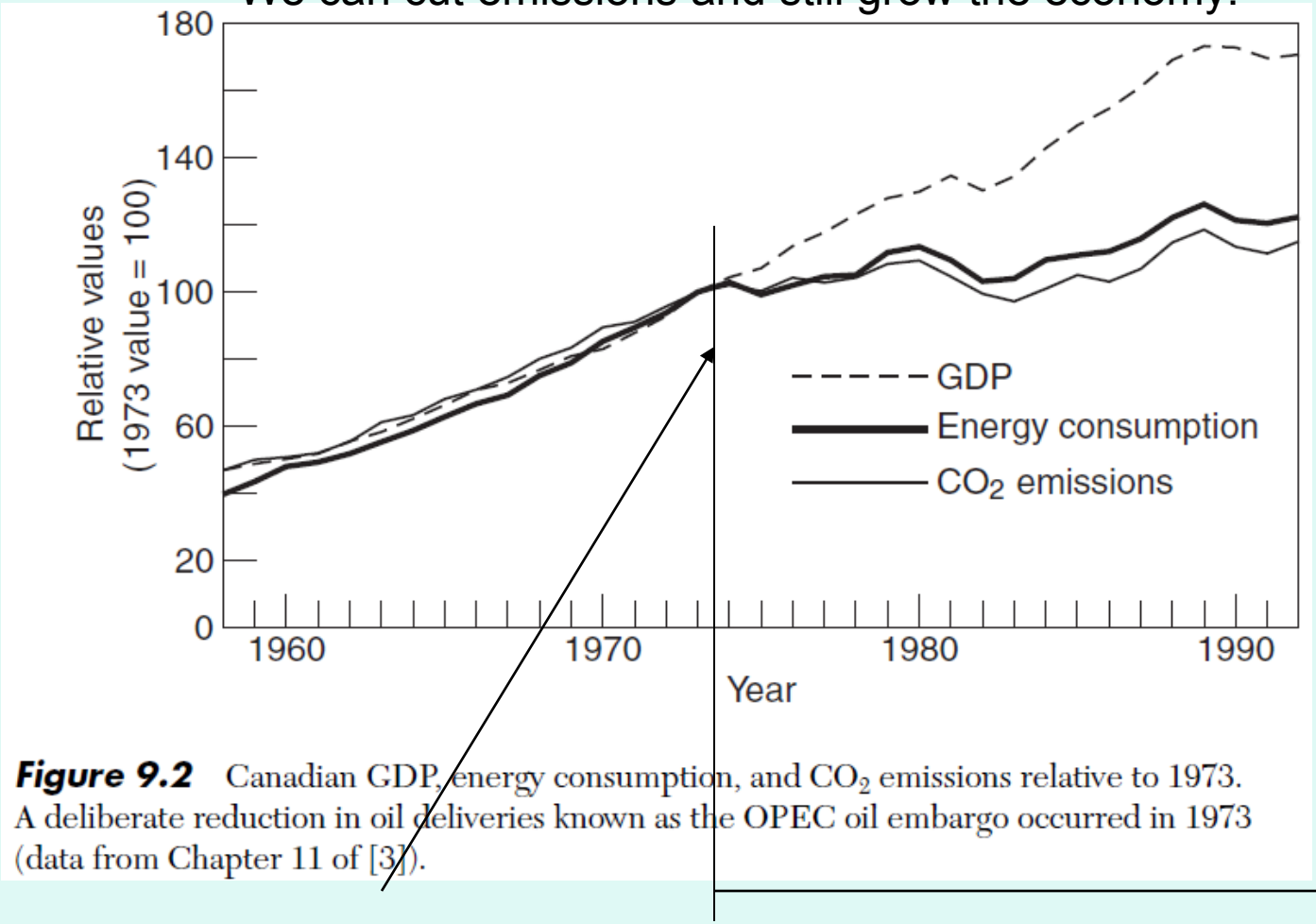


Figure 9.2 Canadian GDP, energy consumption, and CO_2 emissions relative to 1973. A deliberate reduction in oil deliveries known as the OPEC oil embargo occurred in 1973 (data from Chapter 11 of [3]).

OPEC Oil Embargo

More efficient energy use as result of energy crisis.

Process of Global Warming and Climate Change - 1

- Fossil Fuel emissions
  - Combustion of fossil fuels produces waste gas which is released into atmosphere.
    - Mainly carbon dioxide (CO_2).
    - Human activity produces more CO_2 than can be absorbed by plant life.
- Greenhouse effect
  - Sun's radiation passes through atmosphere and warms Earth's surface.
  - Absorbed energy is eventually re-emitted as thermal radiation, which is partially blocked by carbon dioxide (CO_2), methane (CH_4), etc in atmosphere.
  - CO_2 can stay in atmosphere for many decades.

Process of Global Warming and Climate Change - 2

- Global Warming
  - Greenhouse effect is essential since it cushions Earth from stark temperature extremes that exist on planets without an atmosphere.
  - BUT, small deviations in Earth's solar energy balance can produce large effects leading to global warming or cooling.
- Climate Change
  - Severe storms, droughts, floods, increase in sea level caused by small deviations in solar energy balance.

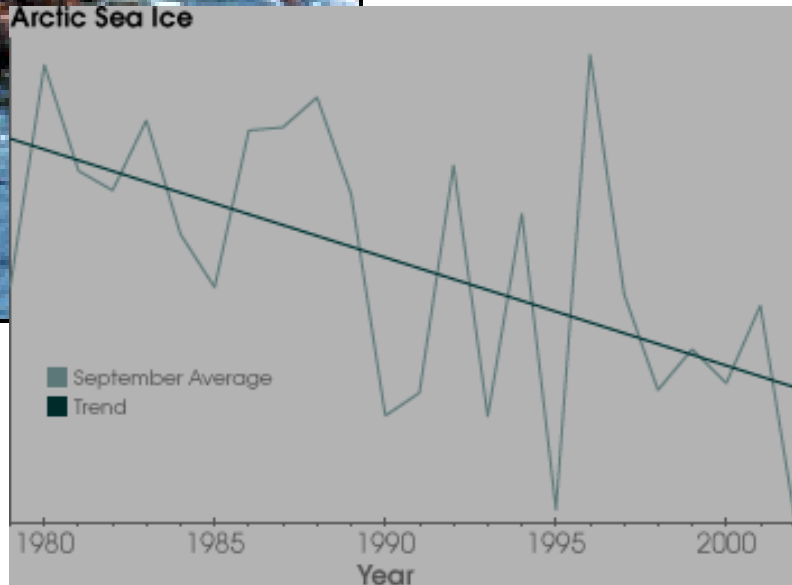
Consequences of Climate Change - 1

- Intergovernmental Panel on Climate Change (IPCC) issued *Fourth Assessment Report* (AR4) in 2007.
  - Shows with great certainty that climate change directly linked to global warming.
    - Caused by GHGs that result mainly from human burning of fossil fuels.
- Human cause
  - Worldwide atmospheric concentrations GHGs at levels which greatly exceed pre-industrial values.

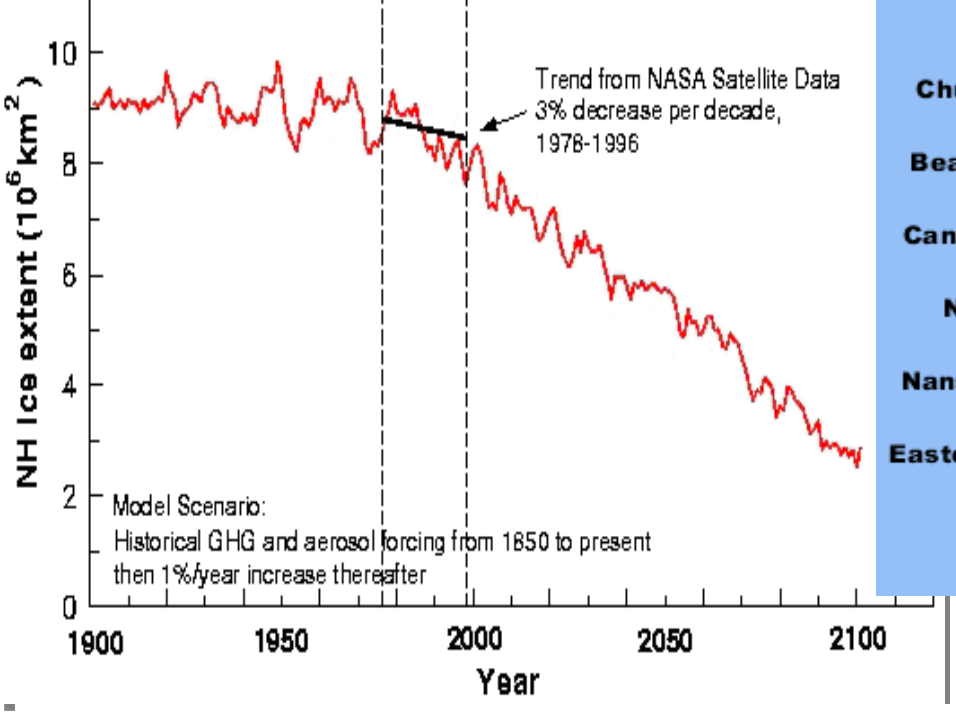
Consequences of Climate Change - 2

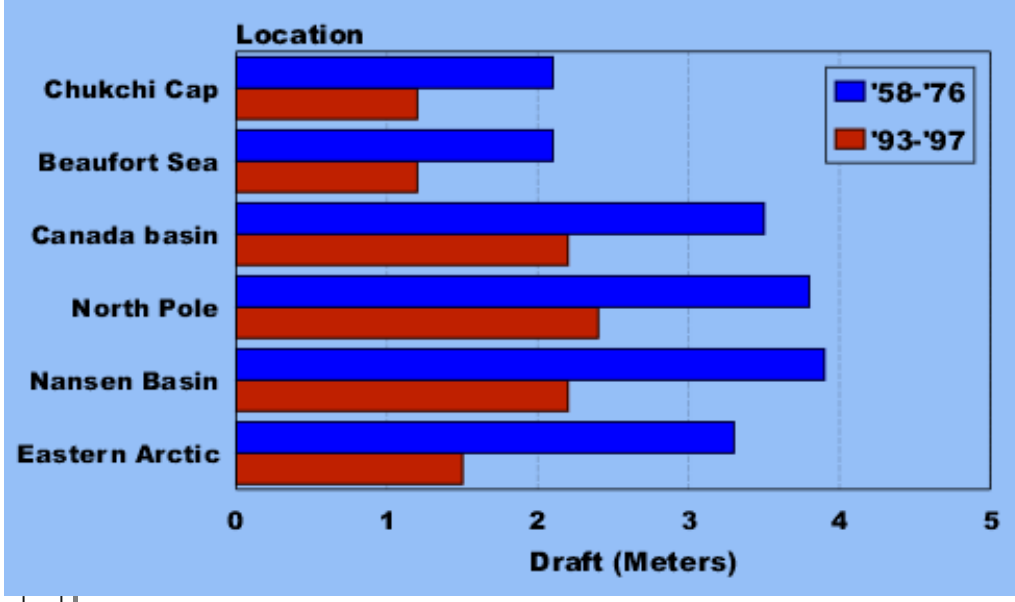
- Temperature rise
  - Will rise 1.8 ^{o}C to 4 ^{o}C over next century.
    - Even if 2000 levels of GHGs maintained, temperature rise of 1 ^{o}C due to GHGs already in atmosphere.
    - Greatest temperature rise will be in Arctic and Antarctic.
- Sea level rise
  - Decline in ice volume may lead to increase in sea level of 18 cm to 59 cm or more.
    - Risk of floods in vulnerable coastal cities.

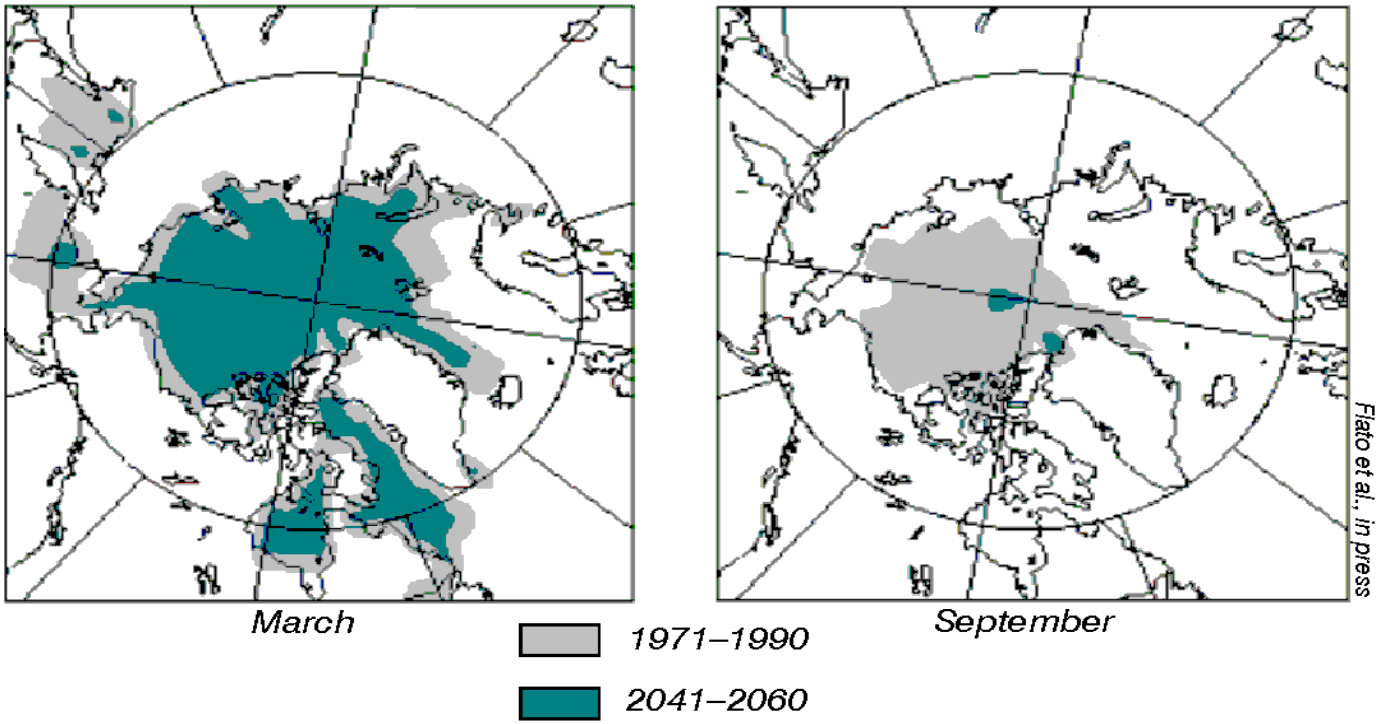
Your view of the effects of climate change may depend on where you live…



Arctic Sea Ice melts as temperature increases







Sea ice is thinning and may Disappear during Summer & Fall

Consequences of Climate Change - 3

- Present observations
  - Changes in arctic temperatures, ocean salinity, wind patterns, extreme weather conditions.
  - 11 of 12 warmest years since 1850 occurred in 12 year span between 1995-2006.
- Other consequences
  - Inland flooding, drought, insect plagues, species extinction.
- Irreversibility
  - Vast peat bogs exist under permafrost in subarctic.
    - Increase of 2 ^{o}C may cause these bogs to decay, releasing huge amounts of GHGs.

Defining Sustainability

- Brundtland Commission of United Nations:
  - "Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs."
- Paul Hawken, in *The Ecology of Commerce*:
  - "leave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do."

History of Sustainable Development - 1

1962 - Rachel Carson publishes "Silent Spring".

- This book brought together research on toxicology, ecology and epidemology to suggest that agricultural pesticides were building to catastrophic levels.
- This was linked to damage to animal species and to human health.
- It shattered the assumption that the environment had an infinite capacity to absorb pollutants.

1968 - The Club of Rome, is established by 36 European economists and scientists. Its goal is to pursue a holistic understanding of the 'world problematique'. It commissions a study on global proportions to model and analyse the dynamic interactions between industrial production, population, environmental damage, food consumption and natural resource usage.

1969 - Friends of the Earth forms as a non-profit organization dedicated to protecting the planet from environmental degradation; preserving biological, cultural, and ethnic diversity; and empowering citizens to have an influential voice in decisions affecting the quality of their environment -- and their lives.

1971 - Greenpeace starts up in Canada and launches an aggressive agenda to stop environmental damage through civil protests and non-violent interference.

History of Sustainable Development - 2

- **1971** International Institute for Environment and Development (IIED) established to seek ways to make economic progress without destroying the environmental resource base.

- **1972** United Nations Conference on the Human Environment, Stockholm. 'Only one Earth' - led to the development of The United Nations Environment programme (UNEP)

- **1972** Club of Rome publishes "Limits to Growth" (Meadows et.al) report
  - Best seller in several languages.
  - It described the use of a computer model – World 3 - to study the implications of continuing exponential growth in five interconnected trends of global concern: industrialisation, population, growth, widespread malnutrition, depletion of non-renewable resources and ecological damage.
  - The report adopts a pessimistic view of development, warning of severe resource shortages if development were to maintain its current momentum.
  - Extremely controversial - Northern countries criticising it for not including technological solutions and Southern countries criticising it because because it advocates abandonment of economic development.

History of Sustainable Development - 3

- **1974** Rowland and Molina release seminal work on CFCs (*chlorofluorocarbons*) in Nature.
  - They calculated that if human use of CFC gases was to continue at an unaltered rate the ozone layer would be depleted by many percent after some decades. 1995 Nobel Prize for Chemistry.

- **1983** World Commission on Environment and Development forms. The commission works for 3 years to weave together a report on social, economic, cultural, and environmental issues.

- **1984** Worldwatch Institute publishes its first State of the World Report.
  - The report monitors changes in the global resource base, focusing particularly on how changes there affect the economy.
  - It concludes that "we are living beyond our means, largely by borrowing against the future."

- **1985** Antarctic ozone hole discovered.

- **1987** World Commission on Environment and Development publish - *Our Common Future* (The Bruntland Report) – in response to the request from the UN general assembly to propose long-term environmental strategies for achieving sustainable development by the year 2000.

History of Sustainable Development - 4

- **1987** Montreal Protocol – focused on the depletion of the stratospheric ozone layer and eliminating substances that cause this (HCFCs).
  - Has since been strengthened twice - London and Copenhagen.
  - Production of CFCs in North stopped by 1996, countries in the South (China and India) to end production by 2006.
  - One of the most successful international environmental agreements.
- **1988** Inter-Governmental panel on Climate Change (IPCC)
  - Resulted in the framework convention on climate change signed by 153 countries + the then EU, dealing with the threat of global warming
  - Lacked firm agreements on targets, did aim to stabilise 1990 levels of CO2 and other greenhouse gases
- **1992** Meadows, D. B., Meadows, D. L. and Randers, J., *Beyond the Limits*, London: Earthscan.
  - Using a computer model to map patterns of growth, the report concluded that environmental collapse was inevitable.
  - 'If the present growth trends on world population, industrialisation, pollution, food production and resource depletion remain unchanged, the limits to growth on this planet will be reached some time within the next 100 years'.

History of Sustainable Development - 5

- **1992** *United Nations Conference on Environment and Development* (UNCED) held in Rio de Janeiro, Brazil – The Earth Summit. 179 countries participated in this conference working towards reconciling the impact of human socio-economic activities on the environment. Outcomes:
  - Convention on biological diversity
  - Framework convention on climatic change
  - Principles of forest management
  - Agenda 21
  - The Rio declaration on environment and development

The girl who silenced the world for 5 minutes

History of Sustainable Development - 6

- **1994** *Law of the Sea* – national sovereignty of off-shore waters and the national responsibility for the ecosystems within these waters (re. dumping waste, & fish stocks etc.)

- **1997** - Earth Summit+5 - A five year review of Earth Summit progress was made by the United Nations General Assembly.
  - The final document adopted by delegates from over 165 countries -- while taking small steps forward on a number of issues, including preventing climate change, forest loss and freshwater scarcity - disappointed many in that it contained few new concrete commitments on action needed.

History of Sustainable Development - 7

- **1997** – Kyoto Protocol
  - More than 160 countries met to negotiate new GHG emission targets.
  - reduce emissions of serious greenhouse gases – CO_2, CH_4, NO & 3 types of fluorinated gases
  - More than 80 countries agreed to reduce emissions to an average of 5.2 percent *below* 1990 levels by 2010.
  - Canada and US not successful in attaining their targets.

- **2001** – Climate Summit, Bonn – 178 countries developed a framework of how to implement the 1997 Kyoto Protocol

- **2002** - Earth Summit 2002, Johannesburg, South Africa. Rio+10 - *World Summit on Sustainable Development* -'people, planet, prosperity'.

History of Sustainable Development - 8

- **2007** – IPCC Fourth Assessment Report - Climate Change 2007

  The UN Intergovernmental Panel on Climate Change assesses scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation.

  The largest and most detailed summary of the climate change situation ever undertaken, involving thousands of authors from dozens of countries (including from Carleton)

  • "Warming of the climate system is unequivocal."

  • "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

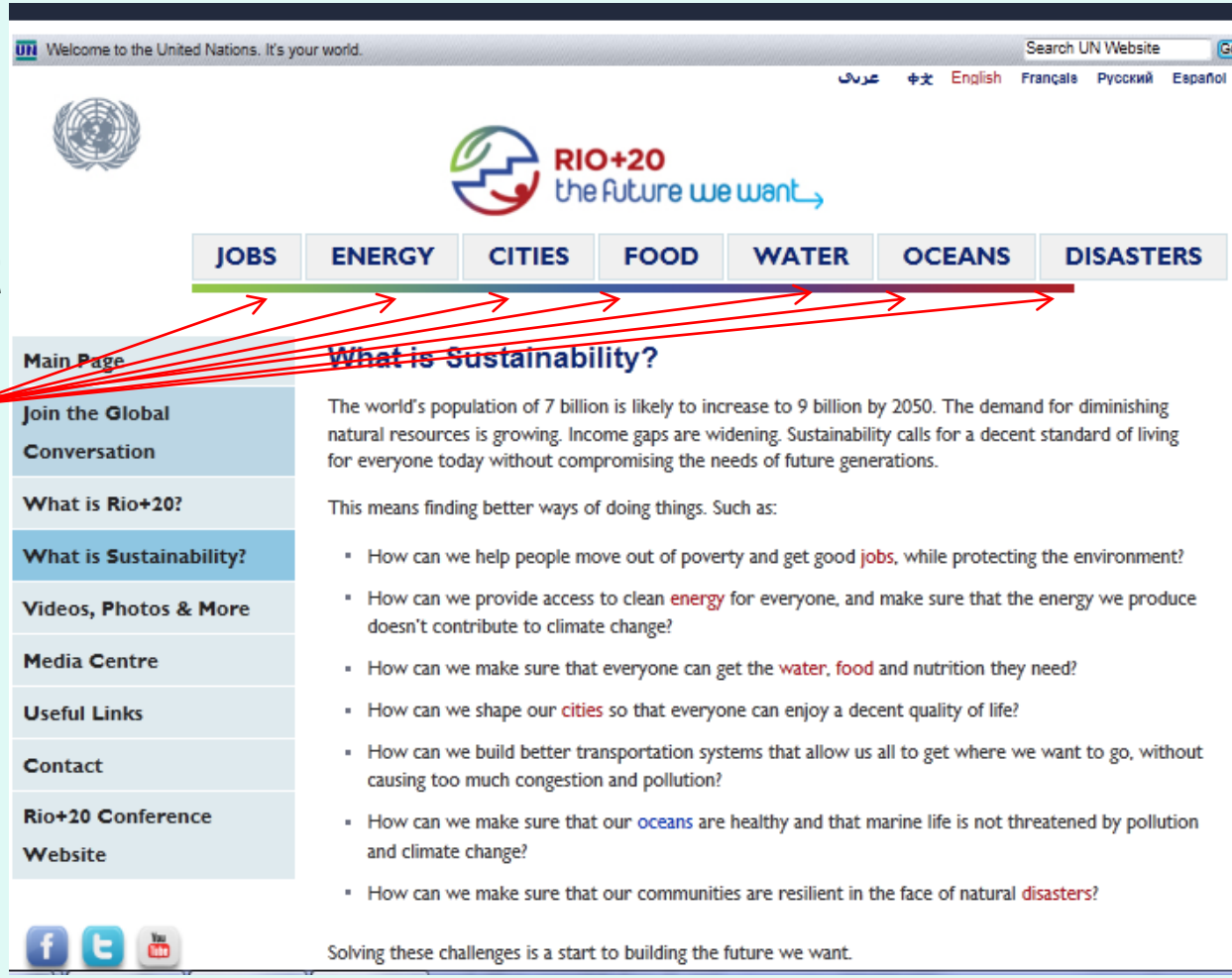
- **2007** – Bali Roadmap, 2007

  United Nations Framework Convention on Climate Change (UNFCCC) adopted this process for negotiating an international agreement on climate change, to follow Kyoto agreement which ends in 2012.

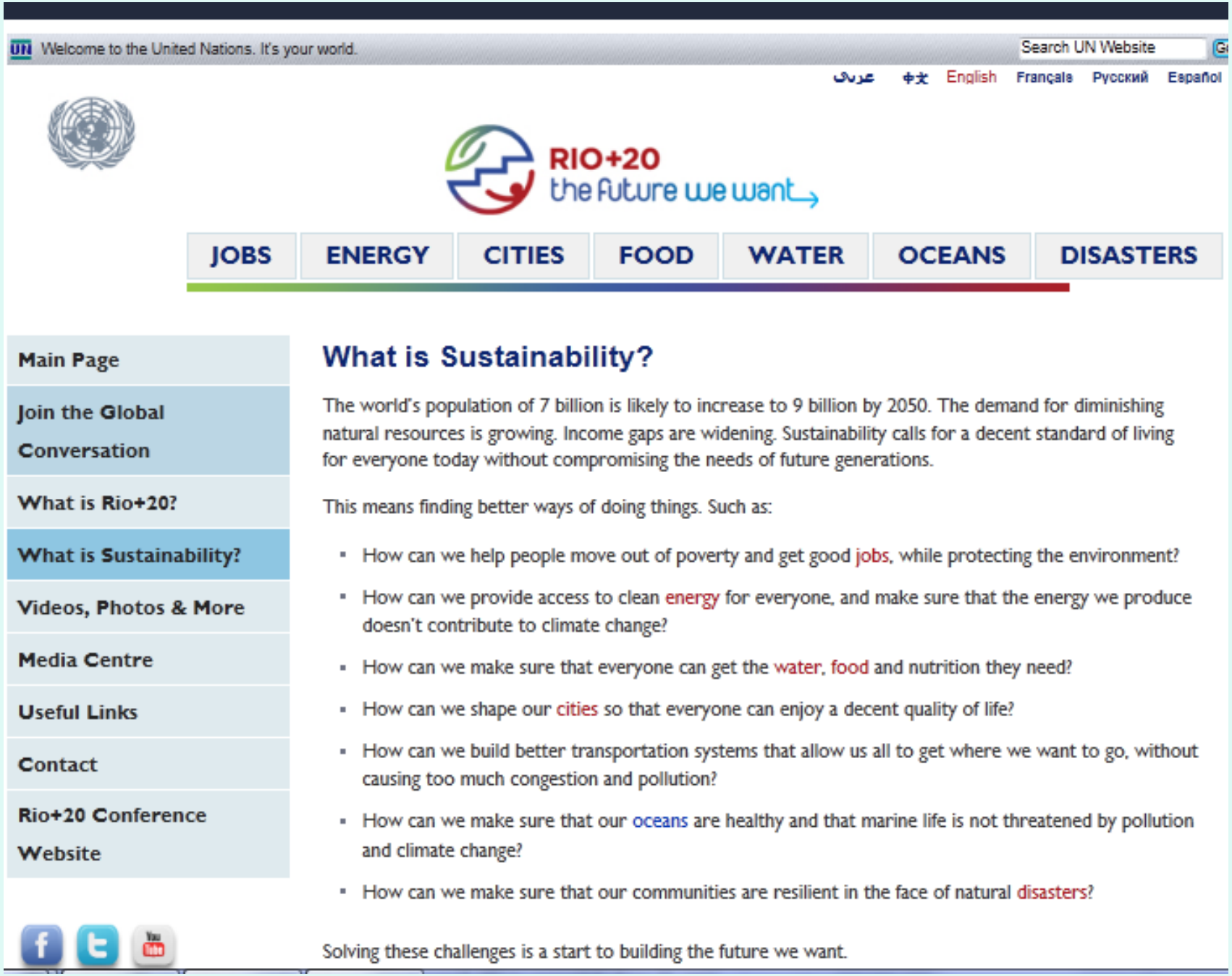
History of Sustainable Development - 9

- **2012** – Rio+20 United Nations Conference on Sustainable Development

  7 Critical Issues at Rio+20



http://www.un.org/en/sustainablefuture/index.shtml



http://www.un.org/en/sustainablefuture/index.shtml

What is Sustainability?

The world's population of 7 billion is likely to increase to 9 billion by 2050. The demand for diminishing natural resources is growing. Income gaps are widening. Sustainability calls for a decent standard of living for everyone today without compromising the needs of future generations.

This means finding better ways of doing things. Such as:

- How can we help people move out of poverty and get good jobs, while protecting the environment?
- How can we provide access to clean energy for everyone, and make sure that the energy we produce doesn't contribute to climate change?
- How can we make sure that everyone can get the water, food and nutrition they need?
- How can we shape our cities so that everyone can enjoy a decent quality of life?
- How can we build better transportation systems that allow us all to get where we want to go, without causing too much congestion and pollution?
- How can we make sure that our oceans are healthy and that marine life is not threatened by pollution and climate change?
- How can we make sure that our communities are resilient in the face of natural disasters?

http://www.un.org/en/sustainablefuture/index.shtml

The little girl 20 years later …

Achieving Sustainability

- Two questions:
  - What kind of planet do we want for our children?
    - Question has ethical implications.
  - What kind of planet can we get?
    - Technical and societal implications.
- Engineers, scientists, and economists can solve technical problems, but …
  - Not all problems have technical solution.
  - Society must be willing to accept major lifestyle changes.

Ethical Questions - Climate Change

- Economic loss caused by climate change will affect poorest nations the most.
  - Increases disparities between societies.
- Is it ethical or fair
  - for richer countries to burn fossil fuels indiscriminately, while imposing climate change on poorer countries?
  - to require third-world countries to meet same emissions standards as western countries, which have emitted about 20 times as much GHG per capita in past century?
- How will industrialized nations respond to the millions of "climate" refugees?

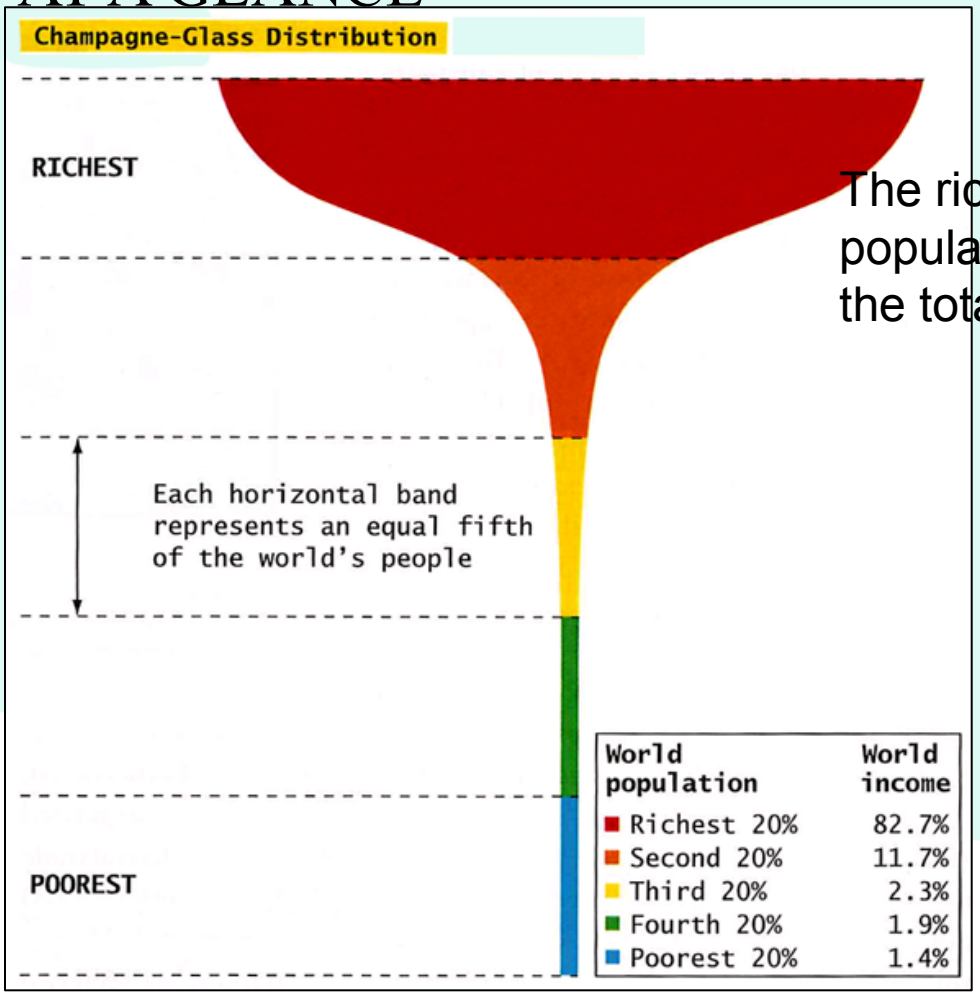
Ethical Implications - Sustainability

- Is it ethical or fair
  - For current generation to consume non-renewable resources inefficiently and thoughtlessly, thus depriving future generations who may need these resources?
  - For a government to restrict population growth?
    - China, introduced a “one child” policy many decades ago.
      - Better to restrict population in an orderly way?
      - Or let wars, disease, and famine control population?

Spare
some
change?

A FRAGILE PREDICAMENT

OUR PLANET AT A GLANCE



The richest fifth of the world's population receives 82.7% of the total world income

The poorest fifth of the world's population receives 1.4% of the total world income

Global Energy & Wealth Disparity

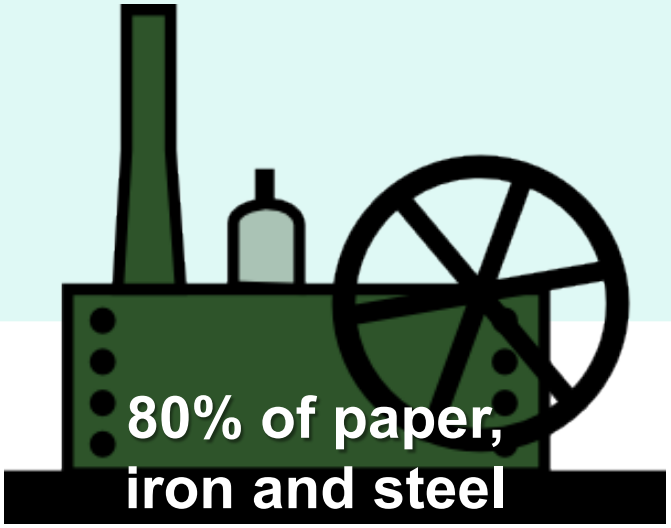
UNDP, Human Development Report 1992 (New York, Oxford University Press, 1992)

GLOBAL CONSUMPTION DISPARITY

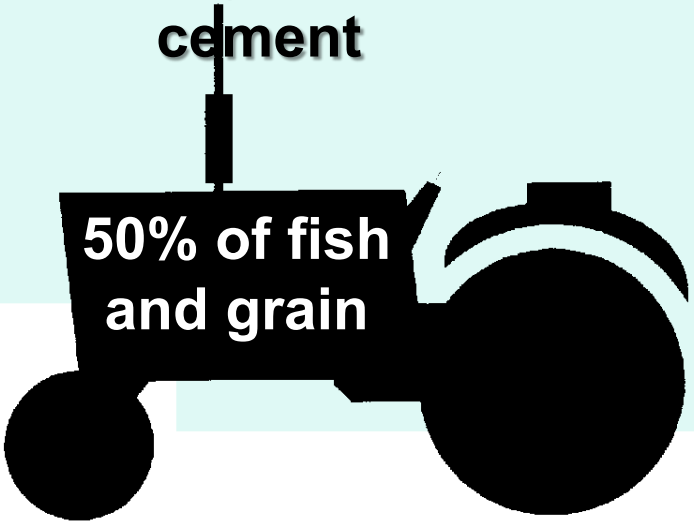
IT'S ABOUT RESOURCES

Developed countries have 20% of the global population but are responsible for consuming:

75% of timber



65% of meat, fertilisers and cement

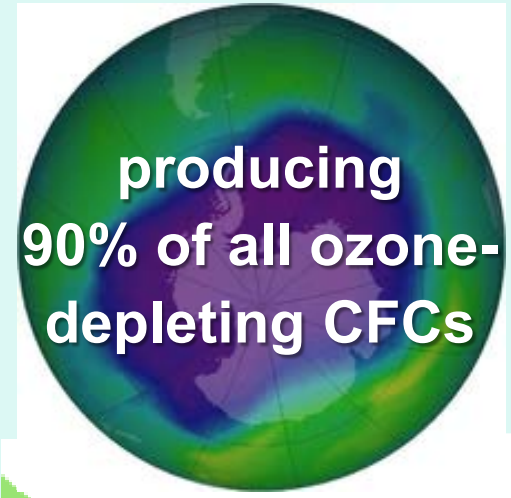


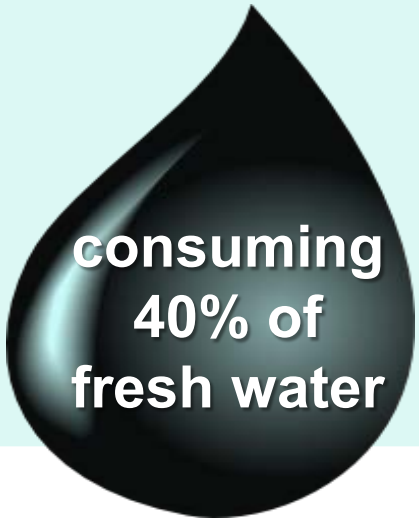
85% of aluminium and synthetic chemicals

GLOBAL CONSUMPTION DISPARITY

IT'S ABOUT RESOURCES

Developed countries have 20% of the global population but are responsible for:





and consuming 80% of commercial energy.

CONSUMING THE FUTURE
ON A FINITE EARTH

If consumption in developing countries were to grow as fast as in developed countries:

Known copper reserves would last only 9.6 more years;

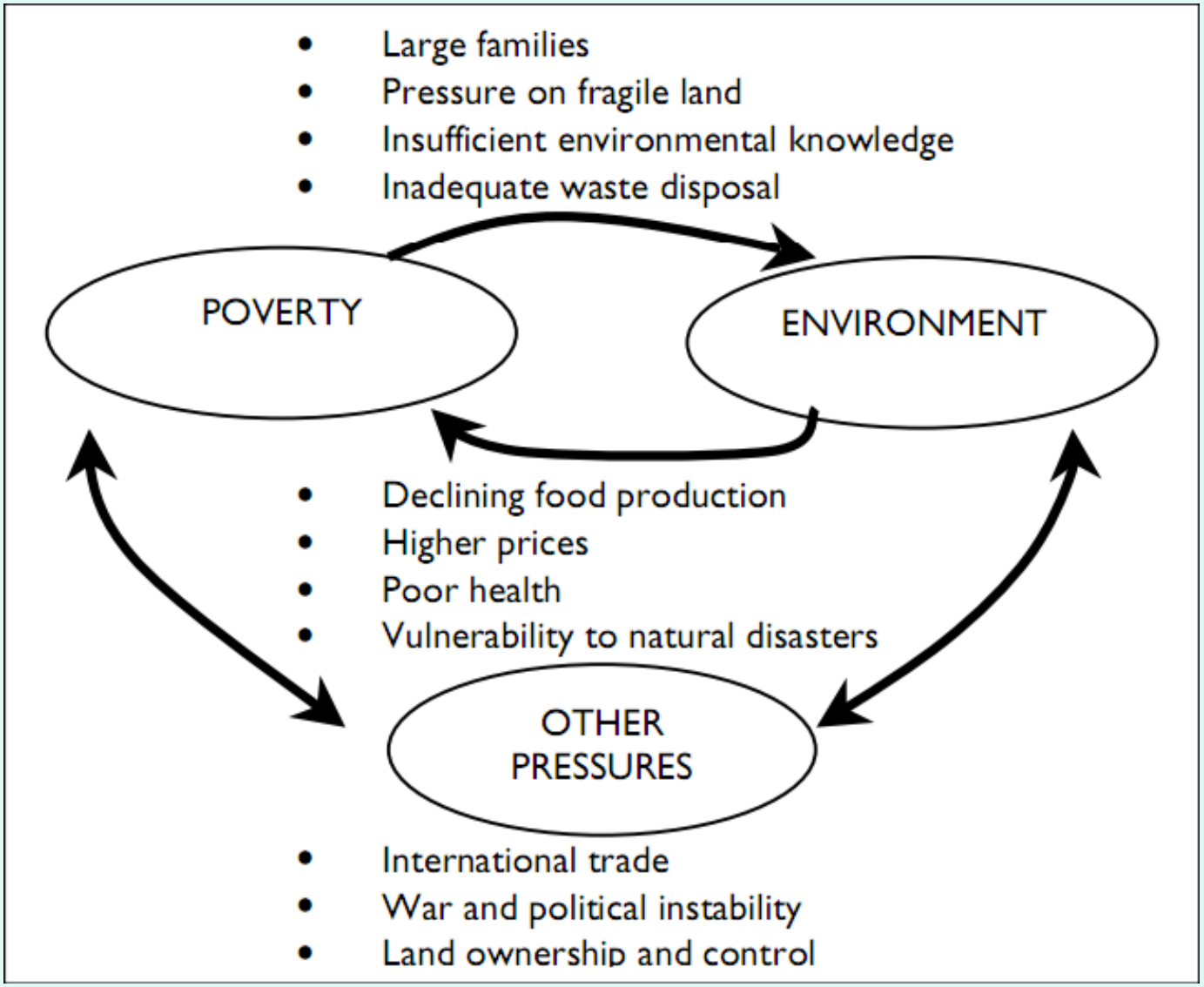
Lead reserves 3.4 years;

Aluminium reserves 341 more years;

And 16 million hectares of arable land would be lost every year.

GIVE AND TAKE

AN INTRICATE RELATIONSHIP BETWEEN PEOPLE AND PLACE



DO AS WE SAY, NOT AS WE DO

DO WE HAVE THE RIGHT TO LIMIT THEIR DEVELOPMENT?

"China is racing to replace its bamboo past with a plastic future, bulldozing land and building its 21st century infrastructure around the private car, rather than public transit."

Sound familiar?

Is it fair to paint their country green?

WHAT ARE WE WILLING TO DO TO CLOSE THE GAP?

BEFORE
YOU ANSWER,
THINK
ABOUT
IT,
REMEMBER
THERE'S
NO
BLACKBERRY
OR
STARBUCKS
AT
THE
BOTTOM.

THINK ABOUT IT

SHOULDN'T AMERICA'S RICHEST 1% SHARE WITH THE OTHER 99%?

OCCUPY WALL ST

THINK AGAIN

WE ARE THE 1%.

OCCUPY WALL ST

PLANET EARTH

(That's you!)

If you make $55,000/year when you graduate, you will be a member of the exclusive top 1% richest people in the world.

If you sacrificed 10% of your income, you would still be in the top 1%.

Source: CBC & Global Rich List

Can Ethical Questions Be Avoided ?

- Only if:
  - Enormous Reductions in Fossil Fuel Use
  - Enormous Reduction in Consumption of Energy Intensive Products, Materials & Processes
- To maintain environmental impacts at their current level, the desired size of impact reduction over the next 100 years (when world population will roughly double) is between a factor of 4 & 20.
- Environmental impact of all products & processes to be reduced by up to 95%.
- But – Factor 20 only maintains current environmental impact

  ↳ global warming continues ?
- **Somehow Society needs to answer Ethical Questions**
- **The Good News ?** ***Lots of Excellent Opportunities for Engineers !***

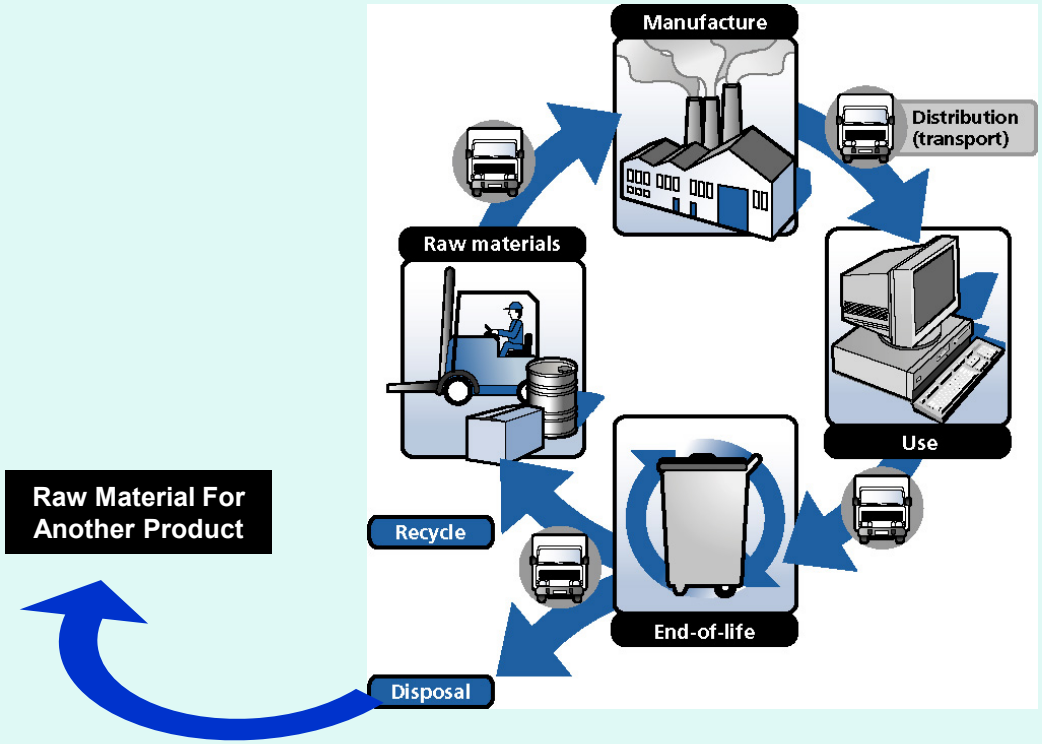
  Without Engineers – Impossible Challenge

Engineering for Sustainability

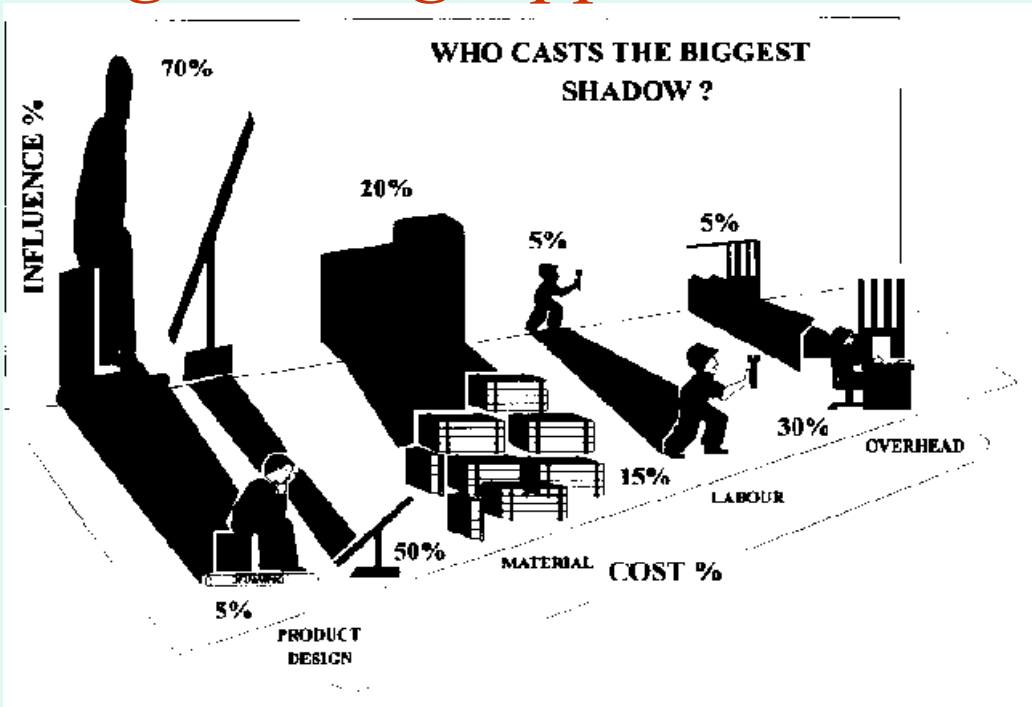
- Engineers can assist society by
  - innovative design for energy efficiency,
  - encouraging research into alternative energy sources,
  - modelling alternatives,
  - highlighting environmental consequences of design / process decisions.
- Modelling
  - model atmosphere and possible effects of climate change.
- Multi-disciplinary engineering and systems thinking
  - bridge gap between science & economics to arrive at good solutions

Engineering for Sustainability

- Life Cycle Analysis (LCA)
  - Evaluates environmental impact of a product from source material to disposal.
  - Cradle-to-Grave analysis & design
  - Cradle-to-Cradle analysis, design & application



Engineering Opportunities



The design / engineering stages of product development have a direct influence over about 70% of the final product – this brings with it responsibility…

Designers / engineers play an important role because they are the industry's connection with the marketplace, interacting between people and products

"There are few professions more harmful than … design, but only a very few… by creating whole new species of permanent garbage to clutter up the landscape, and by choosing materials and processes that pollute the air we breath, designers have become a dangerous breed…

In this age of mass production when everything must be planned and designed, design has become the most powerful tool with which man shapes his tools and environments (and, by extension, society and himself). This demands high social and moral responsibility from the designer."

Victor Papanek, 1927-1988
Designer & Educator

Why Focus on Design & Engineering?

- The Brundtland Report made recommendations for a new approach to design and production, setting out terms for:
  - 'a production system that respects... the ecological base' and,
  - 'a technological system that searches continuously for new solutions'.
- Environmental impact occurs at every stage of the life cycle
- Different products have different impacts at different stages…
  - furniture = raw materials
  - household appliances = use; energy consumption
- Impacts are often 'locked in' at the design stage when decisions about materials, function, performance, energy source, aesthetic, purpose etc. are made
- Only careful consideration at these early stages can make sure that negative effects excluded and positive features are included.
- Trying to retro fit solutions is often very costly and less beneficial – involving additional equipment, rather than solving the problem from first principles.

What Can We Do?

- Reduce, Reuse, Recycle
- Efficiency Paradox
  - Technology improves energy efficiency, but those savings are often lost to greater consumption.
    - Efficiency of air conditioner has risen 17% since 1990, but use of these units increased by 36% over that time.
- Rethink
  - As a society, we must develop new ways to avoid inefficient or excessive consumption of energy.

Guidelines for Engineers - 1

- In Alberta, the APEGGA *Guideline for Environmental Practice* explains engineer's duty to environment.
  - Encourages licensed professionals to be involved actively with environmental issues.
  1. Understand / monitor environmental and sustainability issues;
  2. Use specialists in environmental and sustainability when needed;
  3. Apply professional and responsible judgment;
  4. Environmental planning and management should be integrated into all activities likely to have any adverse effects;

Guidelines for Engineers - 2

5. Include costs of environmental protection when evaluating the economic viability of projects;
6. Recognize value of environmental efficiency and sustainability; consider full lifecycle assessment and endeavour to implement efficient, sustainable solutions;
7. Solicit input from stakeholders and strive to respond to environmental concerns in a timely fashion;
8. Comply with regulatory requirements and endeavour to exceed or better them; disclose information necessary to protect public safety to appropriate authorities;
9. Work actively to improve environmental understanding and sustainability practices.

But, these are only guidelines that are not binding, and only in Alberta.

Reading Assignment

- Read Chapter 9

ECOR 1010 – ELEC 1908

Technology, Society & Environment
Lecture 3

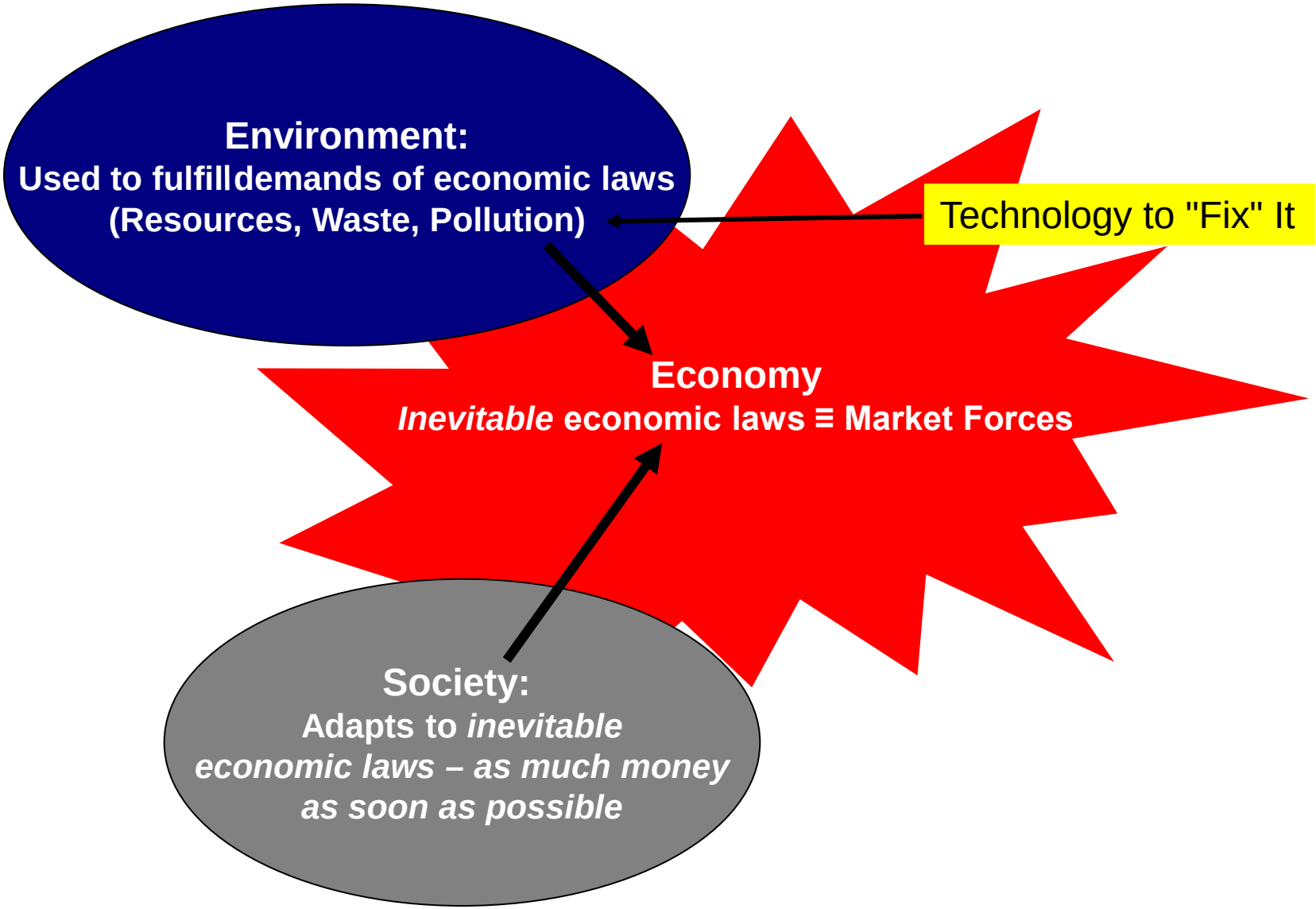
Engineers & Sustainability

Adapted from: *Technology & Sustainable Development*,
J. Segalas, Polytechnic University of Catalonia

What Role for Engineers in Sustainable Development ?

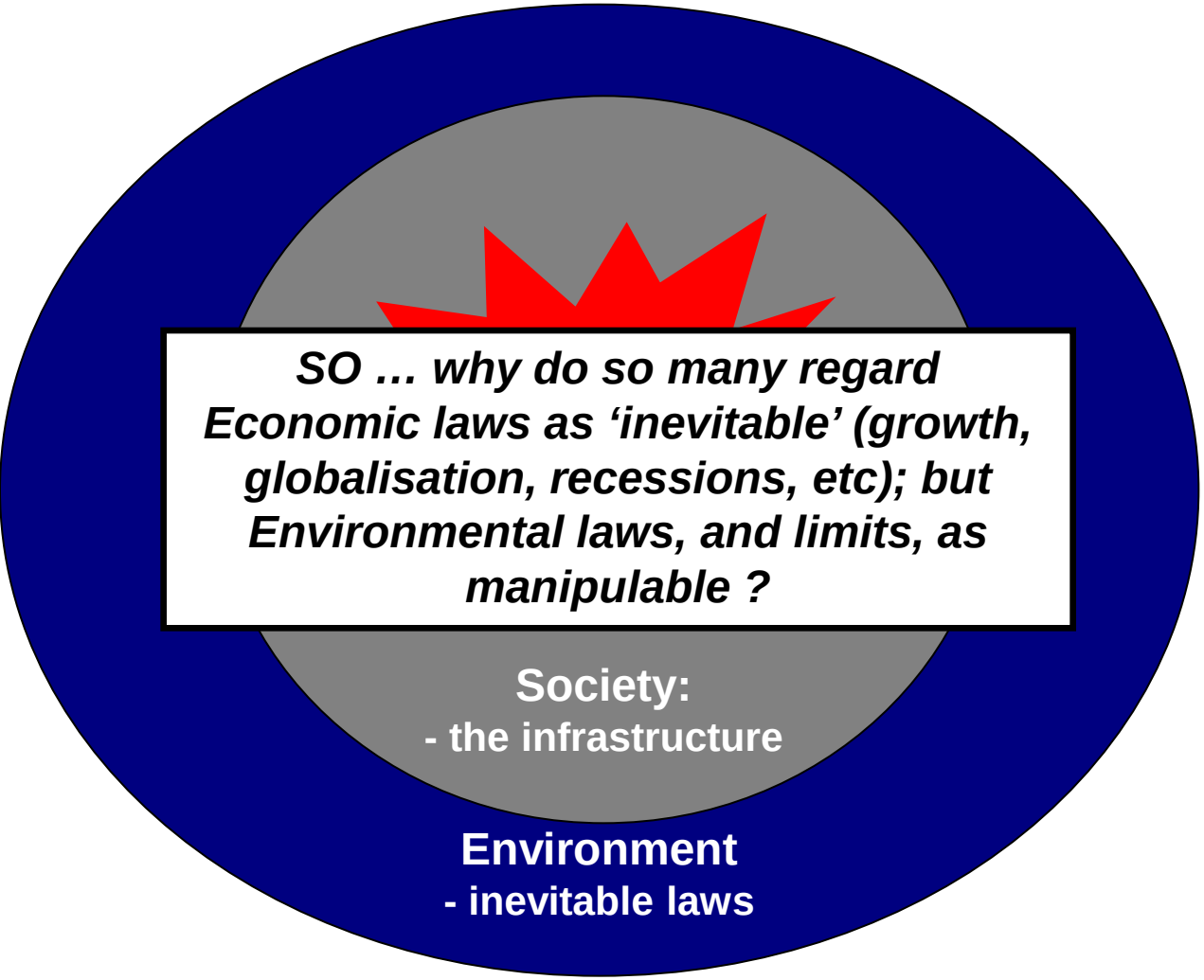
What Role for Engineers in Sustainable Development ?

One Current World View ?



But we all depend on this … So …

Engineers Are the Interface – An Alternate Current World View ?



Environment: inevitable laws ⇨ Laws of Nature

Environment nurtures, Supports and makes possible …
Society – mixture of instinctive & learned/ cultural laws

Society has invented, to serve society's purposes….
Economy - whose rules and practices are totally 'invented' by society

Engineers:
Serving Needs (Quality of Life) or Wants?

- “Traditional cultures, having more limited means to satisfy human needs, tend to meet as many needs as possible with as few resources as possible.

- In contrast, industrial capitalism emphasises the creation of specialised products that fight for market niches to fill ‘needs’ that, as often as not, cannot be satisfied by material goods.

From: "Natural Capitalism: The Next Industrial Revolution", Jawkin, Lovins, Lovins.

Engineers:
Serving Needs (Quality of Life) or Wants?

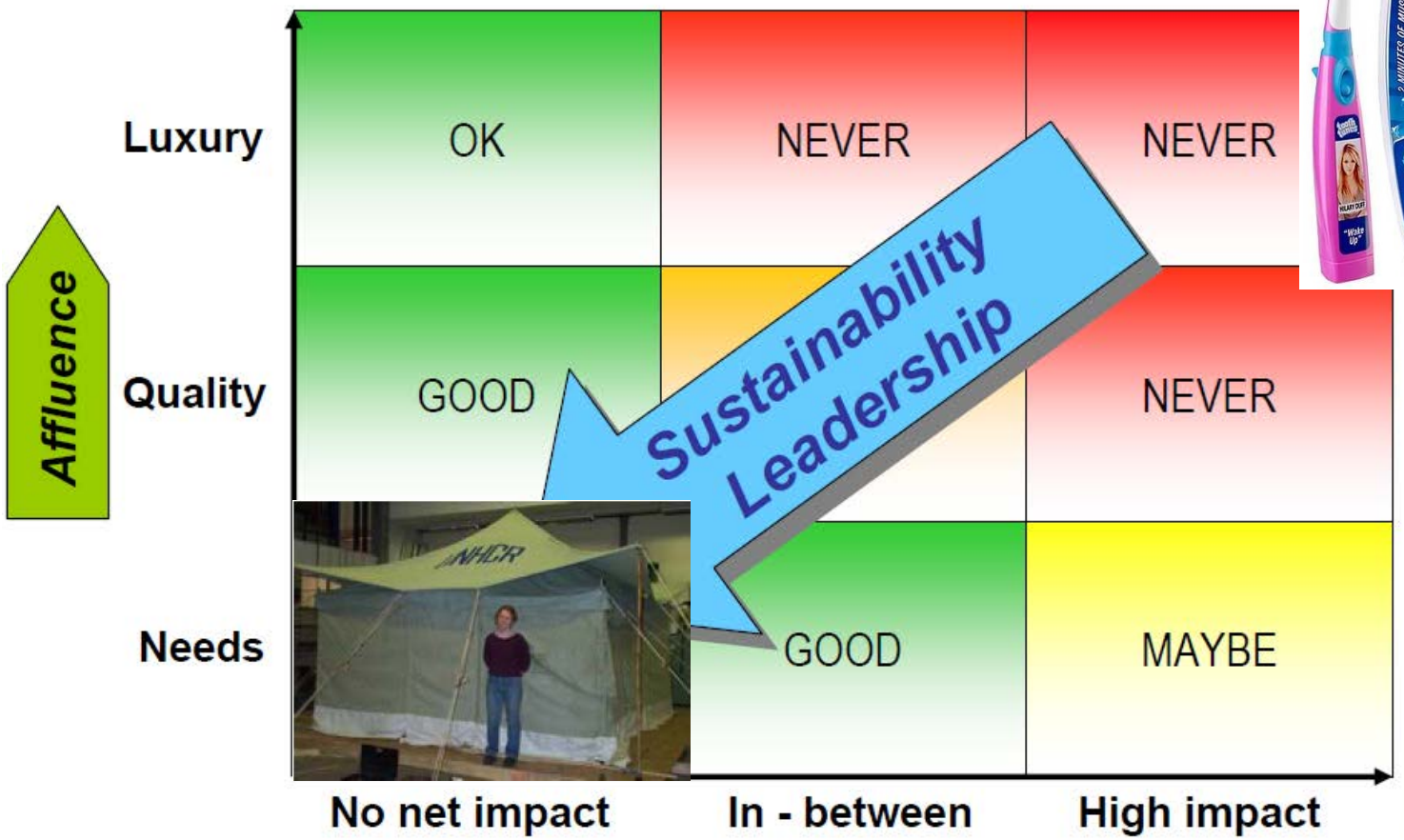
•"What better way to get your kids to brush twice daily than by pumping two minutes of Raffi through their bicuspids? …
•At the push of a button, the brush starts to play back the recording stored in it through a built-in transducer.
•The sound flows from the front teeth to the jawbone and then to the inner ear.
•Hasbro is talking to various artists about getting rights to their recordings."

•Thousands of refugee deaths from hypothermia could be prevented every year by a new design for refugee tents. The tents will pay for themselves in saved heating costs in one winter.

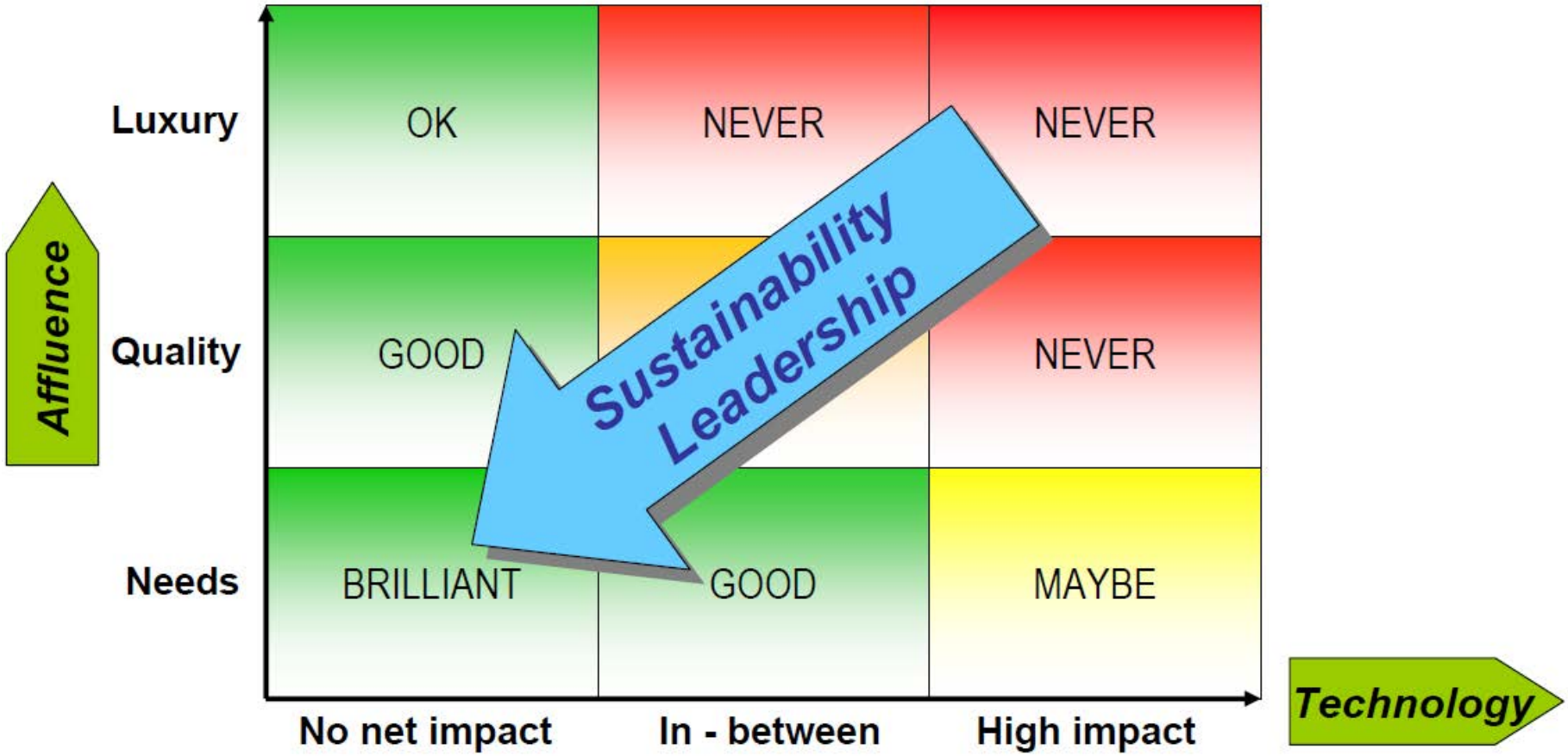
•They are made of 'sandwich' lining of: polyester wadding similar to a winter coat and a cheap breathable waterproof membrane.

Choose What You Engineer: You Can't Be Neutral

??



Engineers:
Professionals or Mercenaries ?



What is a 'Socially Sustainable Product' ?

- Is being "*manufactured sustainably*" enough, regardless of the product's *social impact ?*

- Or, should engineers push for socially sustainable features in the products: for example … *affordability and accessibility for the 'excluded' - the poorest 10%?*

- Or, should we put our energy and interest into products and projects that *serve 'needs' rather than artificially created 'wants'?*

These are questions you need to answer individually as part of your engineering career.

Case Study

INTERFACE.

http://www.interfacesustainability.com/

At his carpet company, Ray Anderson has increased sales and doubled profits while turning the traditional "take / make / waste" industrial system on its head. In a gentle, understated way, he shares a powerful vision for sustainable commerce.

http://www.ted.com/talks/ray_anderson_on_the_business_logic_of_sustainability.html

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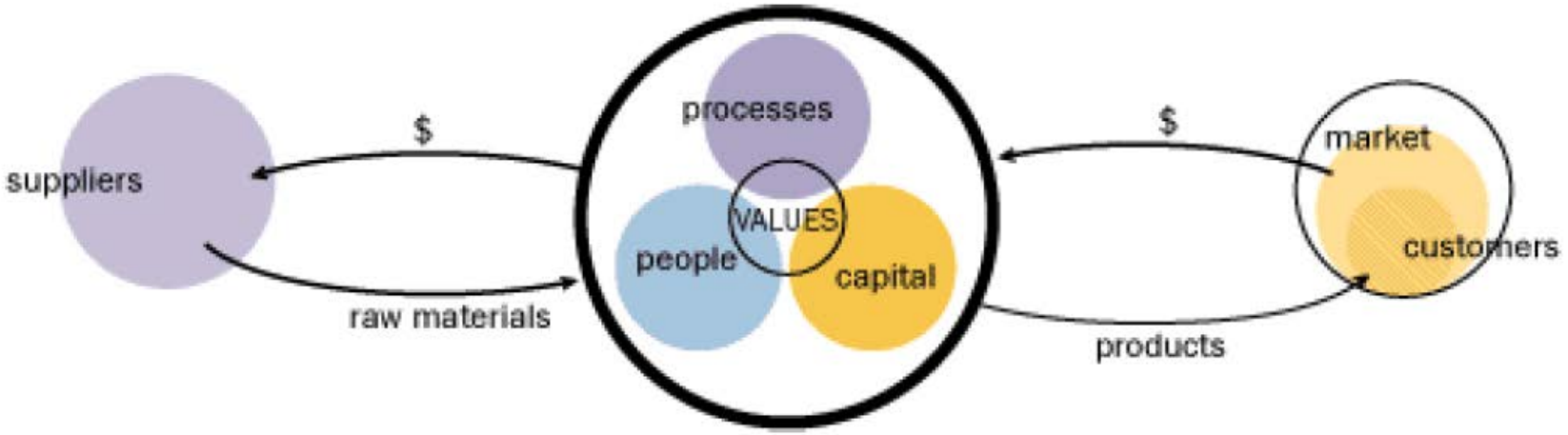
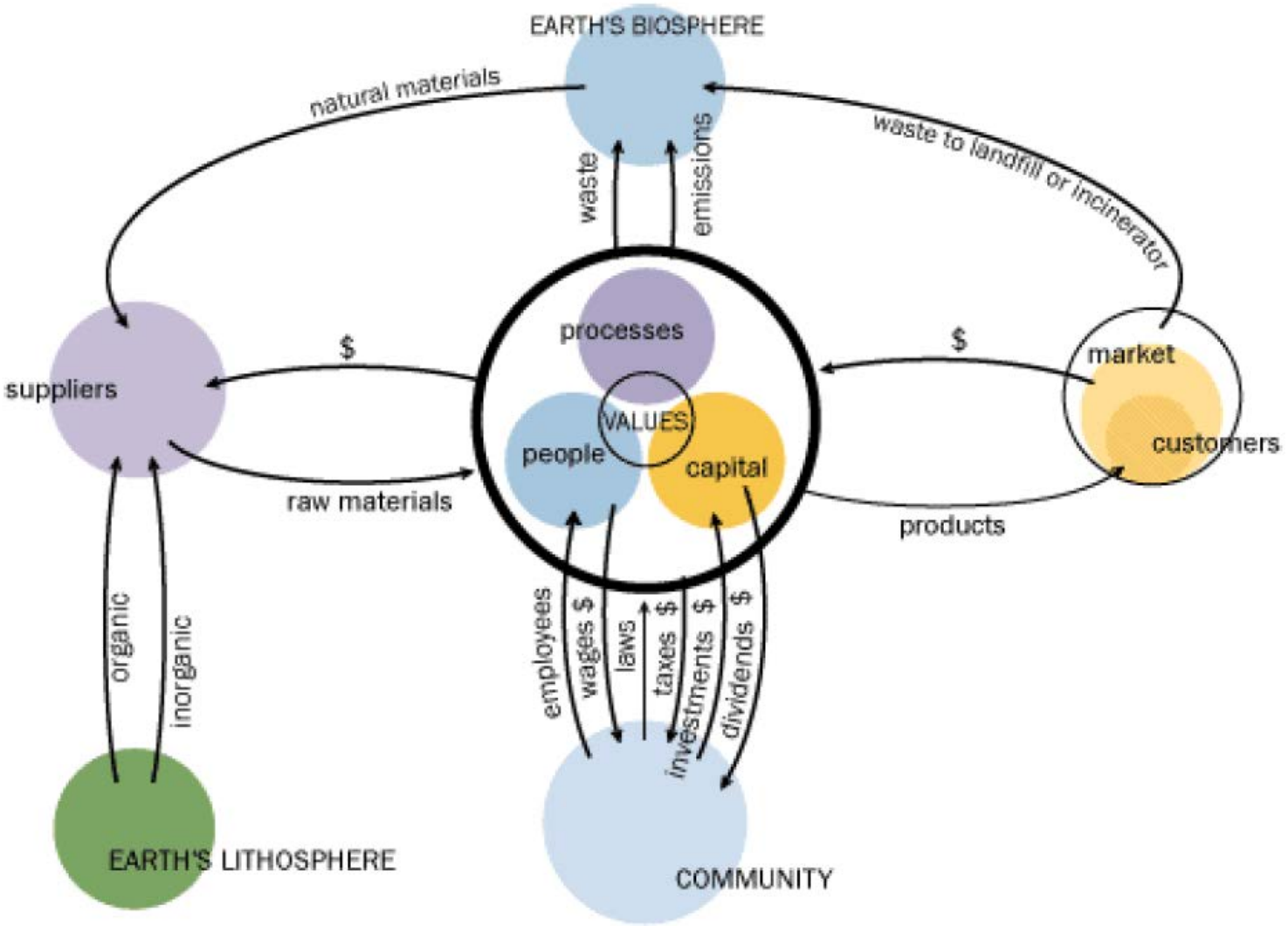
The Company

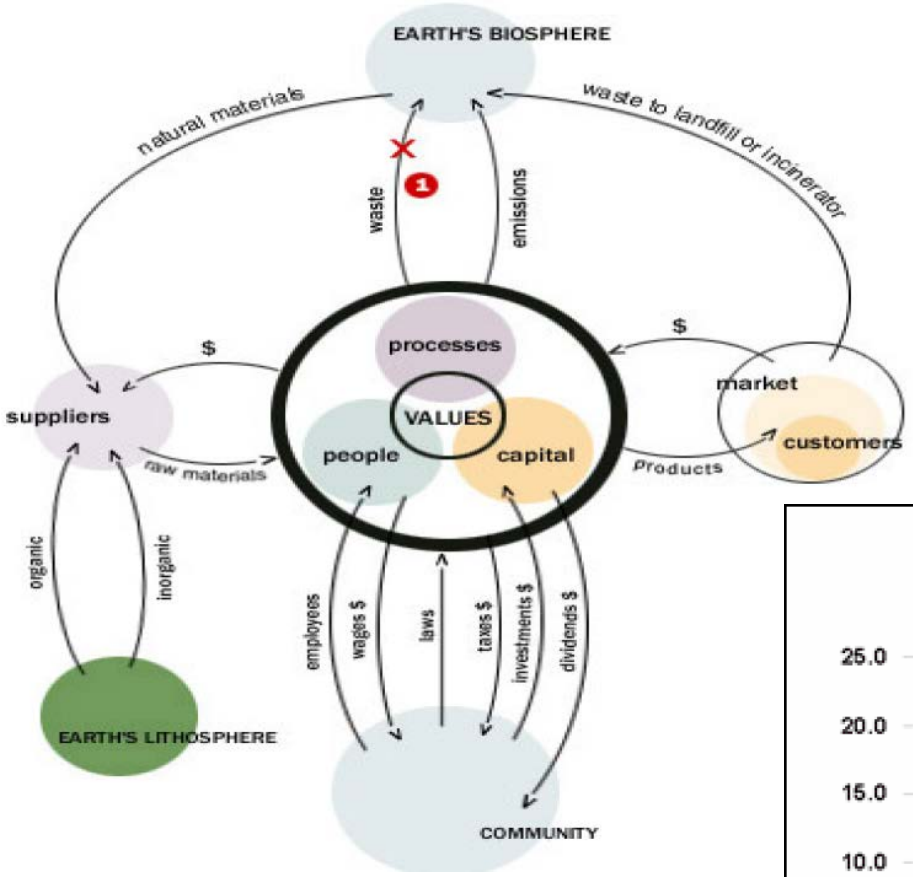


- Company part of a supply chain, with suppliers, customers and a market
- Hopes to increase market share
- Products flow through that supply chain in one direction; money flows in the other direction.

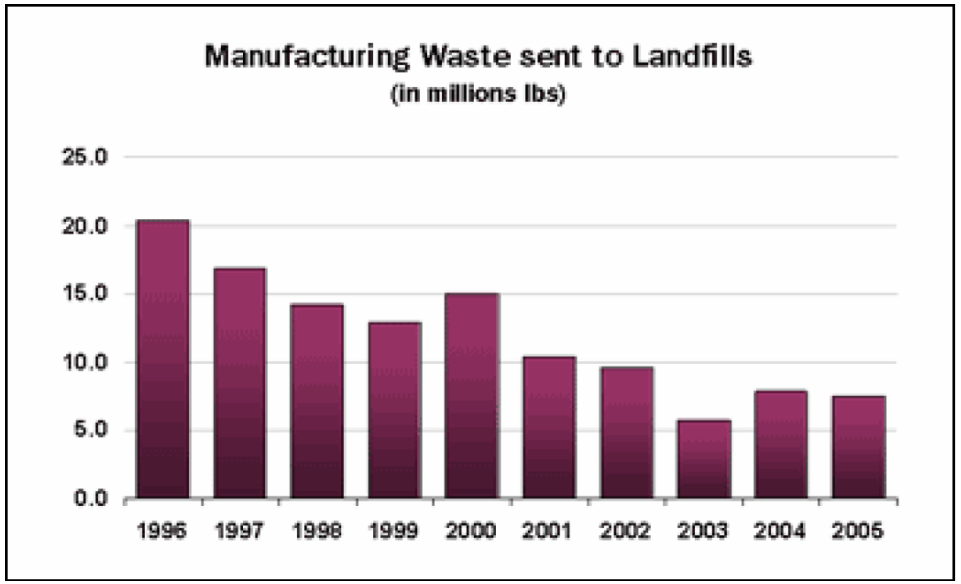
The 'Traditional' Company Operation



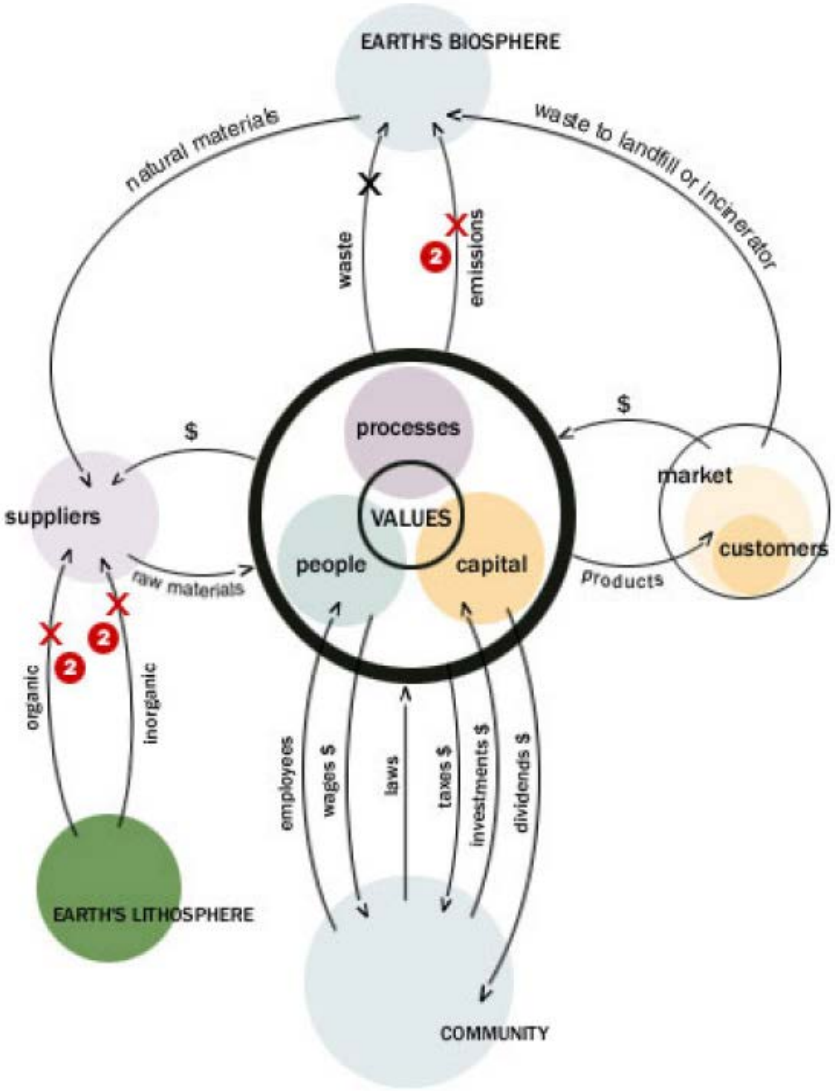
❶ *Attack Waste*



Against ideal operational standards identified $70 million in waste, based on 1994 Operations – 10% of sales

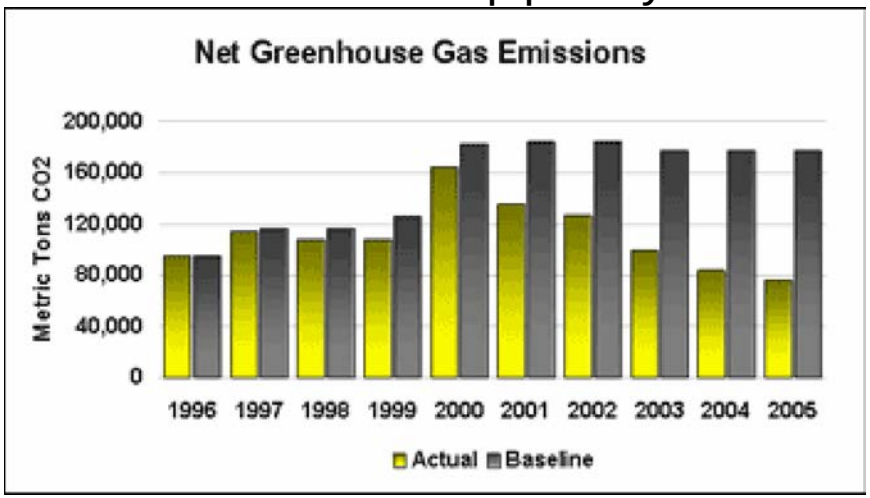


❷ *Attack Emissions*

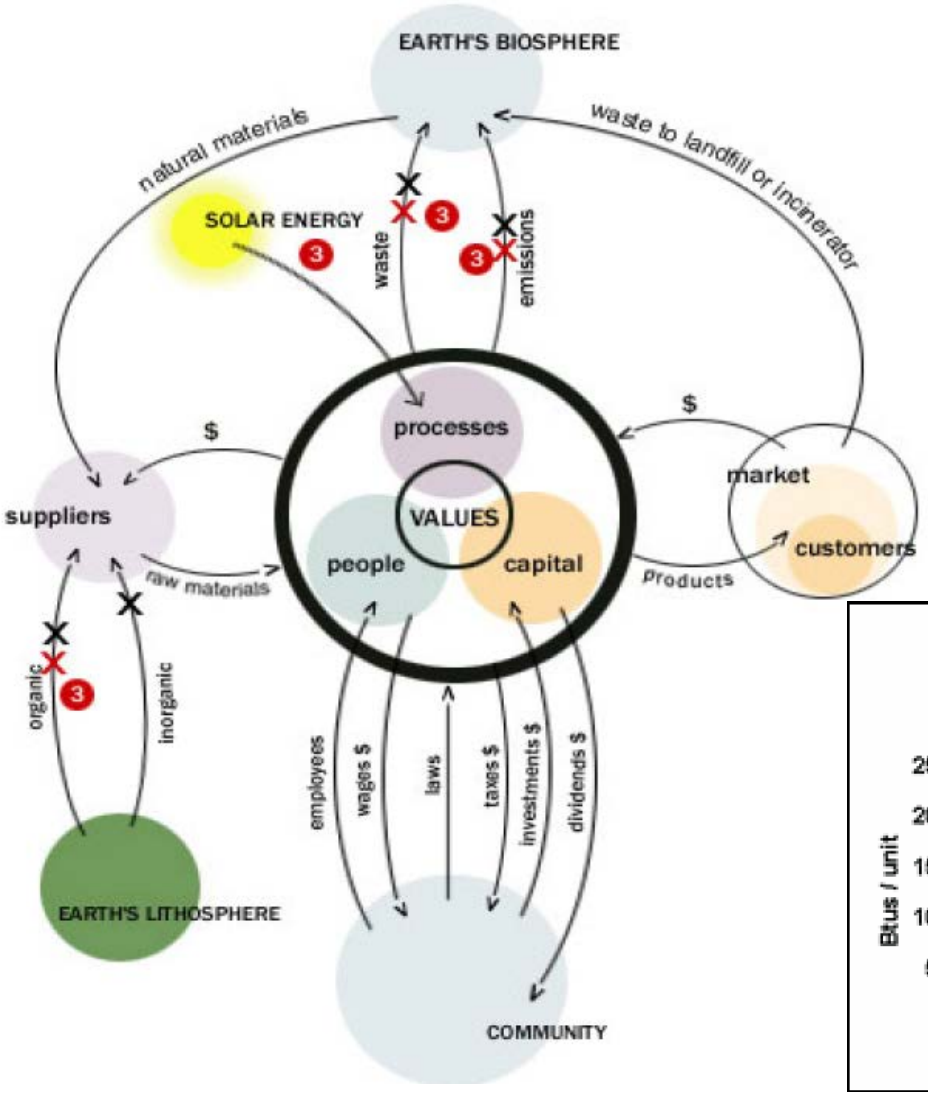


Identified and inventoried 247 air emissions stacks and 19 waste water effluent pipes at manufacturing locations.

Reduced:
number of stacks by 35%
Number of effluent pipes by 53%

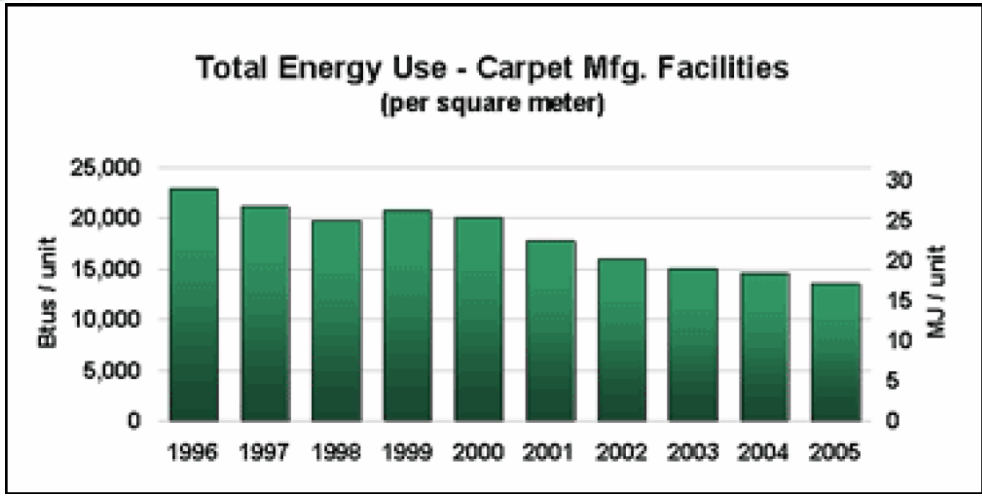


❸ *Renewable Energies*

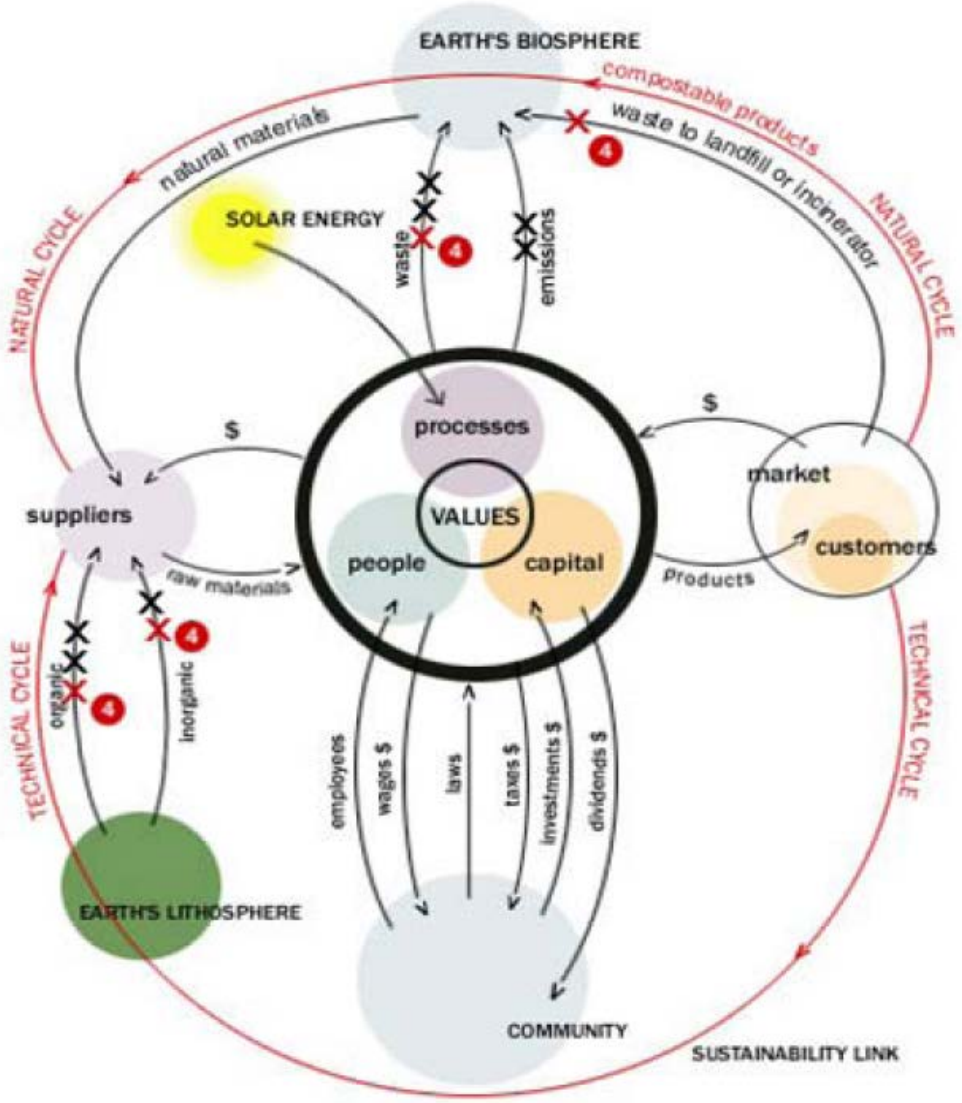


Renewable energy will attack numerous unwanted linkages, both to the lithosphere & biosphere.

13% Renewable Energy Use
Reduced Total Energy



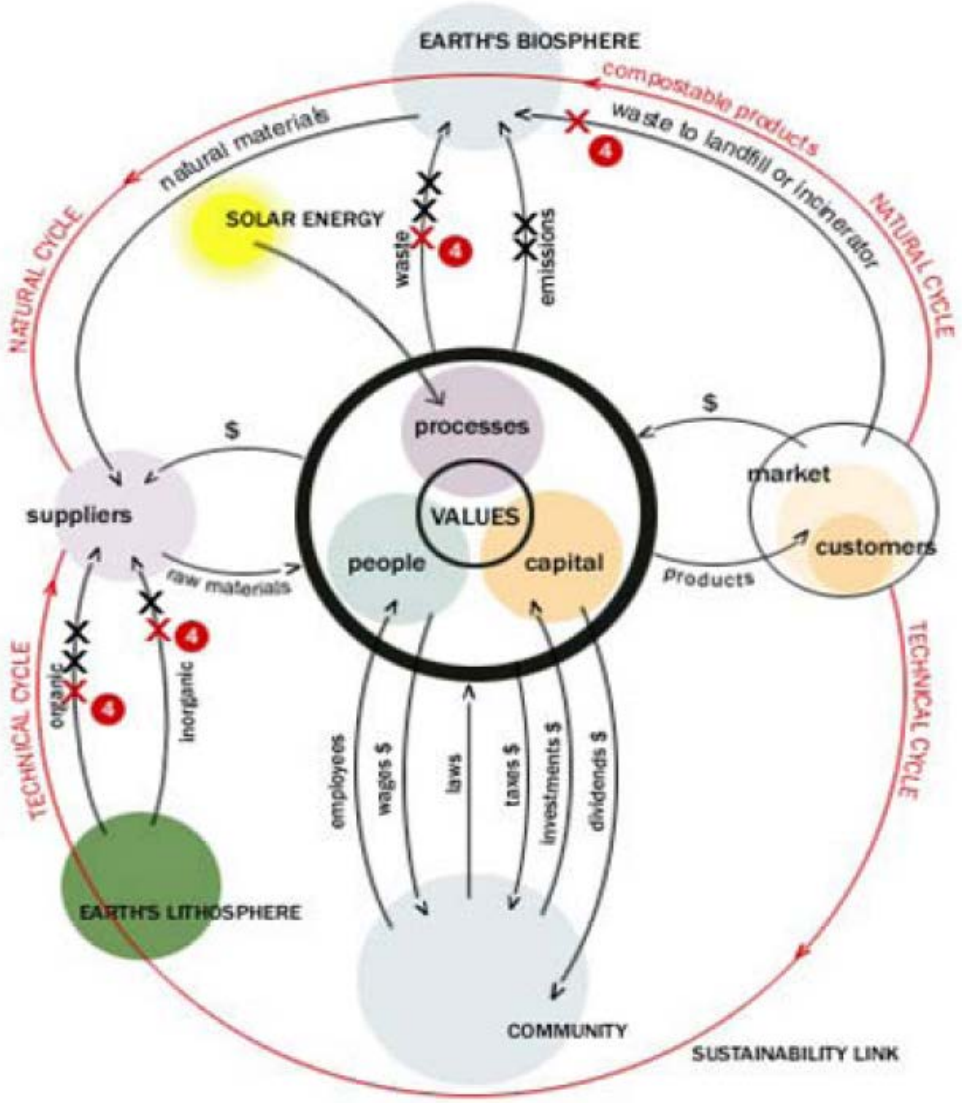
❹ *Close Cycles*

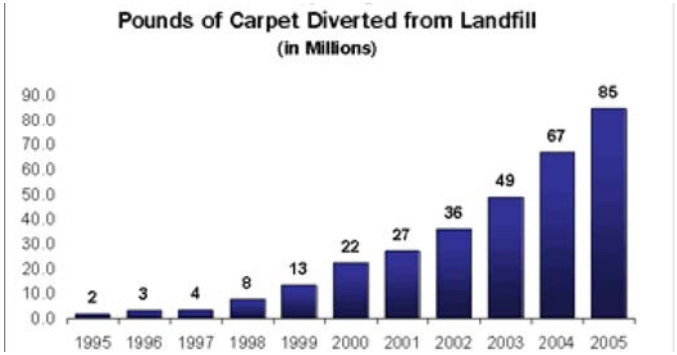


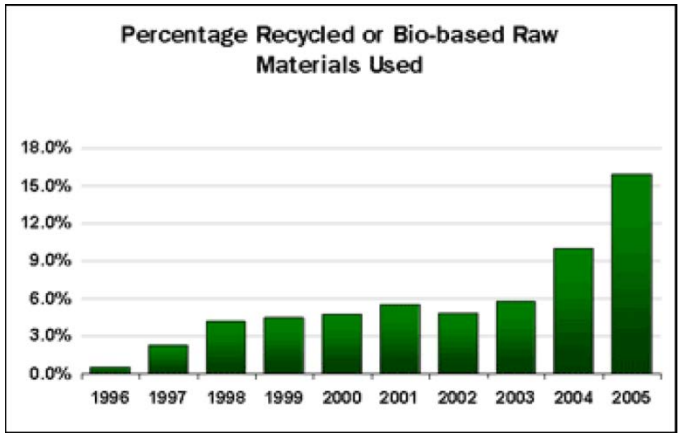
Natural, organic cycle, emphasizing natural raw materials and compostable products ("dust to dust")

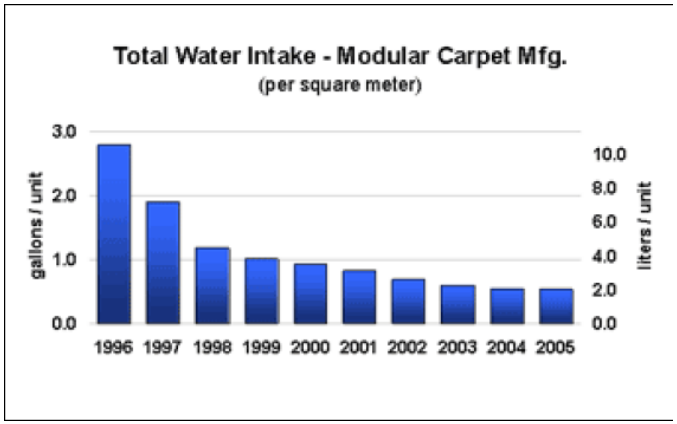
Technical cycle, giving manmade materials and precious organic molecules life after life, through closed loop recycling.

❹ *Close Cycles*

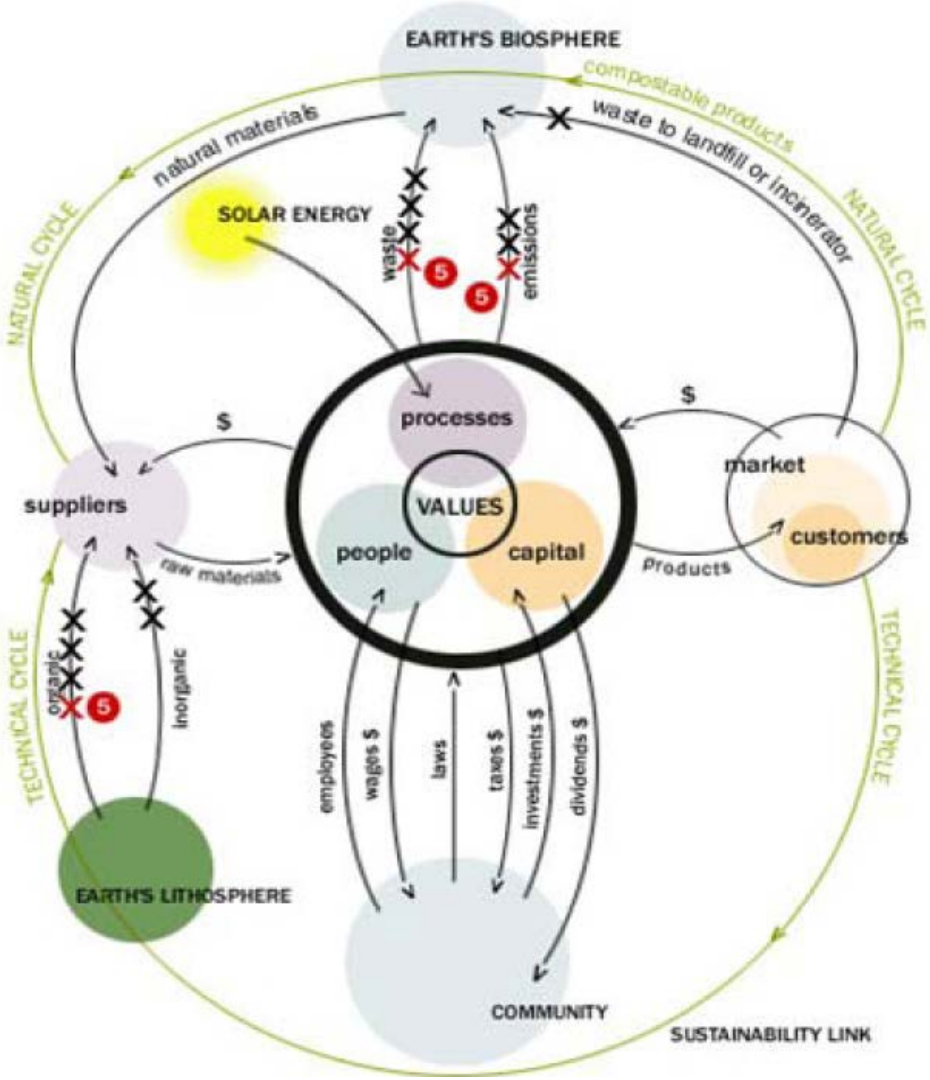






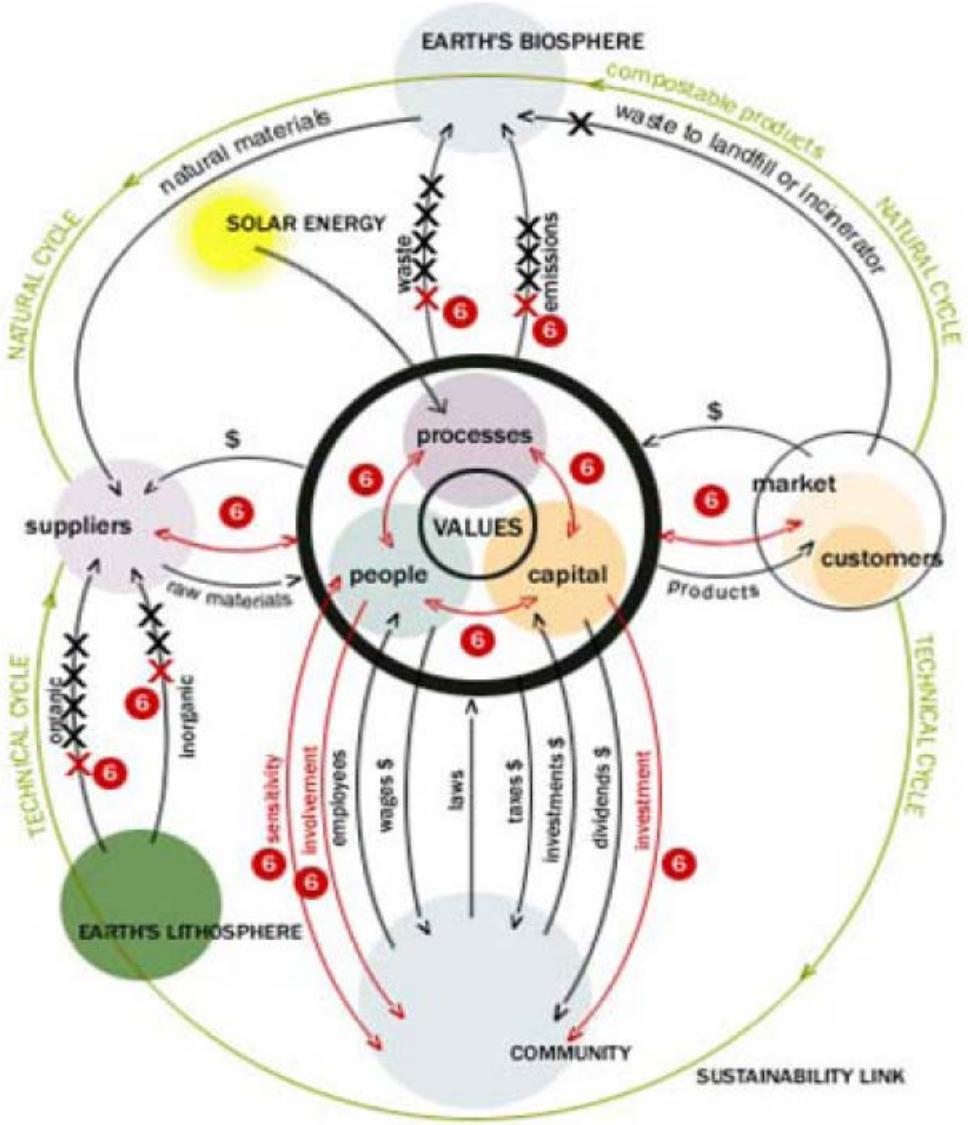


❺ *Resources / Good Transportation*



- videoconference to avoid unnecessary trips for meetings.
- drive the most efficient automobiles available.
- site our factories near the markets they serve
- plan logistics for maximum efficiency

❻ *Redesign Commerce*



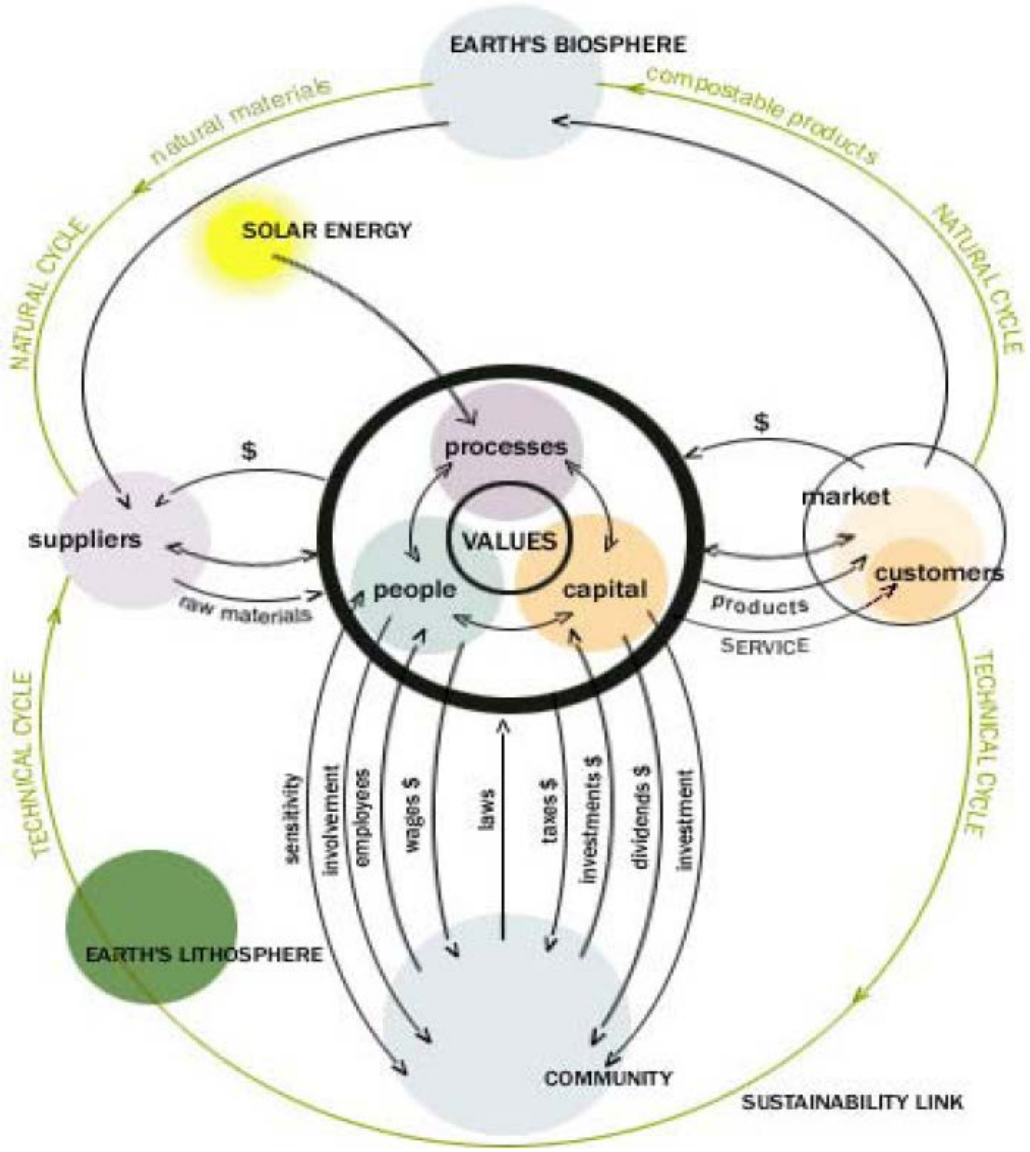
- acceptance of entirely new notions of economics
- prices that reflect full costs
- shifting emphasis from simply selling products to providing services
- relationships based on delivering, via leasing agreements, the services our products provide, in lieu of the products themselves

❻ *Redesign Commerce*

Examples:

- Xerox – sells copy services rather than copies
- Aircraft Engines – 'power by the hour', supplier does maintenance, charges by number of flight hours
- Beverage Cans – You don't buy the can, you just get to drink out of it once, then must return it for recycling
- Word Processing – Do not buy software, use it online for an hourly fee.

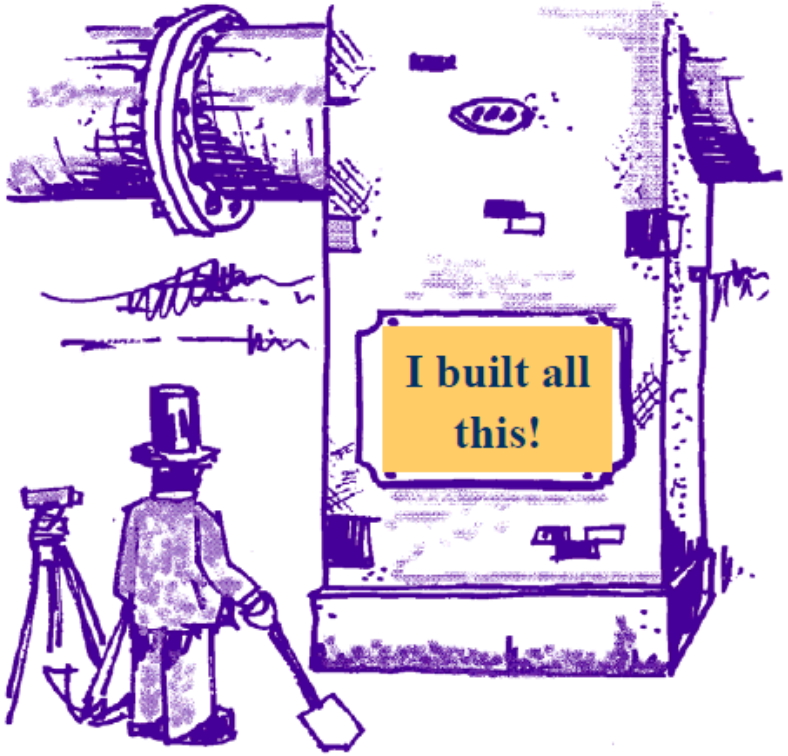
Emerging 21st Century Company ?



- service oriented
- resource-efficient
- wasting nothing
- maximize renewable energy
- no 'once through' operations but cyclical operations
- connected to stakeholders:
  - communities
  - customers
  - suppliers

Redirect Engineering: from 'Building things' to 'meeting needs sustainably'?

The 19th (& 20th?) Century Engineer

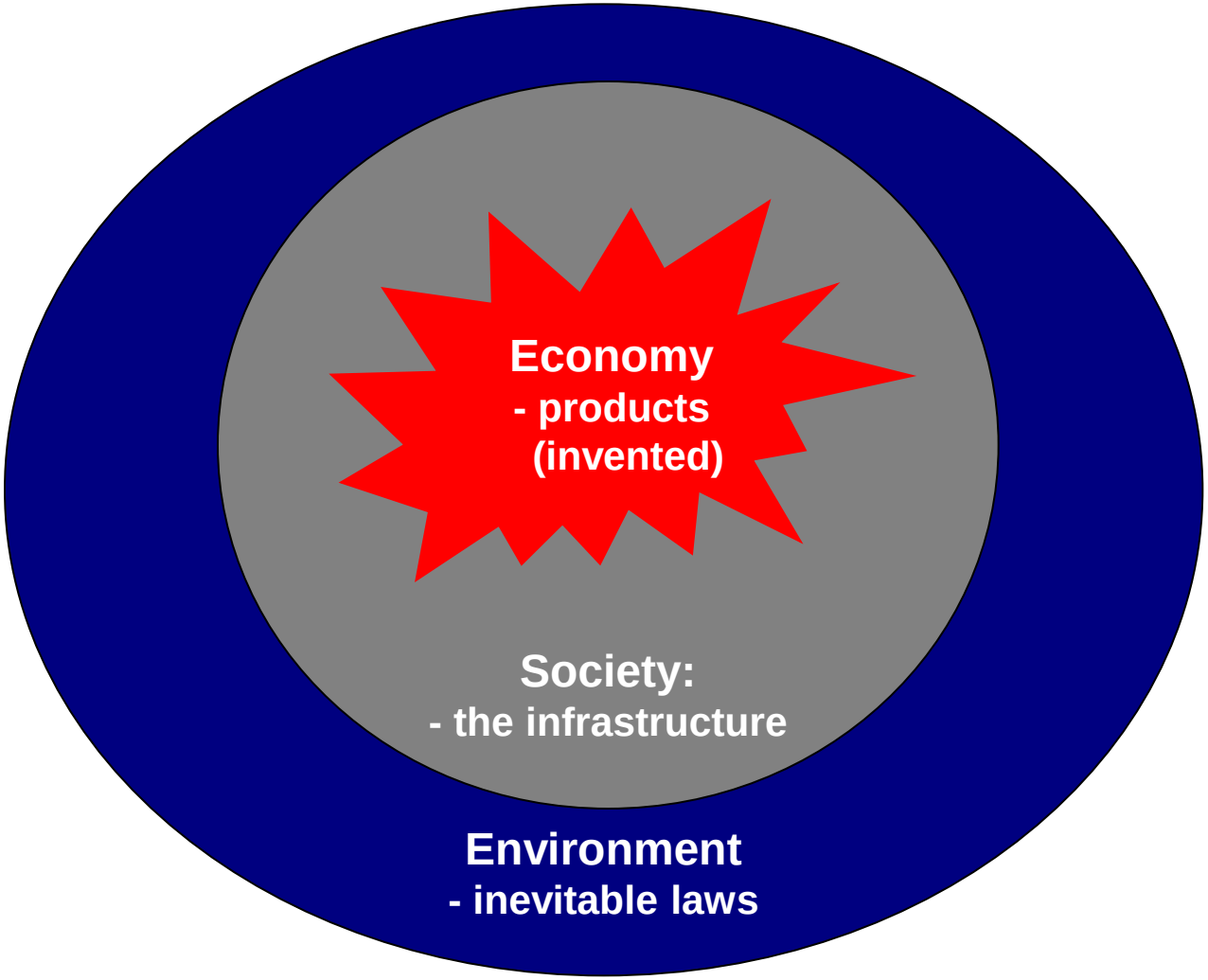


Visible construction, at great public expense, to meet society's wants

The 21st Century Engineer

Providing and Refurbishing the minimum to meet society's *needs*

Engineers Are the Interface



Becoming Sustainable requires leaders who recognize this world view, and act accordingly.

What Role for Engineers in Sustainable Development ?

ECOR 1010 – ELEC 1908

Technology, Society & Environment
Lecture 4

Common Pool Resources:
A Problem with No Technical Solution?

Common Pool Resources (CPR)

- A natural or human-made resource system that ‘belongs’ to everyone, but because of its size, and characteristics, it is difficult to control how people use it.
  - Examples of common-pool resources include irrigation systems, fishing grounds, pastures, forests, water or the atmosphere.

- A ‘common’ pasture allows for a certain amount of grazing to occur each year without the pasture being harmed. But, if one herder allows his/her sheep to overgraze, then the common pasture may become more prone to erosion and then no one can use it.

Sustainability of Common Pool Resources

Example – Commuting to work.

- Common Pool Resource (CPR): Finite road capacity

- Two choices 1. take the bus, or 2. drive your car

- Everyone takes the bus:
  - 20 min on bus plus 10 min walk/wait for bus
- You drive, everyone else takes the bus:
  - 20 min commute, you save 10 min
- Everyone drives:
  - traffic jams, commute takes 40 min
- Everyone drives, but you take the bus:
  - commute takes 40 min (bus stuck in traffic) plus 10 min walk/wait

You want to do what is good for you individually (selfish?)

You want everyone else to do what is good for whole group (socially responsible?)

CPR Management Options - 1

- Add Incentive to take bus:
  - Add bus lane → bus+walk/wait time = drive time
- Add Deterrent to Driving:
  - Convert driving lane to bus lane → bus+walk/wait time < drive time

- The "*Invisible Hand*" solutions:

  An economic principle, first postulated by Adam Smith, holding that the greatest benefit to a society is brought about by individuals acting freely in a competitive marketplace in the pursuit of their own self-interest.

➢ But still, some individuals will make choices that are unfavourable for the whole group

CPR Management Options - 2

- Introduce Public Awareness Campaign
  - Cajole (convince) individuals to take the bus
- The "*Education*" solution
  - But some individuals cannot learn

    (of course: not you & me – the other guy or girl, they are the problem)

CPR Management Options - 3

- Appeal to Conscience of Individuals
  - "Don't be a selfish jerk !"
- The "*Public Shame*" solution
  - But some individuals like to be selfish jerks, have no conscience and do not care

    (really & truly: not you & me – the other guy or girl, they're the jerk)

CPR Management Options - 4

- Take the bus or else !
  - Take the bus or Big Tony (Bertha, Al …) will break your knees
- The "*Vigilante*" solution
  - But, do we really want Big ??? really running things ?
  - and, what happened to democracy, freedom & all those things we like?

    (of course, we want our freedom and democracy,

    but might be less concerned about this for others)

CPR Management Options - 5

- $500 fine if you drive your car
  - Take the bus or Officer Tony (Bertha, Al …) will give you a fine
- The "*Mutually Agreed On Mutual Coercion*" solution
  - But, what about my individual freedom ?
  - "Freedom is the recognition of necessity."

    Friedrich Engels (1820–1895) was a German social scientist & philosopher
  - Rights & Freedoms must be restricted for good of everyone

Your right to swing your fist ends at my nose

"The Tragedy of the Commons"

- The **tragedy of the commons** is when multiple individuals, acting independently and rationally in their own self-interest, deplete a shared limited resource, even when it is clear that it is not in anyone's long-term interest for this to happen.

"The Tragedy of the Commons"

- G. Hardin, "The Tragedy of the Commons" *Science* 1968
  - See the last slide for how to get this reference … **Read It!**

➢ Deals with problems that have no technical solution

- Better for group as a whole if everyone makes choice *A* rather than choice *B*
- But each person individually prefers to make choice *B*

- When I choose B, it hurts you, and when you choose B, it hurts me – *negative externality*
- Commute example: My driving creates an external cost by creating congestion that slows down everyone behind me.

Externality Definition

- By definition, an externality is an activity of one group/person that affects the welfare of another group/person in a way that is outside the ‘money’ market mechanism.
- Pollution is a good example of a negative externality.
  - There are many different ways to address negative externalities like pollution including: emissions fees, cap-and-trade, and command-and-control regulation.

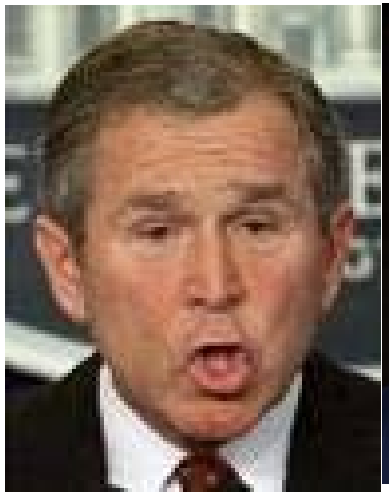
Common Pool Resource - Examples

- Residence Common Areas:
  - It is better for the *group as a whole* if everyone cleans up after themselves.
  - But, each person individually prefers to leave their dishes in the sink.
    - Negative externality: I create external costs by leaving dirty dishes for my housemates.
- Splitting the bill at a Restaurant
  - Better for group as a whole if everyone orders a moderately priced dish
  - I prefer to order something very expensive: filet mignon.
    - Negative externality: I create external cost because I only pay 1/*n* of the cost of my more expensive meal.

The individual incremental benefit > individual incremental hardship, but the group incremental benefit ≤ the group incremental hardship.

Common Pool Resource - Examples

- Voting:
  - It is better for the *group as a whole* if everyone pays attention to politics and votes responsibly.
  - But, each person individually prefers to watch *Hockey Night in Canada*
    - Negative externality: ?



Common Pool Resource Sustainability Examples

- Electricity from Coal Fired Generating Facilities:
  - Globally it is better if everyone avoids coal to generate electricity (because it is high in GHG, sulfur) in favour of wind, solar, natural gas, etc.
  - But, my/each region prefers coal since it is the cheapest of the available fuels.
    - Negative externality: My pollution contributes to global warming for everyone – we have a shared and finite atmosphere.

Common Pool Resource Sustainability Examples

- Overfishing:
  - Better for the *group as a whole* if everyone limits how much they fish so that there will be enough fish next year and fish stock is managed in a sustainable manner.
  - Each person maximizes his/her profit by fishing like crazy.
    - Negative externality: When I catch fish I cause external cost to you by reducing your ability to catch fish next year.

CPR – What Extent of Mutually Agreed On Mutual Coercion ?

Ban Fishing !

- Advantage: It works!
  (Whale populations have rebounded)
- Disadvantage #1: Not economically efficient or equitable for most fisheries.
- Disadvantage #2: What about tribal rights to fish?

CPR – What Extent of Mutually Agreed On Mutual Coercion ?

Limit Fishing !

- Restrict types of boats, types of gear, etc.
- Limit annual catch (*TAC - Total Allowable Catch*)

- Advantage #1: These can help limit overfishing
- Disadvantage #1: Economically inefficient.
- Disadvantage #2: There's still a **race for fish** that can be dangerous and inefficient.

The race for fish

- Fish today—while you still can—before the TAC limit is reached for the season!
- Example: the 2005-2006 Alaska king crab season lasted just 4 days (250 boats caught 14M pounds?)
- Dangerous for workers, consumers get frozen fish

upload.wikimedia.org/.../220px-Redkingcrab.jpg

www-rohan.sdsu.edu/.../Ocn_books.htm

Solution ? "Privatize the commons"

- Combine a TAC limit with private property rights over that catch.
- Individual Tradeable Quotas (ITQs) makes it possible to "own" part of this year's catch.
- Advantage #1: The TAC limits overfishing.
- Advantage #2: No race for fish (b/c of ITQs).
- Disadvantage #1: Equity? (Who gets ITQs?)
- Note: This is just like carbon cap-and-trade!!!

Carbon Cap and Trade

- **Emissions trading** is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants.
- A central authority (usually a governmental body) sets a limit, or **cap**, on the amount of a pollutant that can be emitted.
- The cap is sold to companies in the form of emissions permits, which represent the right to emit a specific volume of the specified pollutant.
- Companies are required to hold a number of permits (or *carbon credits*) equal to their emissions. The total number of permits cannot exceed the cap, limiting total emissions to that level. Companies who need to increase their emissions must buy permits from those who require fewer permits.
- The buying of permits is referred to as a **trade**. In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions.
- In theory, those who can reduce emissions for the least amount of money will do so, achieving the pollution reduction at the lowest cost to society.

See Wikipedia

Common Pool Resource Sustainability Examples

- Other CPR's to think about …
  - Emissions into water
  - Use of arable land
  - Management of natural areas
  - Global population

Reading Assignment

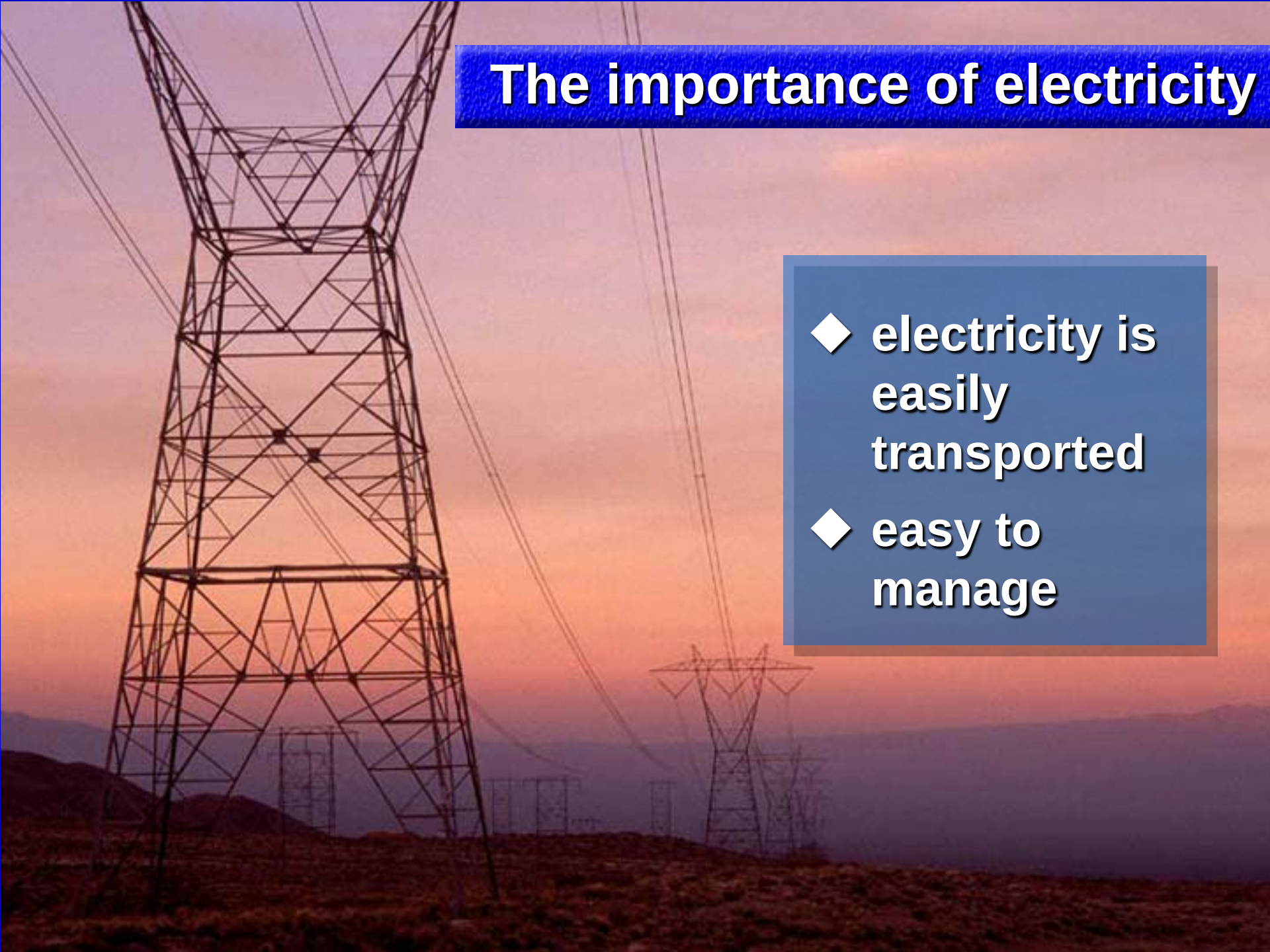
- ***Read*** - “The Tragedy of the Commons”
- Google Tragedy of the Commons or go to:

http://en.wikipedia.org/wiki/Tragedy_of_the_commons

Links to the original article by Hardin can be found at the end of the wikipedia page under note 1, or at:

"The Tragedy of the Commons". *Science* **162** (3859): 1243–1248. 1968

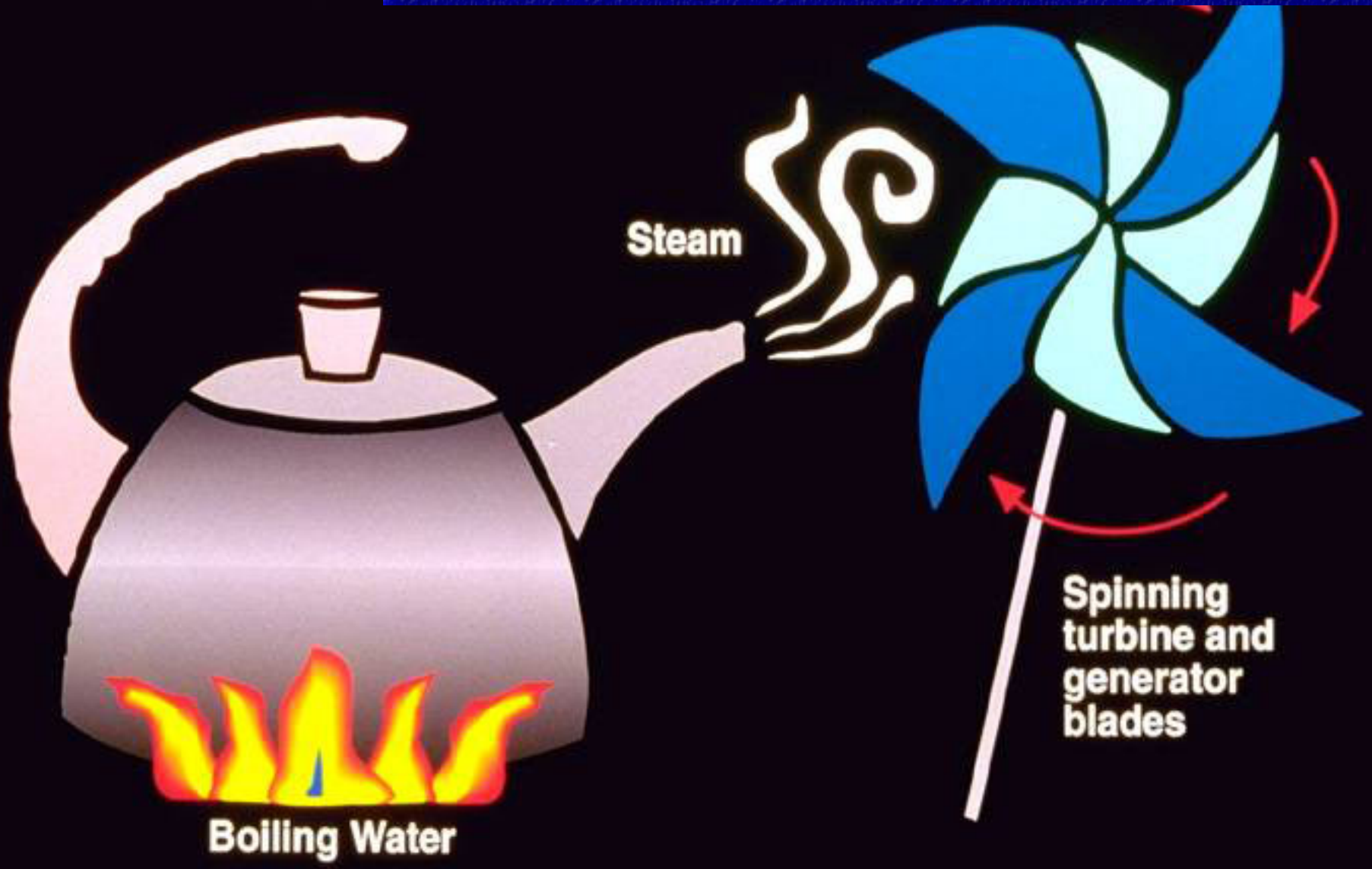
Nuclear Energy



The importance of electricity

- electricity is easily transported
- easy to manage

How do you make electricity?



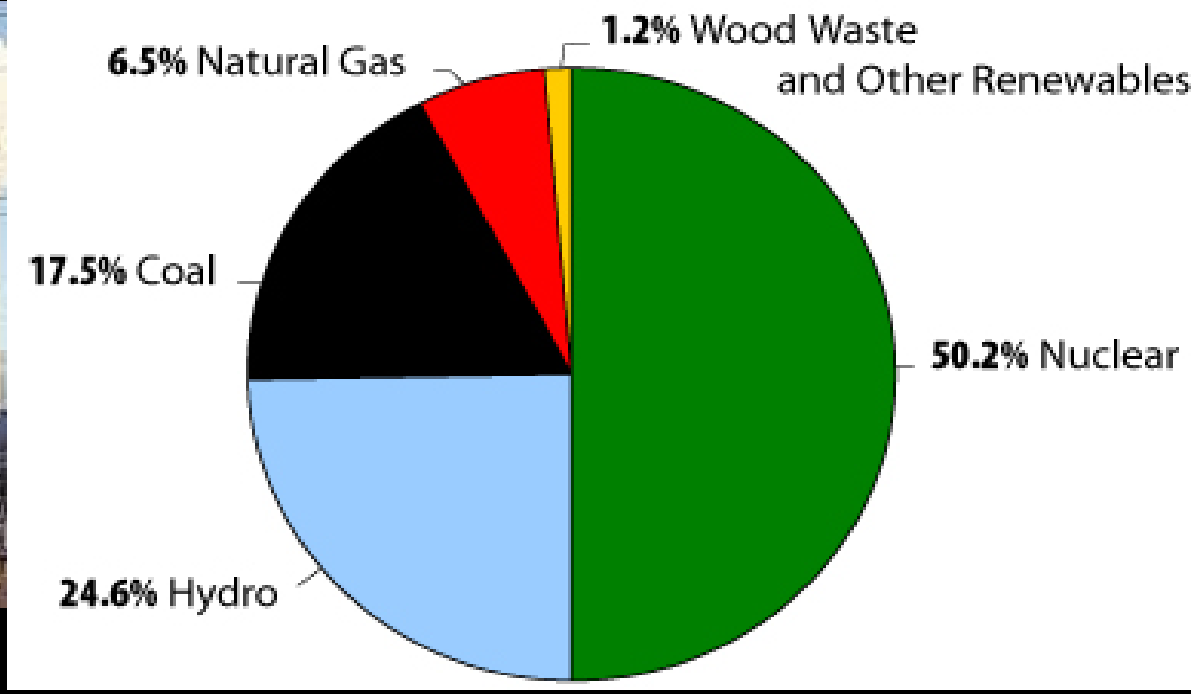
How do you heat the water?

Oil

Coal

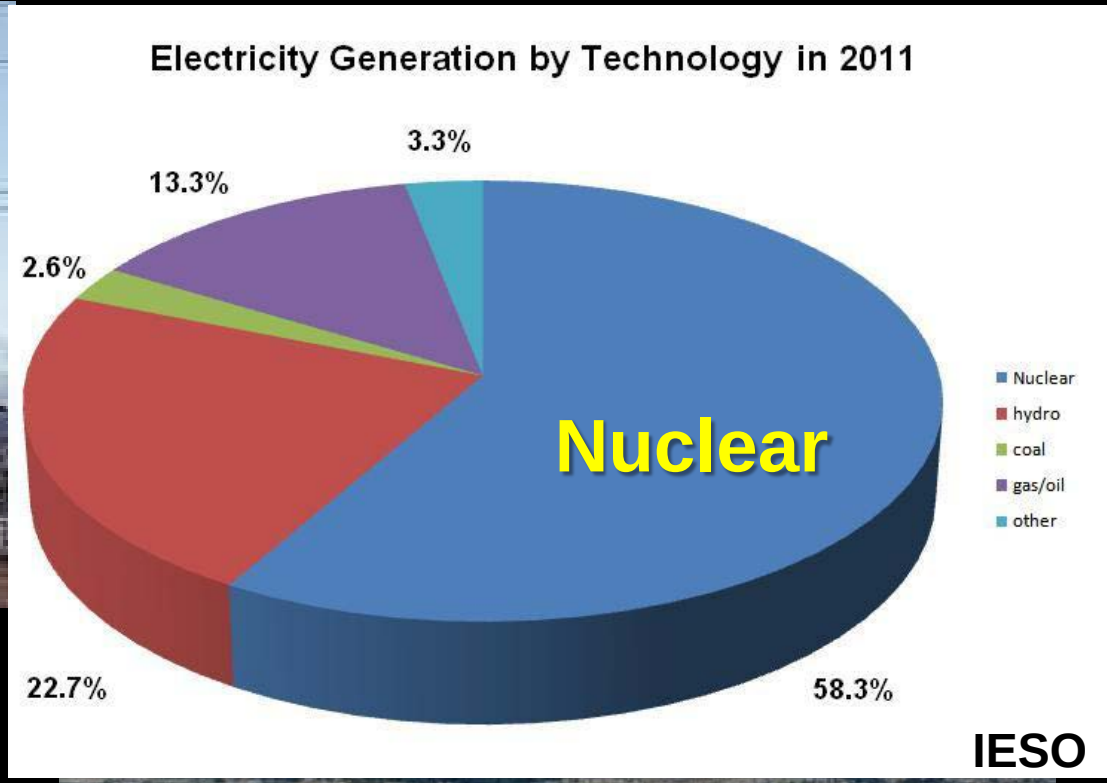
Natural gas

Nuclear fission



Ontario in 2004

Fossil


Electricity Generation by Technology in 2011
3.3%
13.3%
2.6%
22.7%
58.3%
Nuclear
Nuclear
hydro
coal
gas/oil
other
IESO

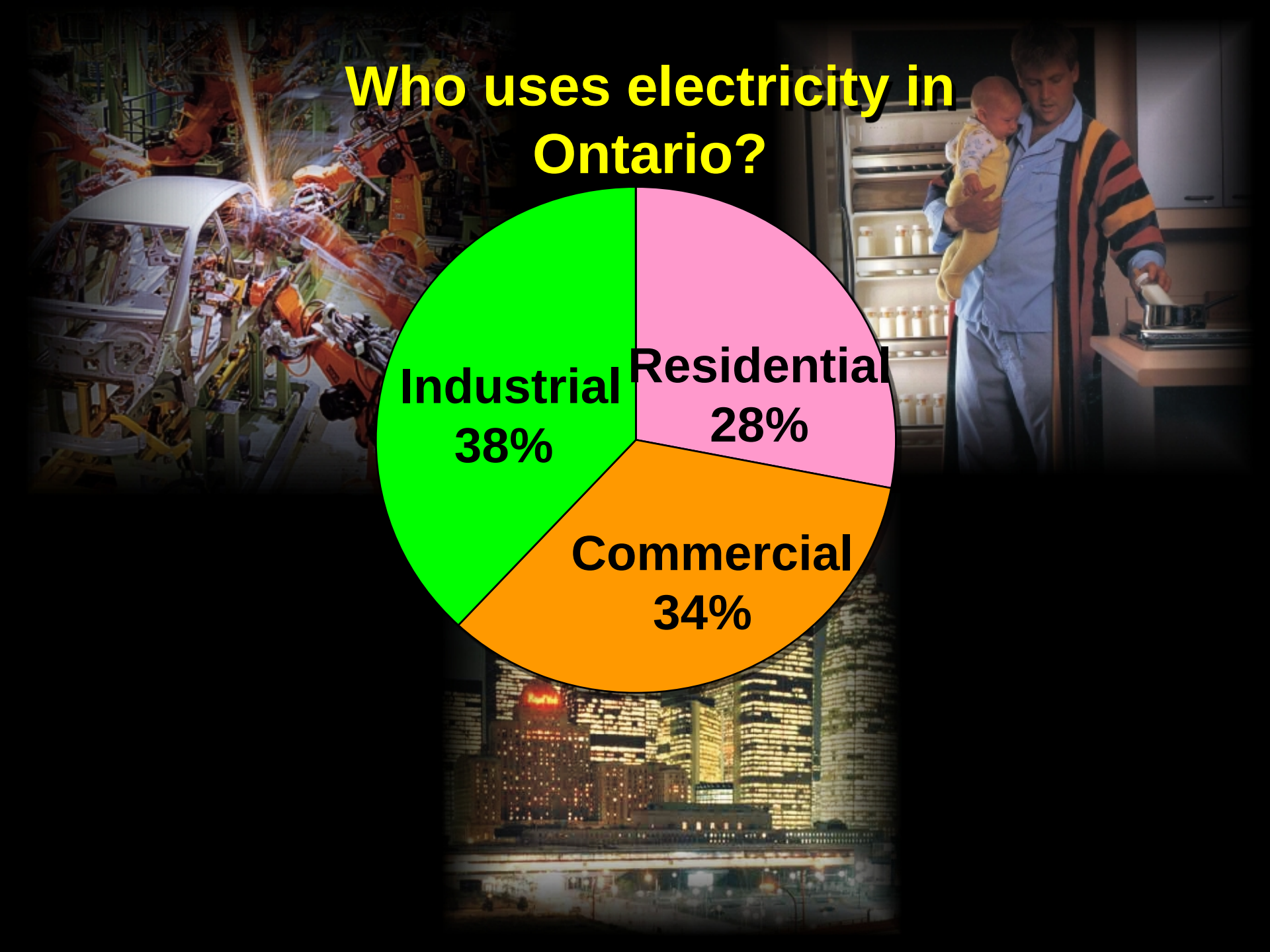
Hydro

Nuclear

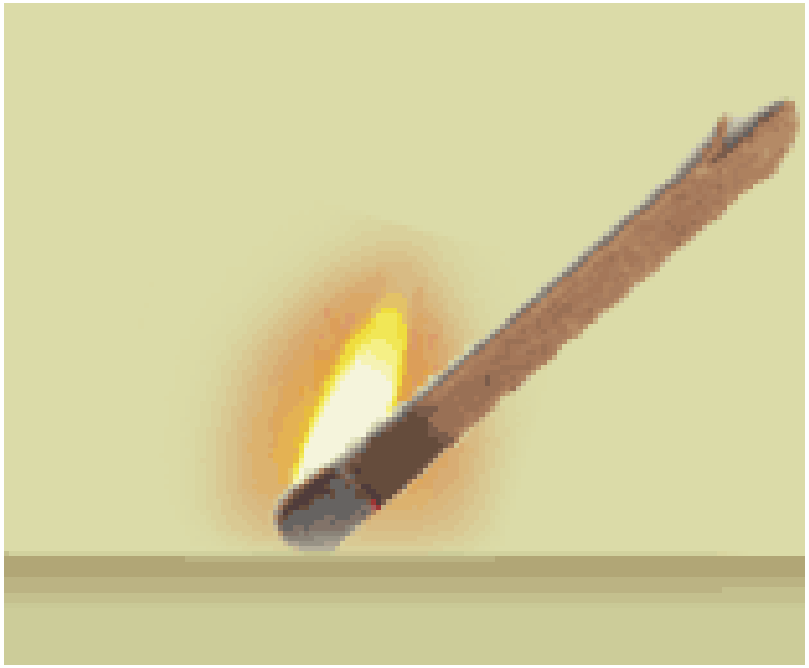
Coal is almost non-existent in Ontario's Energy Supply

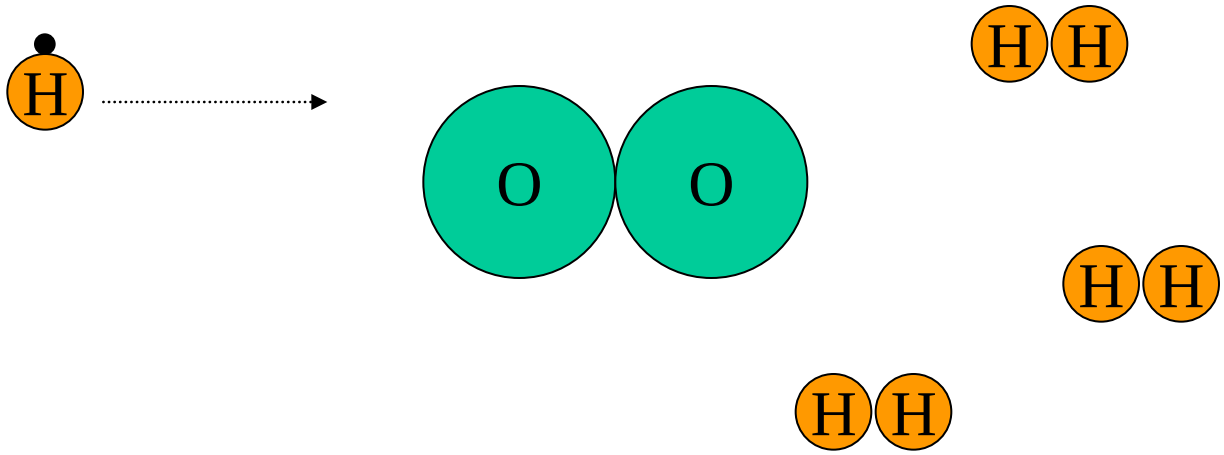
- **The Greenhouse gas footprint of Ontario's electricity generation system, which 8 years ago was about 290 g/kWh, is down today to about 90 g/kWh. One of the cleanest in North America. Germany's electricity generating system, for example, has a GHG footprint of about 500 g/kWh**
- **Where Coal was once used for load following and for providing peaking power, natural gas will be used going forward.**
- **As more intermittent renewable energy is added to the system, there will be much greater challenges in balancing supply and demand because natural gas generation is not as flexible as coal.**

Who uses electricity in Ontario?



What happens when you strike a match ?




H
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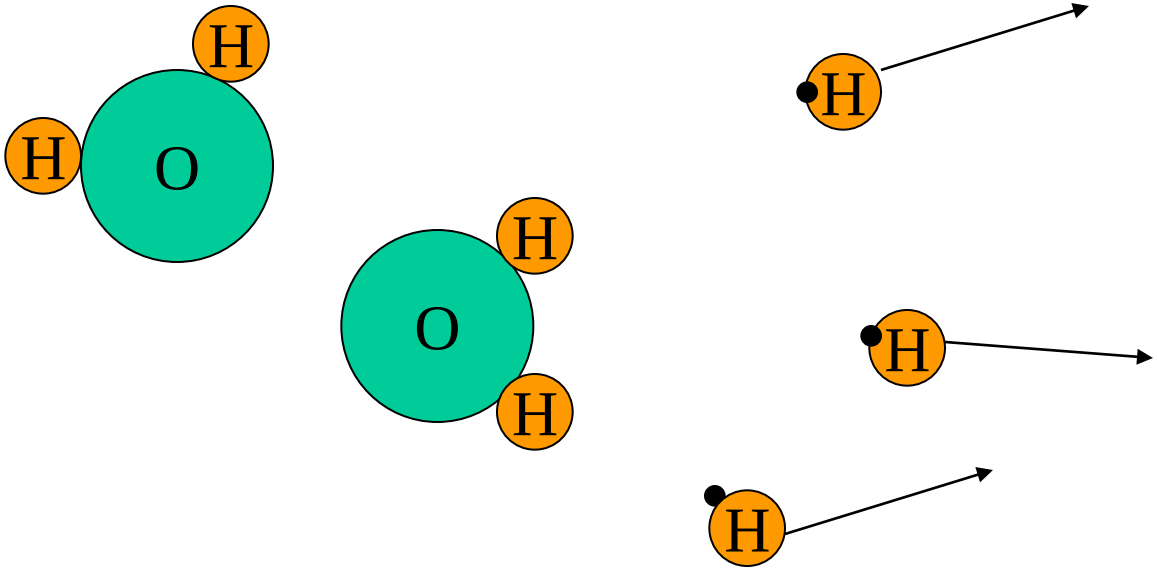


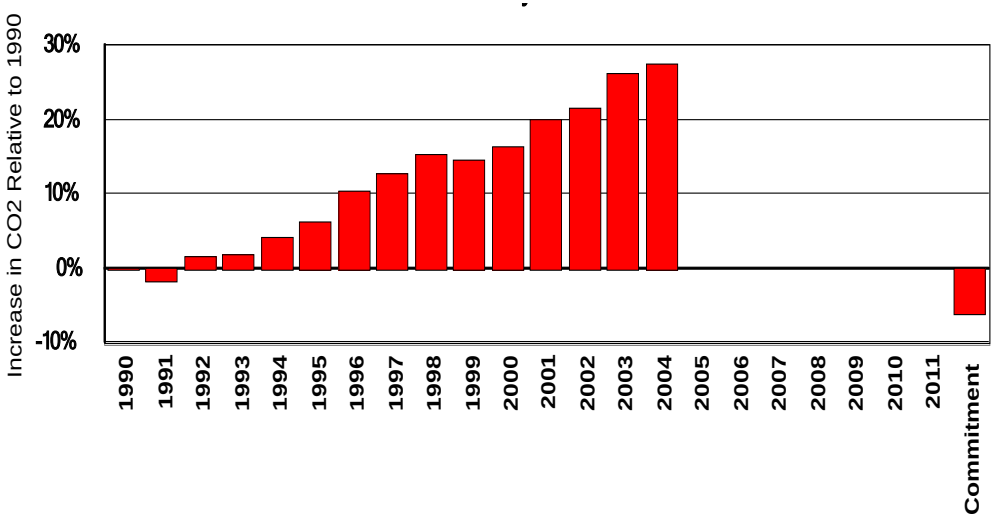
This is known as a branching chain reaction.

Fire is useful because we can control it by ….

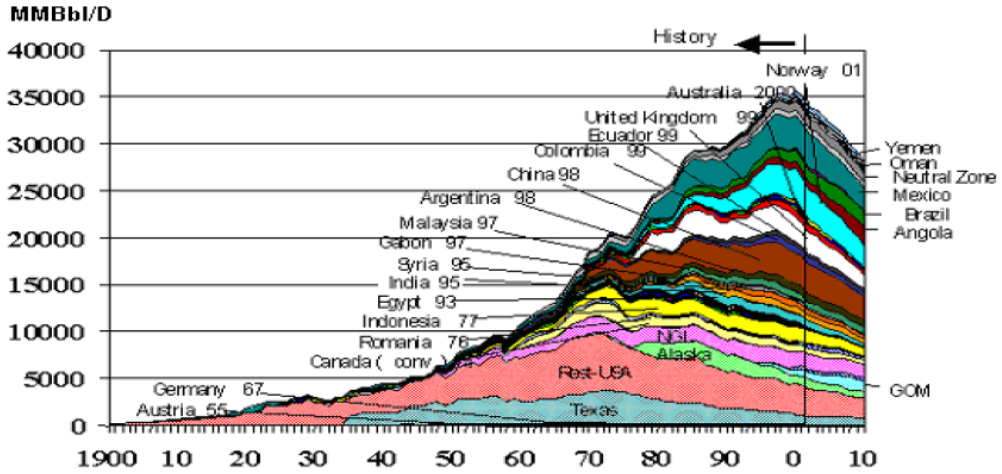
- taking away the fuel, and/or the oxygen;
- lowering the temperature below the critical ignition temperature … taking the heat away faster than it can be produced;
- moderating the chain reaction with inert gases, and extinguishing with H-atom scavengers.

Two Reasons for Moving Beyond Fossil Fuels:

- Global warming



- Peak Oil



The Problem with Emissions: it is more than just CO_2

"A cost benefit analysis released in April [2005] uncovered massive health and environmental costs from coal-fired generation. The study found emissions from all coal-fired stations were responsible for up to 668 premature deaths, 928 hospital admissions and 1,100 emergency room visits in Ontario per year."

(Ontario Ministry of Energy June 15, 2005)

Nuclear power

Is it environmental friendly?

- No pollutants that cause smog and acid rain
- No greenhouse gases that contribute to global warming
- No fuel supply issues, potentially …

Let’s talk about nuclear power

- use uranium to generate heat through a reaction called fission

Pickering

Uranium

- Atomic number 92 (92 protons), symbol U
- Heaviest naturally occurring element in nature: composed of U235 (0.7%) and U238 (99.3%)
- Silvery white metal, found in hard rock or sandstone
- 48th most abundant element
- Largest deposits found in Canada and Australia

Source: strategic resources ltd.

U235 = 92p+143n

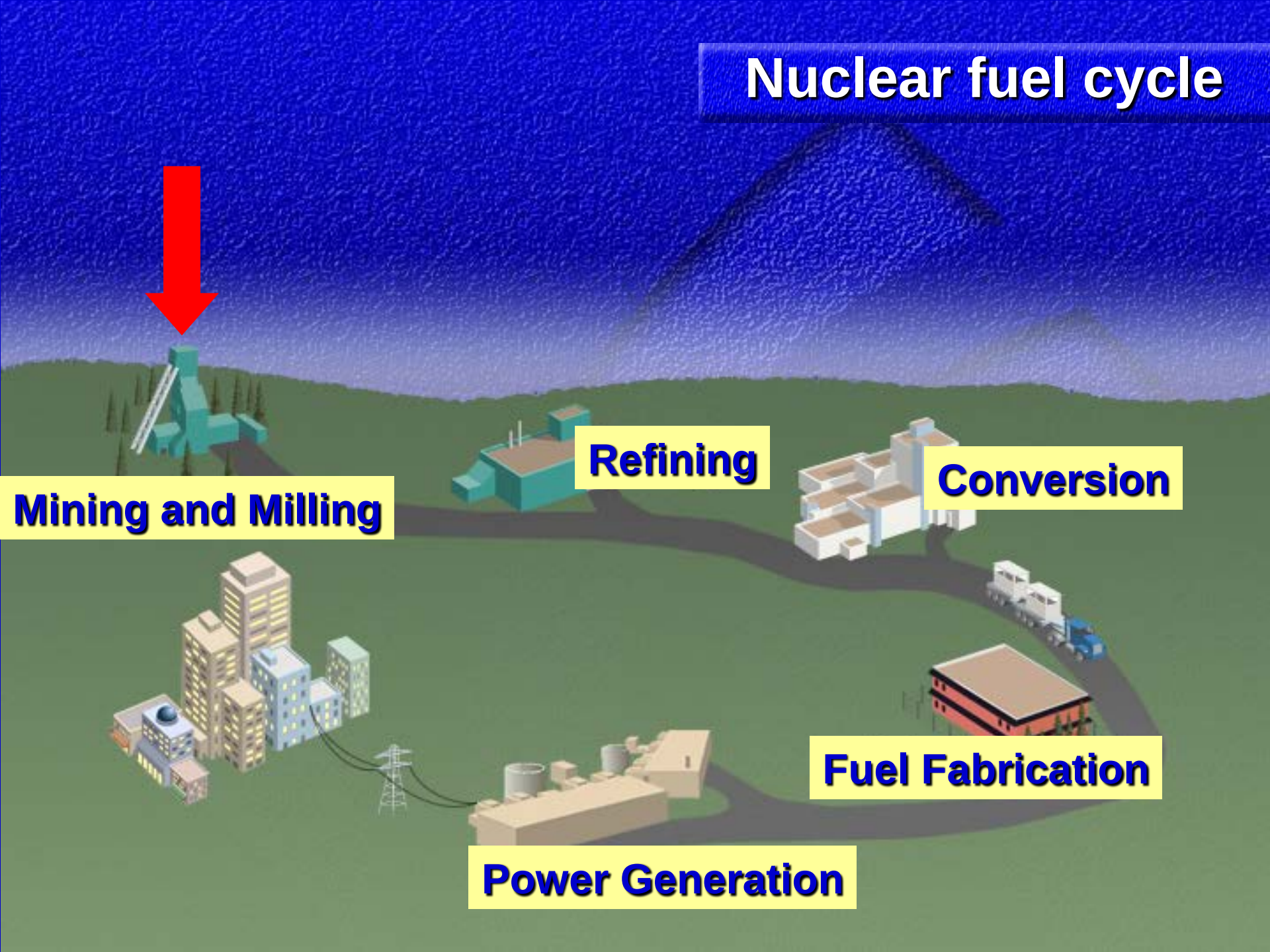
Canada's Uranium

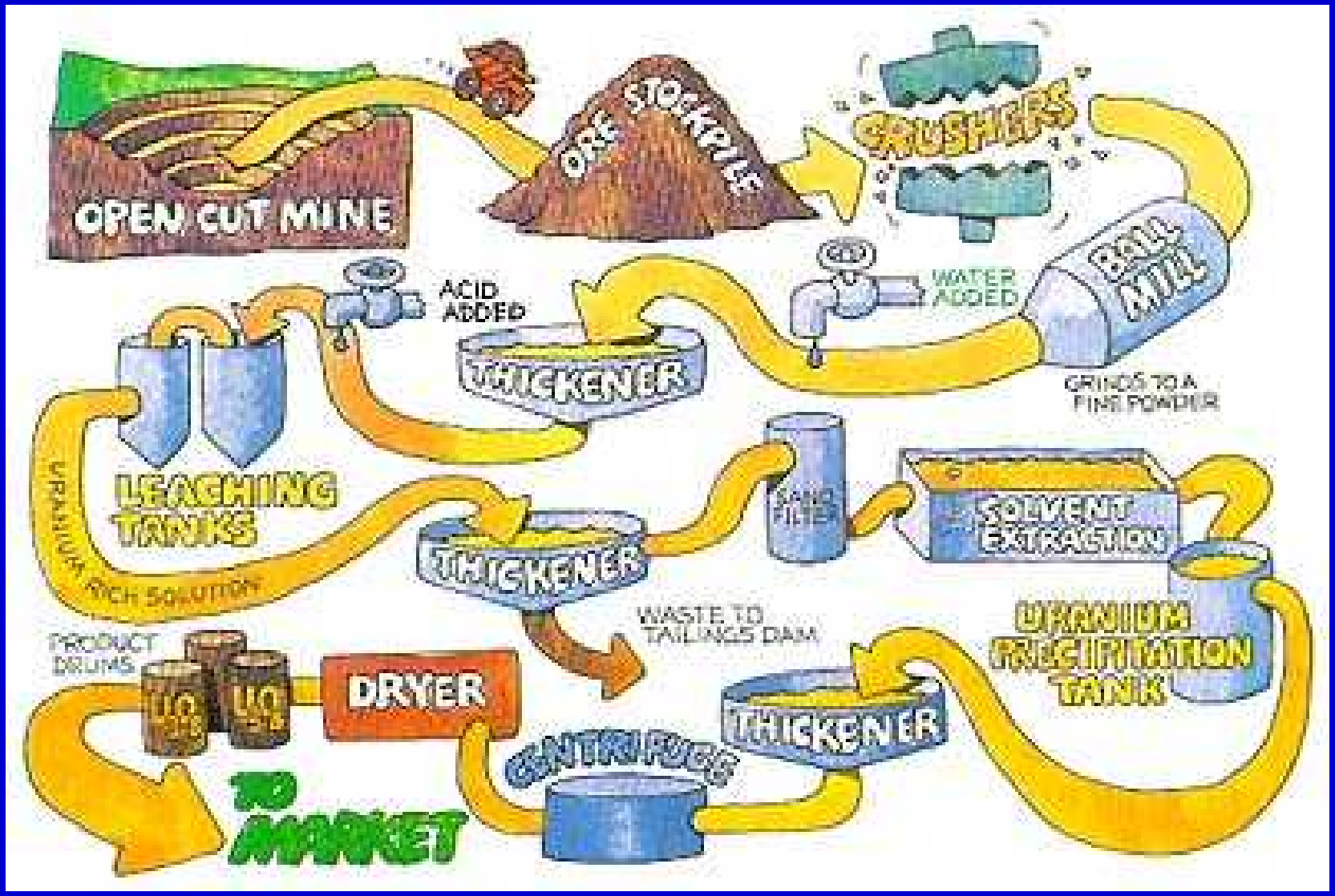
World's largest supplier (34%)

All from Saskatchewan

85% exported
→ $500 million annually

Nuclear fuel cycle



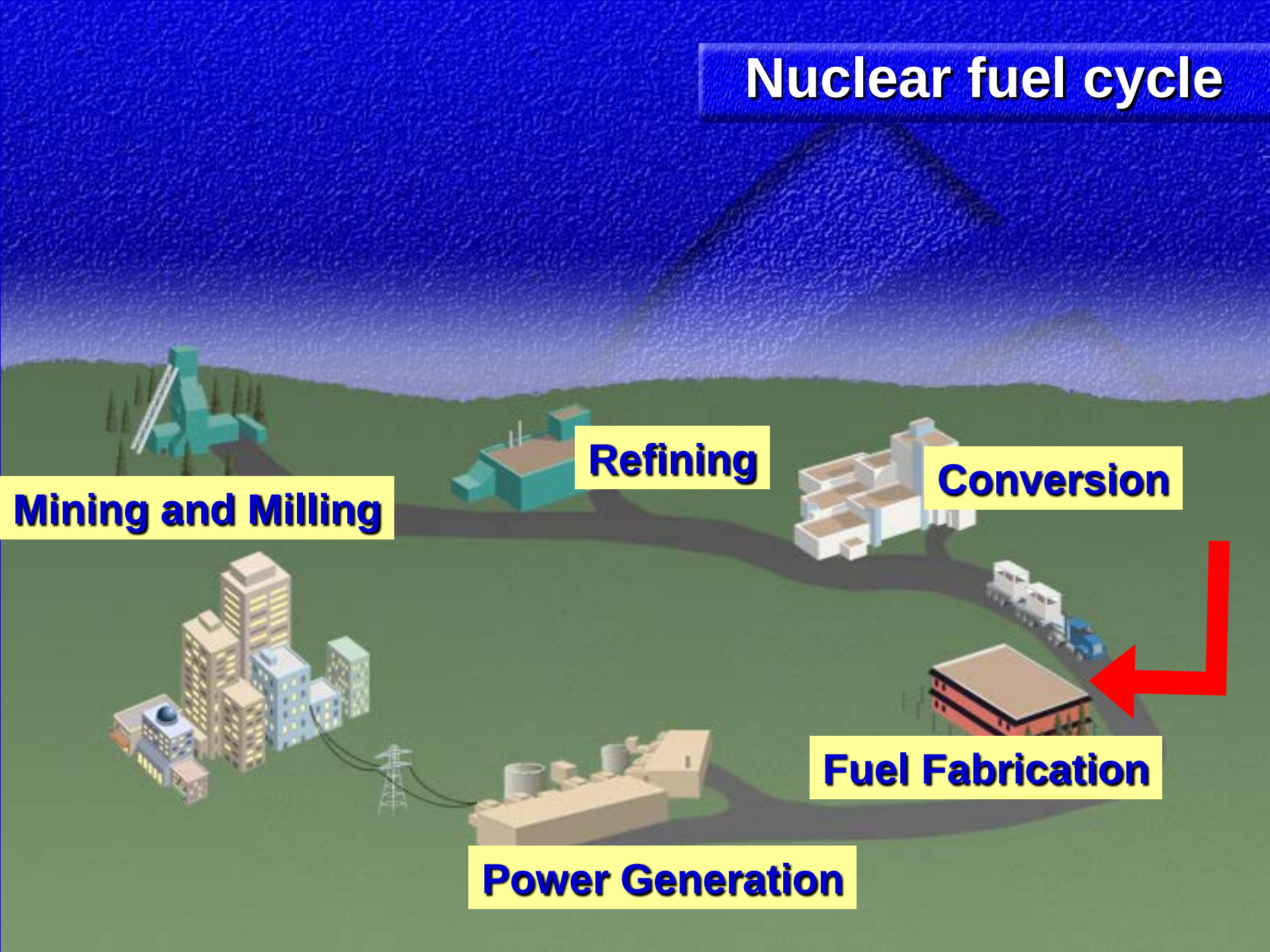


Preparation of yellow cake, purified $U_3O_8(s)$ (Courtesy of the Uranium Information Center)

Yellowcake, U_3O_8, is a fine powder that is packaged in steel drums for shipping

A drum of yellowcake

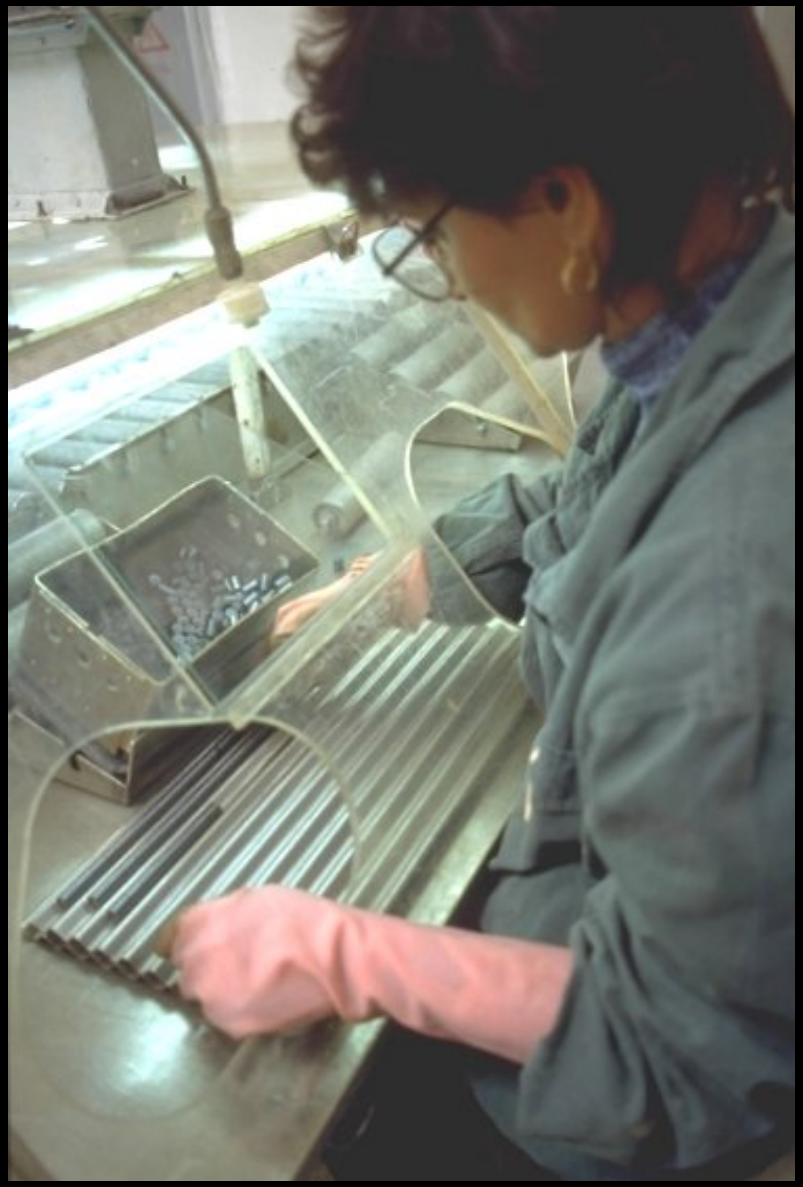
Nuclear fuel cycle



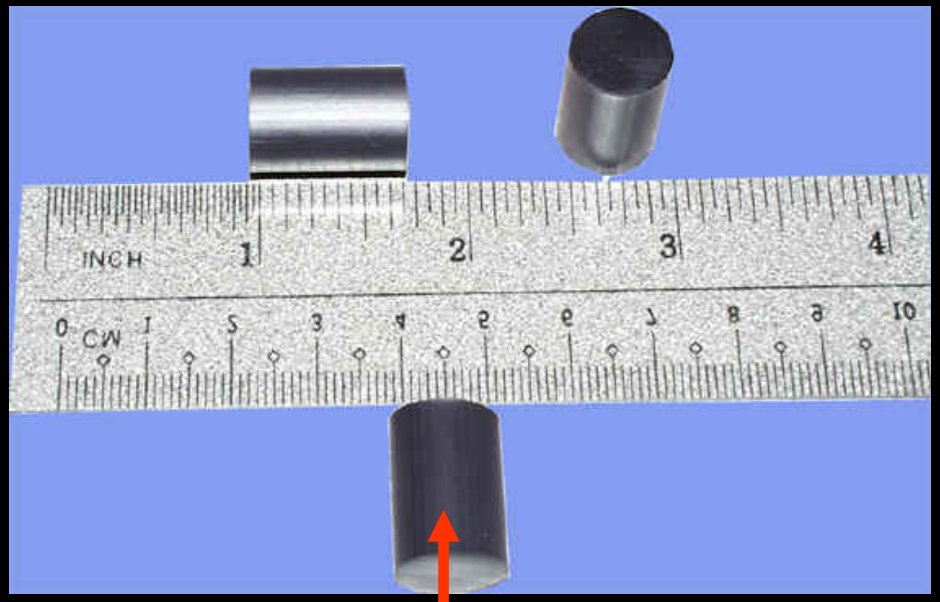
Fuel fabrication

- UO_2 pressed into small pellets and placed in zirconium tubes to form fuel rods

- fuel rods are arranged in bundles and inserted into a nuclear reactor



UO_2 Fuel Pellets



***Fuel Pellet*: 10 of these provide one home's electricity for a year**

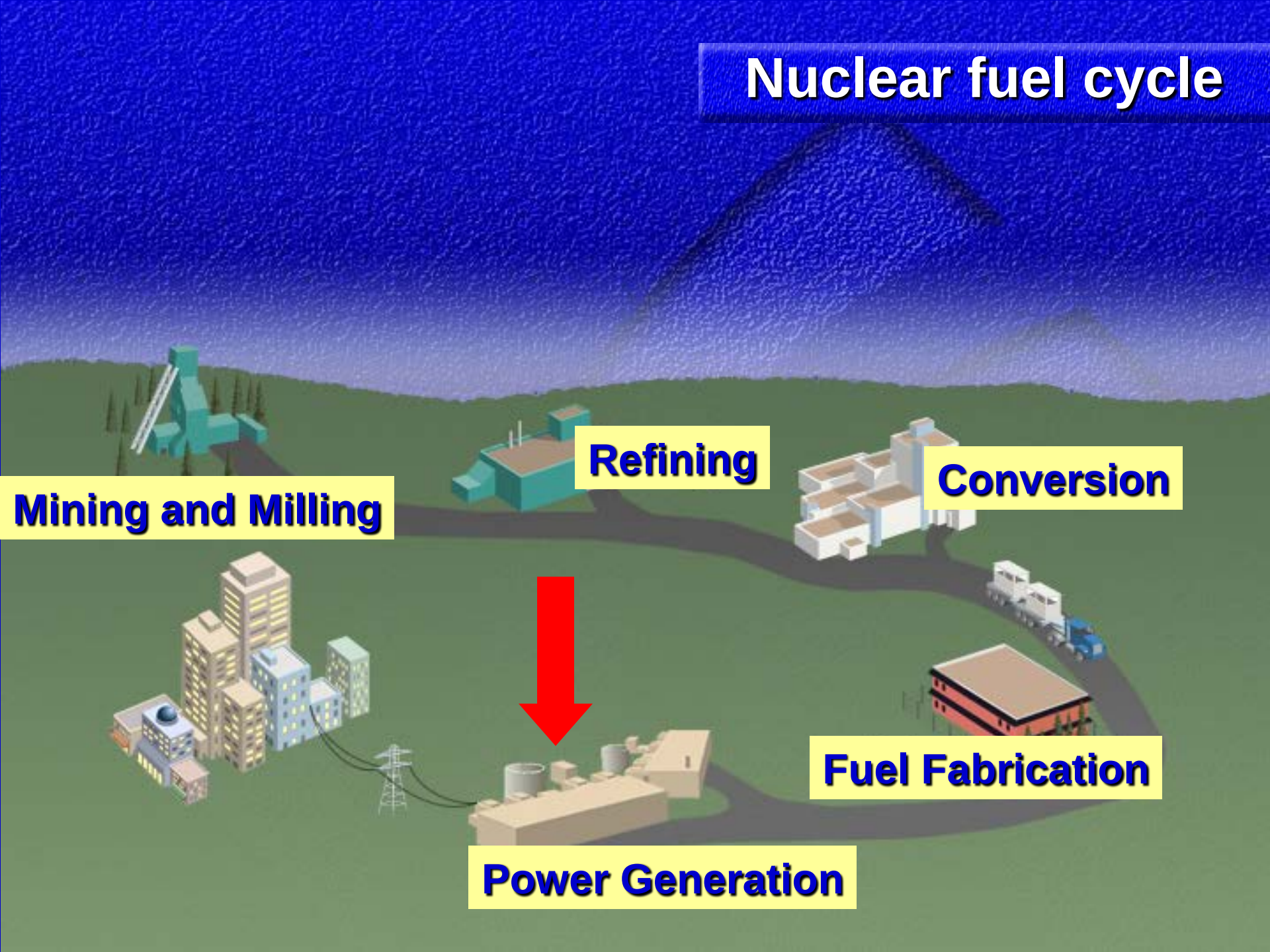
Fuel fabrication

Zircatec Precision Industries (Port Hope)

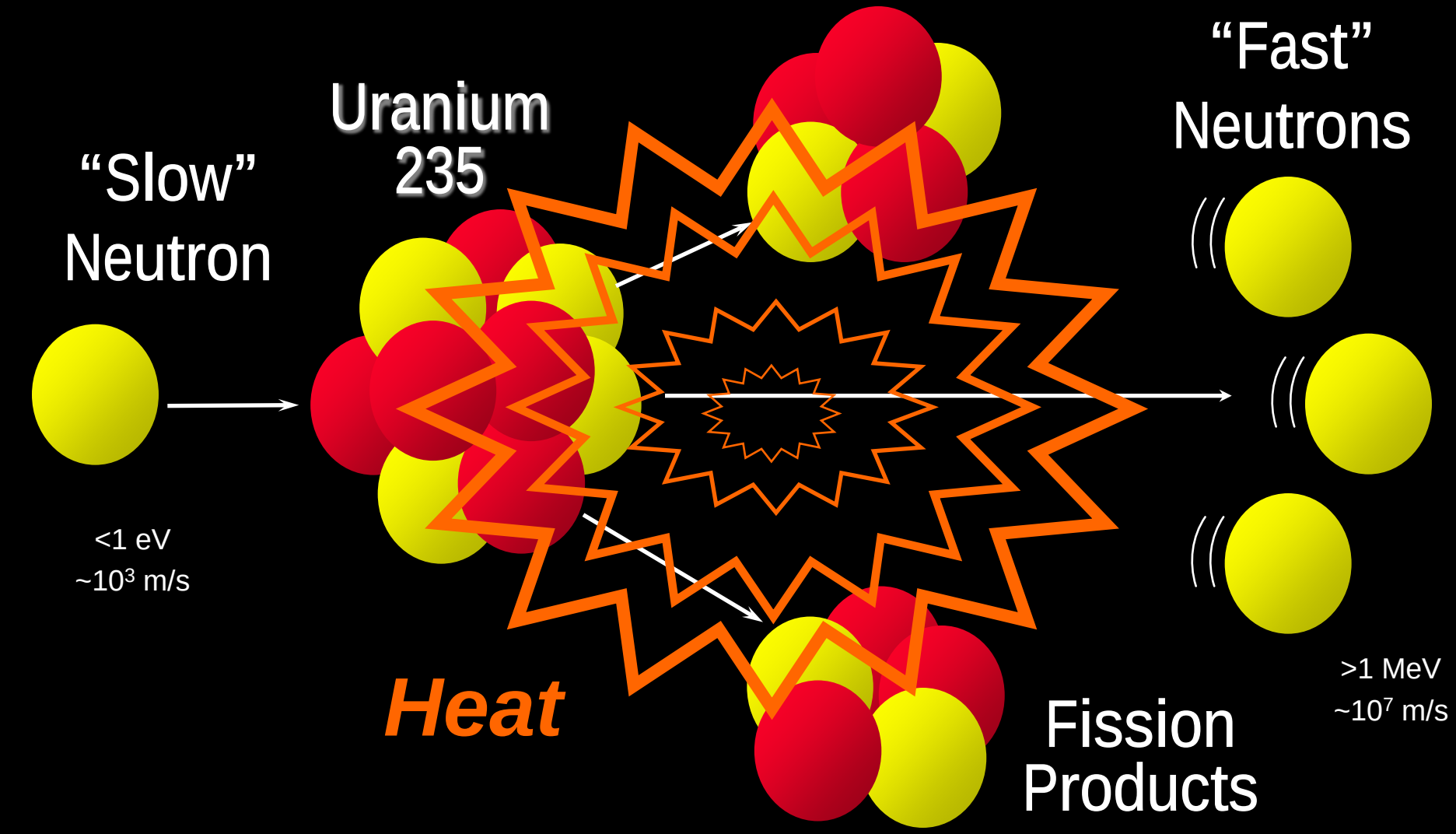
&

GE-Hitachi (Arnprior and Peterborough)

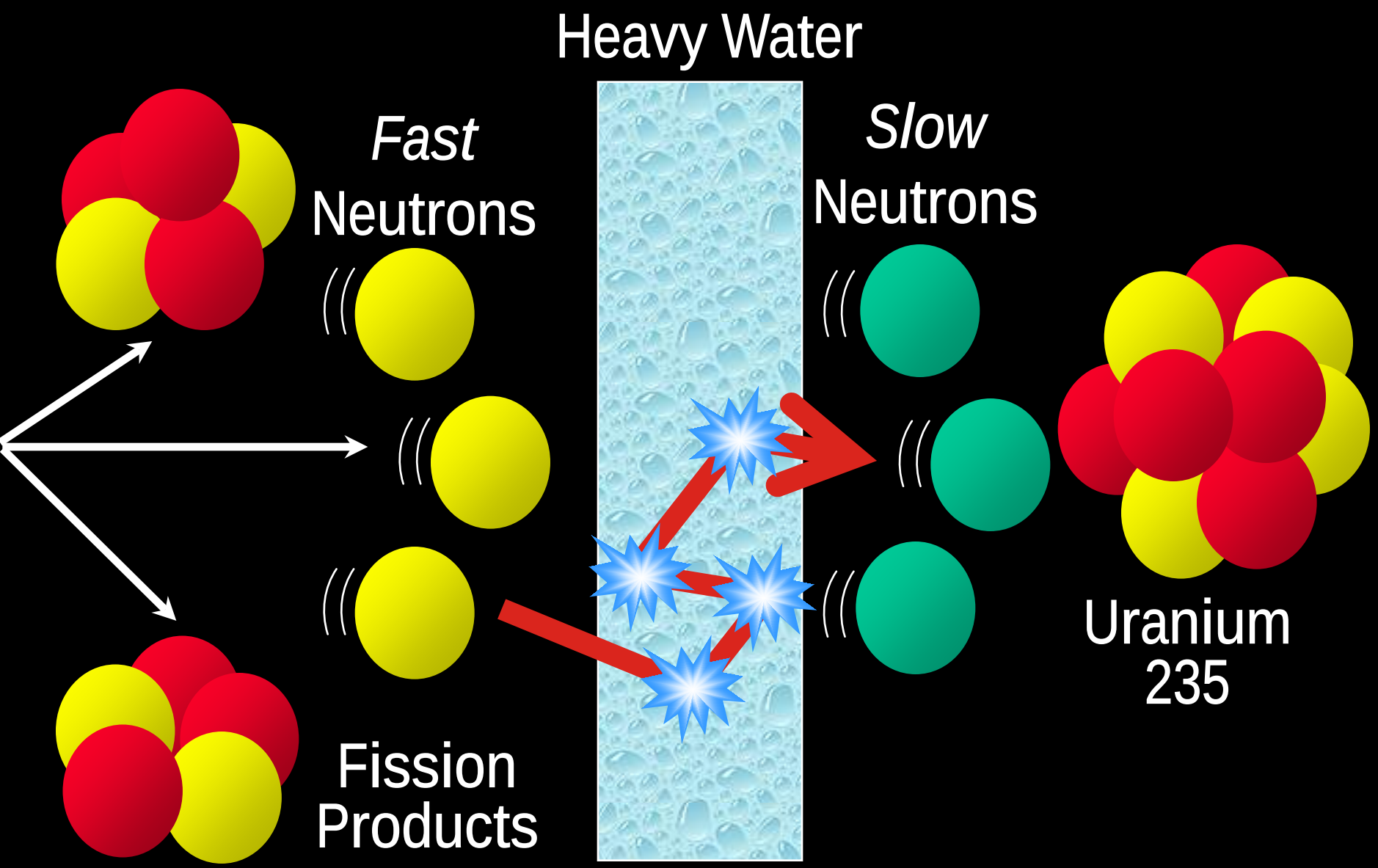
Nuclear fuel cycle



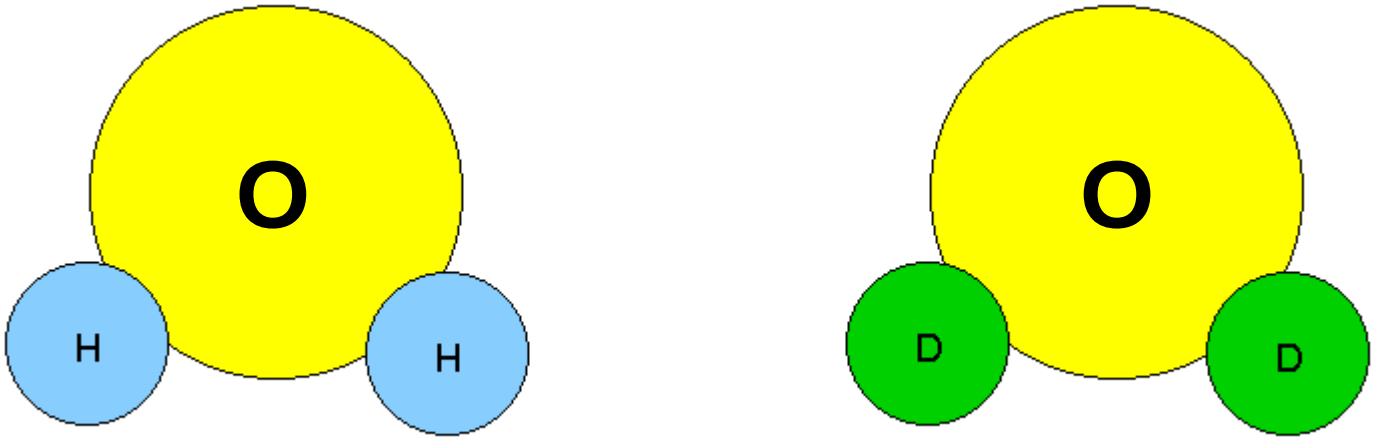
Nuclear fission



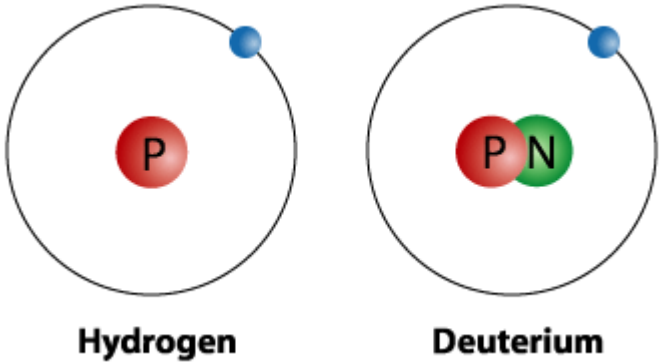
What does heavy water do?



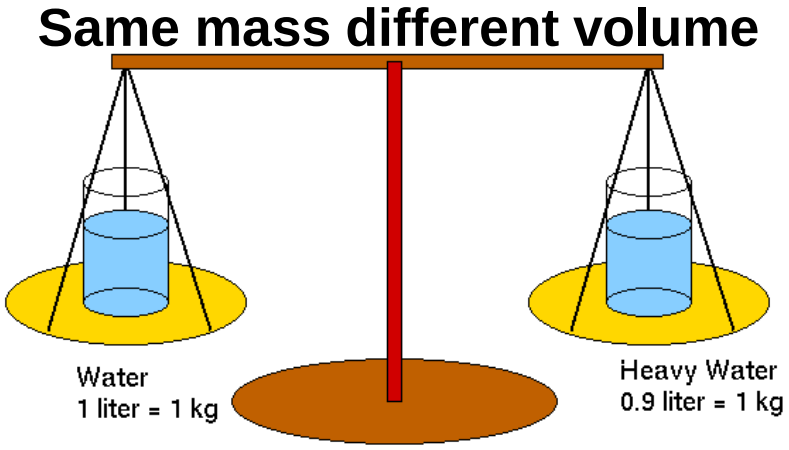
What is Heavy Water?

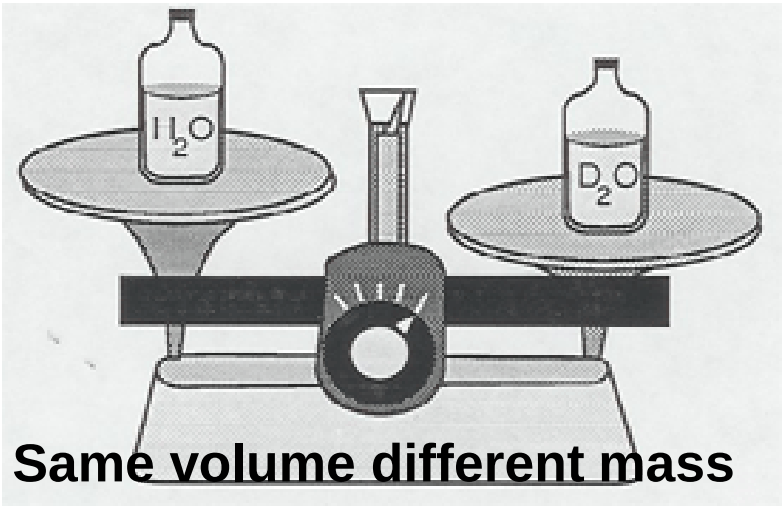


What is H and D?



What is Heavy Water?





- Heavy water ice cubes sink in ordinary water

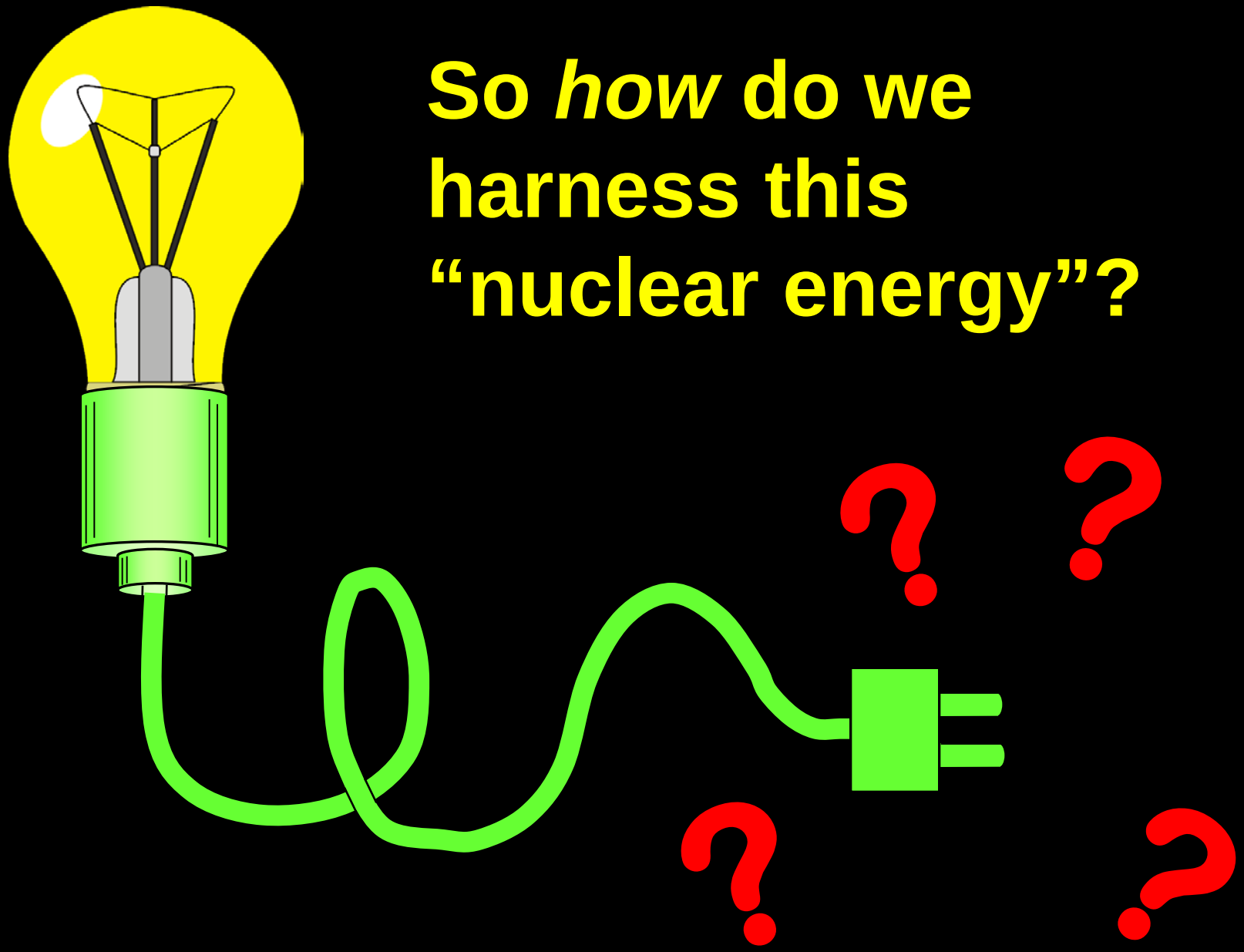
Nuclear power

Is it safe?

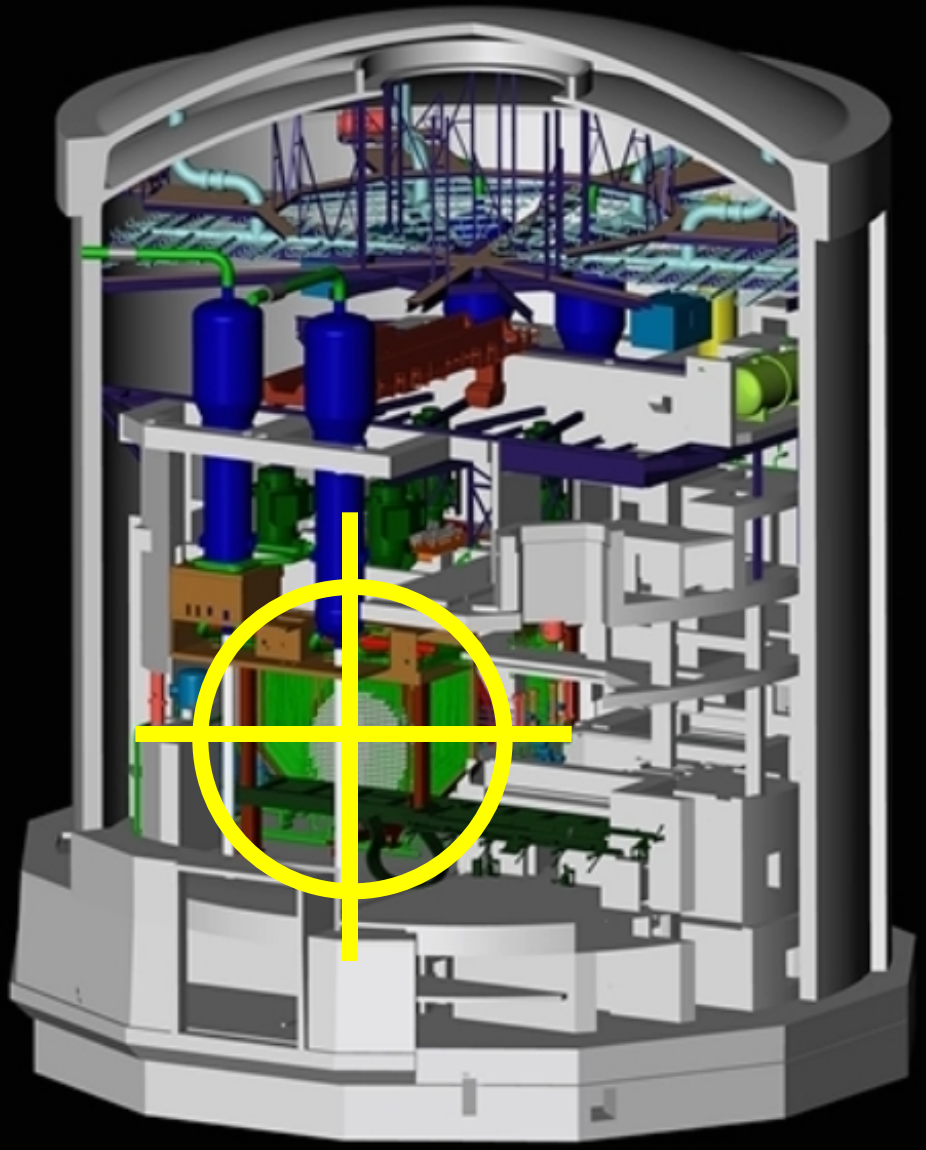
- In nuclear power plants, the back-up safety systems have back-ups
- Canadian nuclear power plants have operated safely for more than 40 years!!

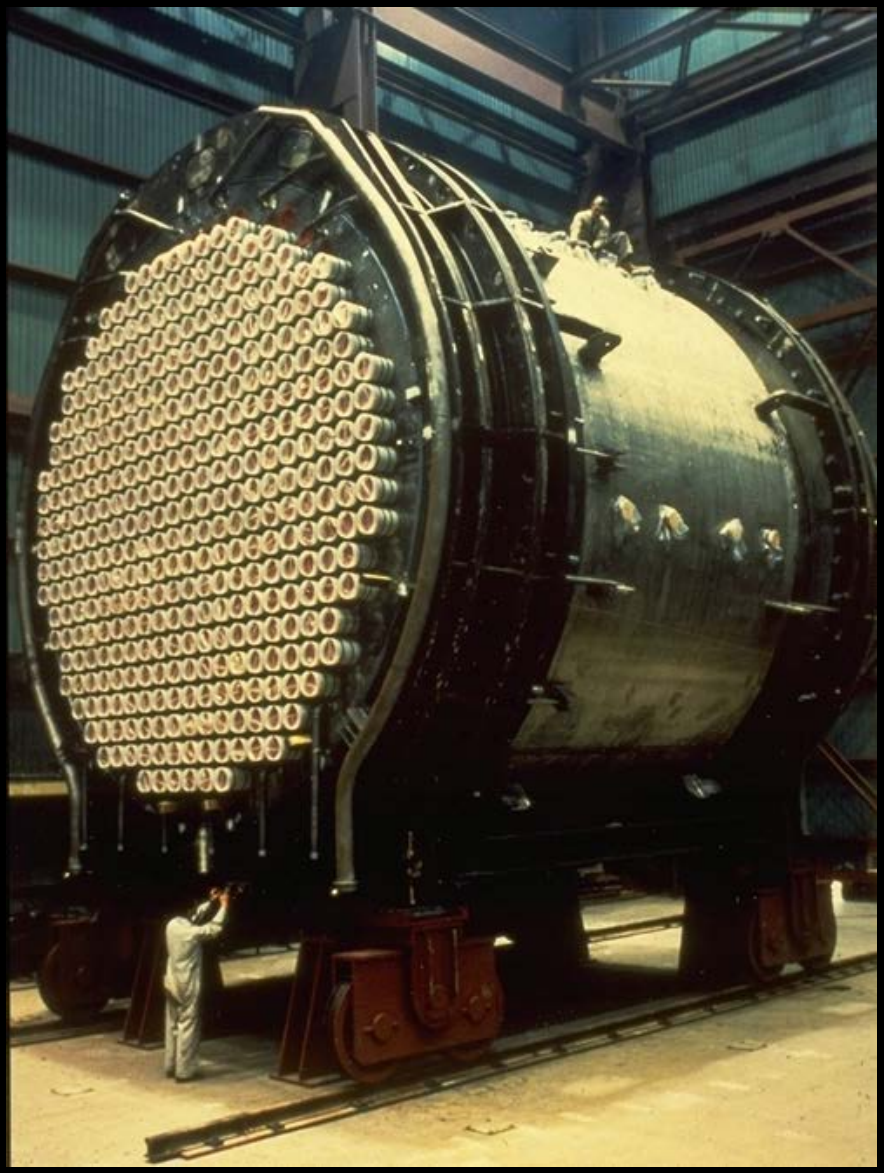
Nuclear Fission is useful because we can control it by ...

- adding neutron scavengers;
- keeping below critical mass;
- moderating the chain reaction;
- ‘delayed neutrons’ …

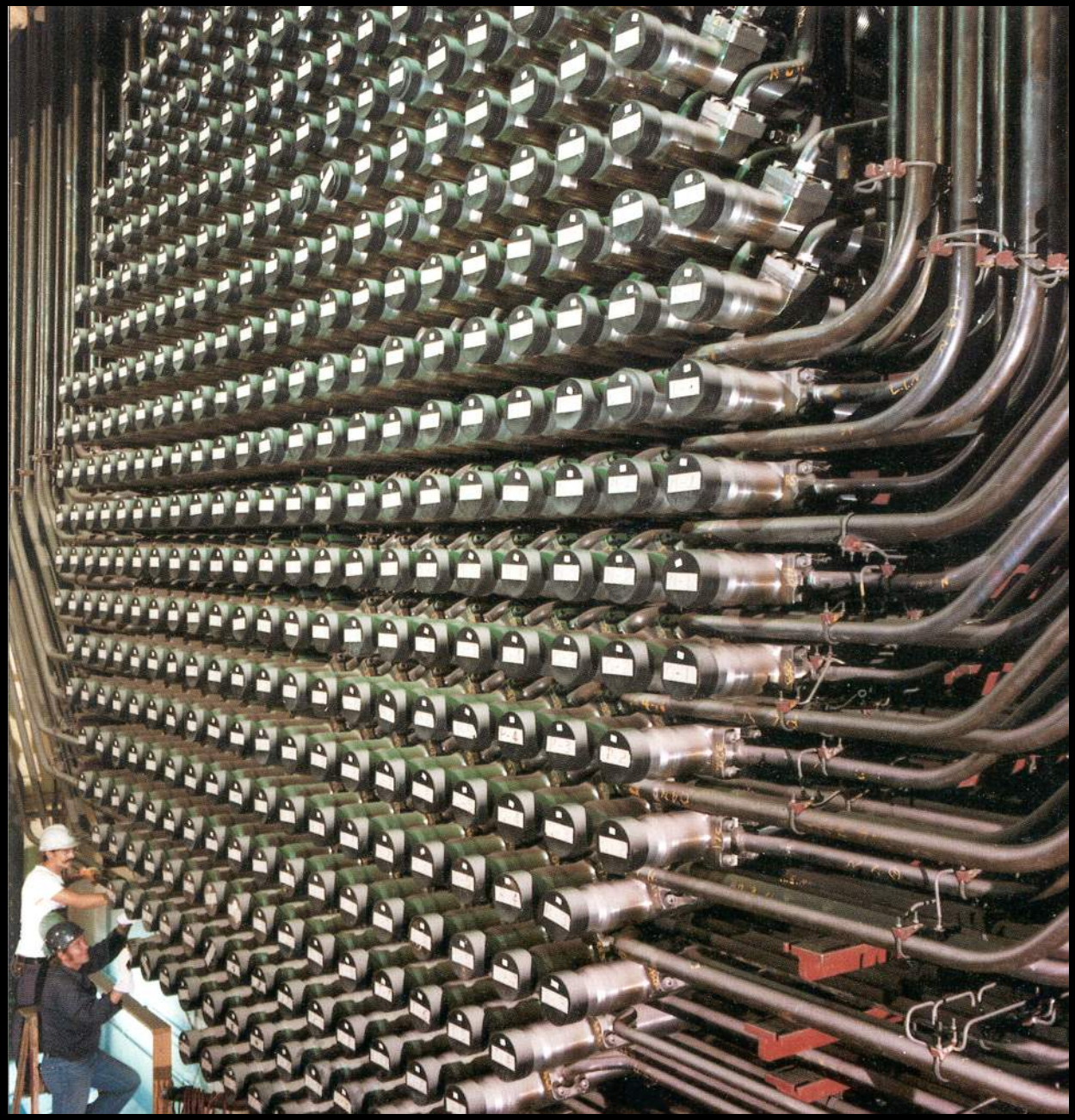

So *how* do we harness this "nuclear energy"?

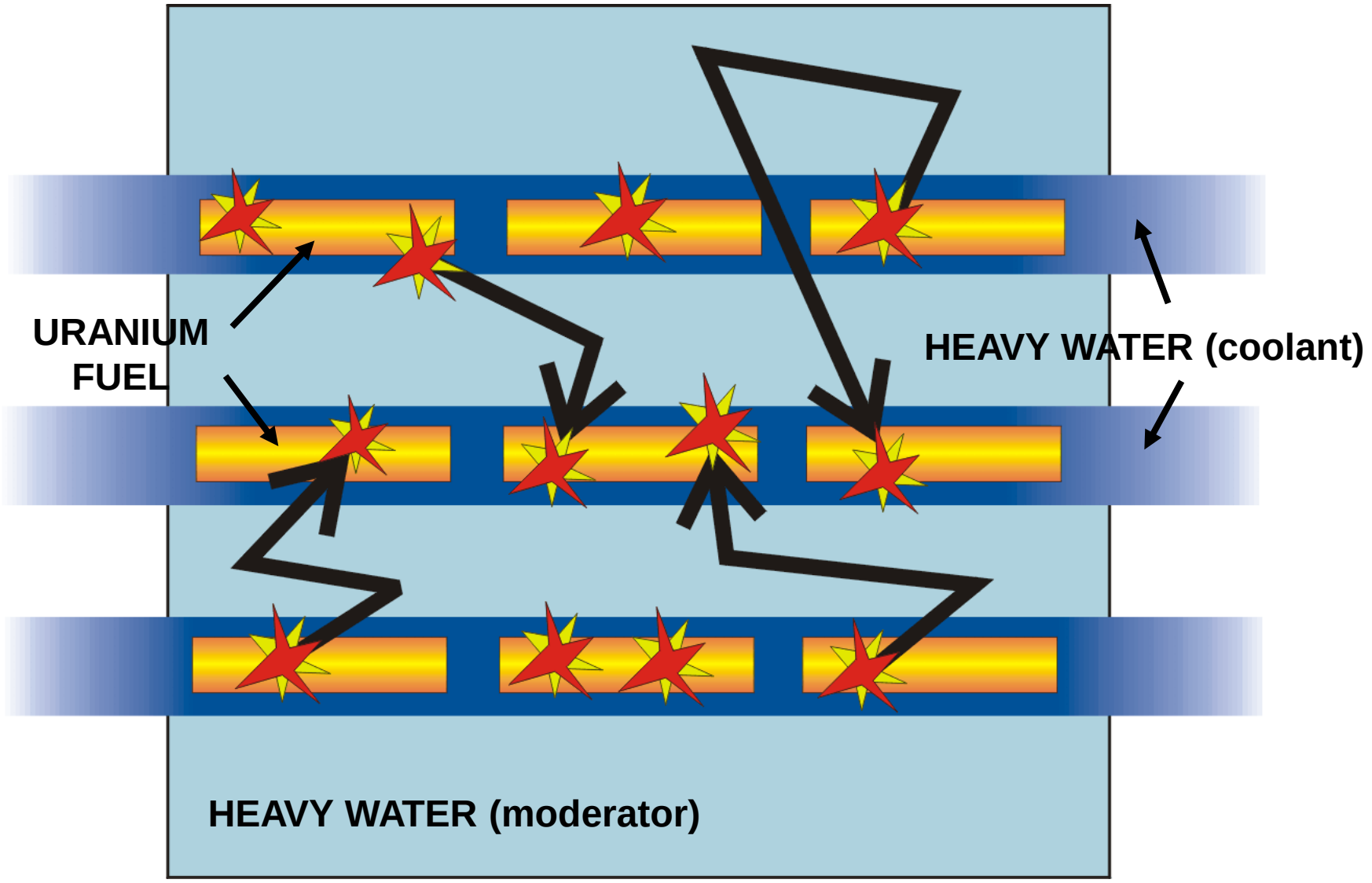
Let’s look under the hood …

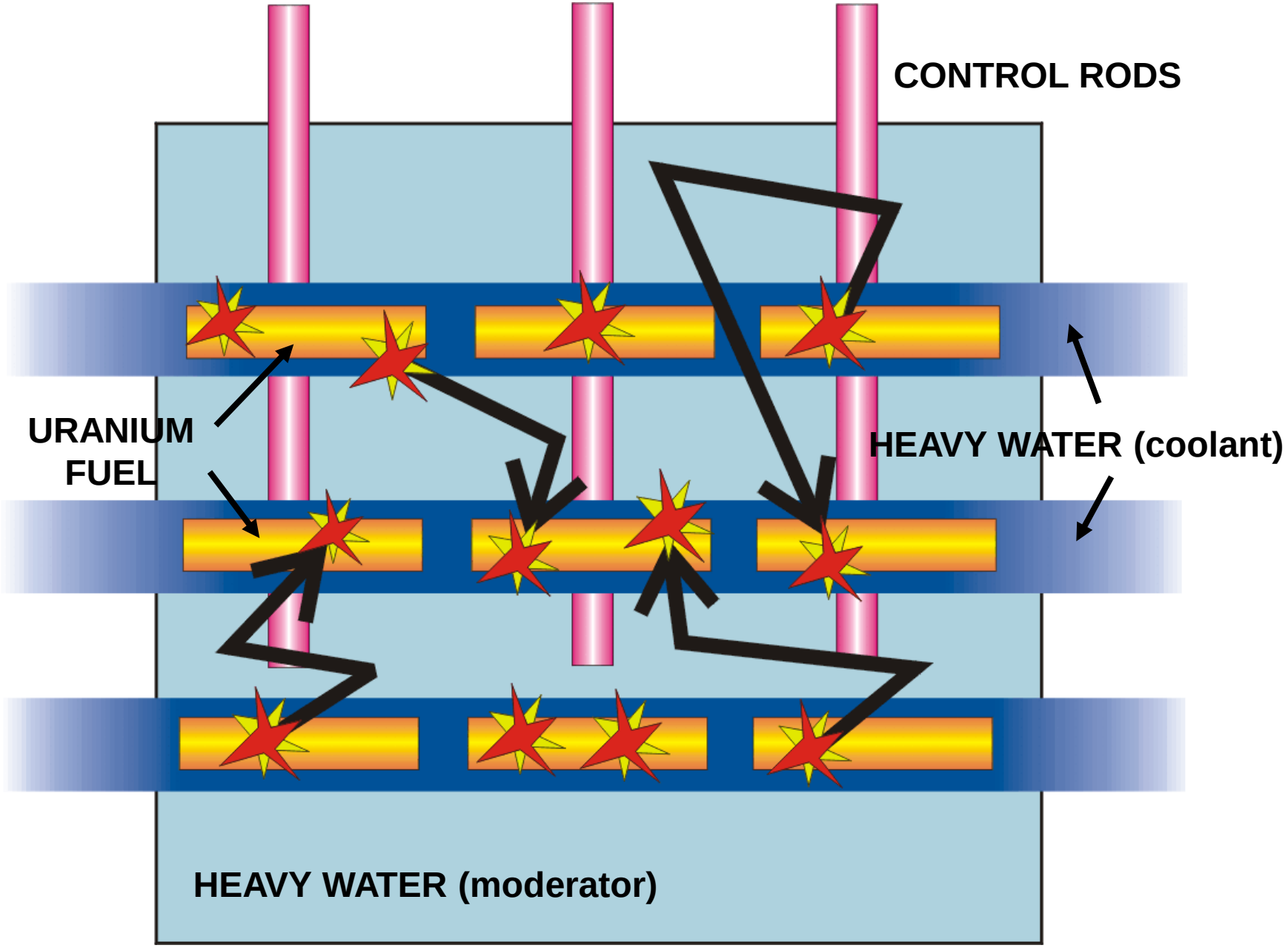




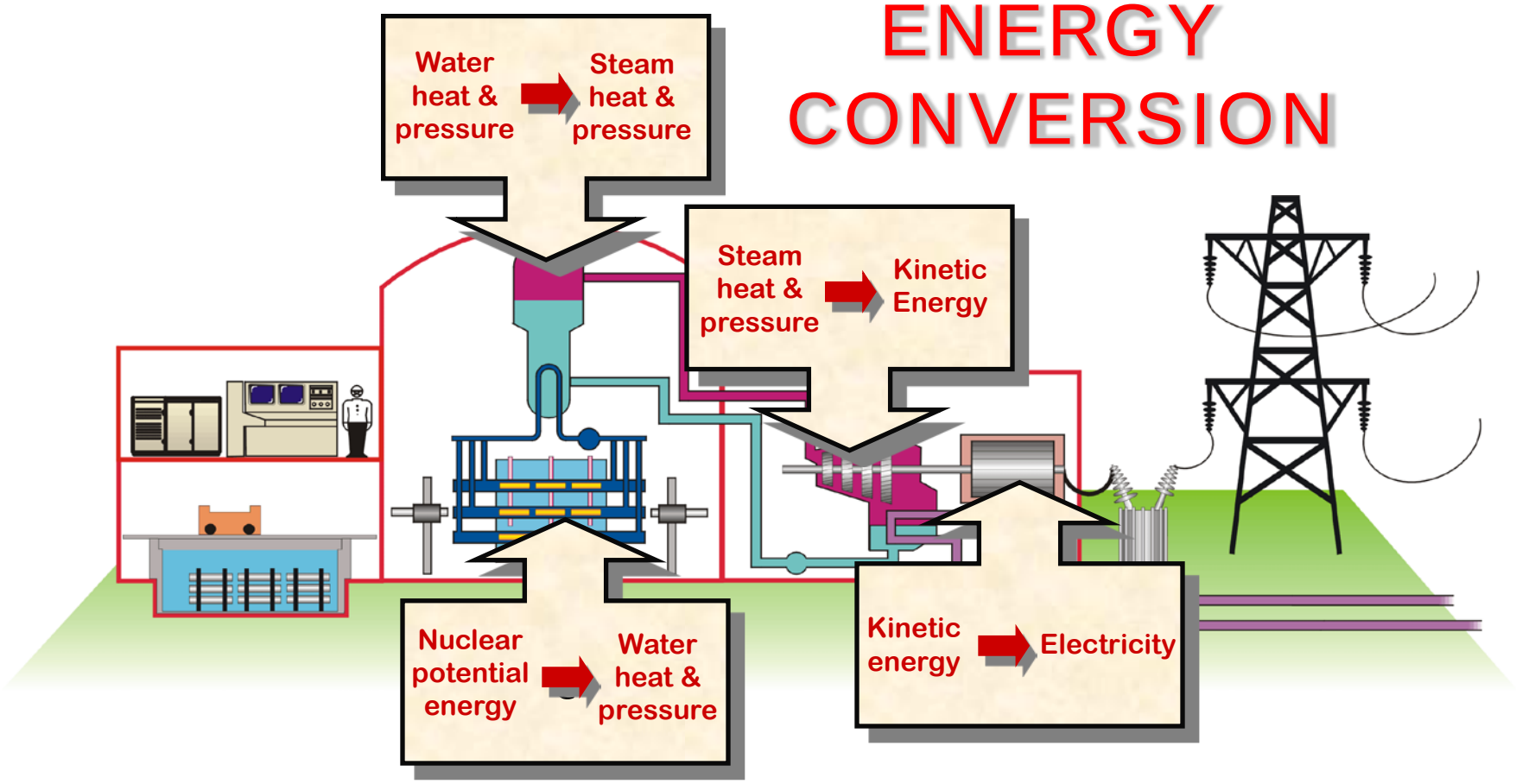
“Calandria”

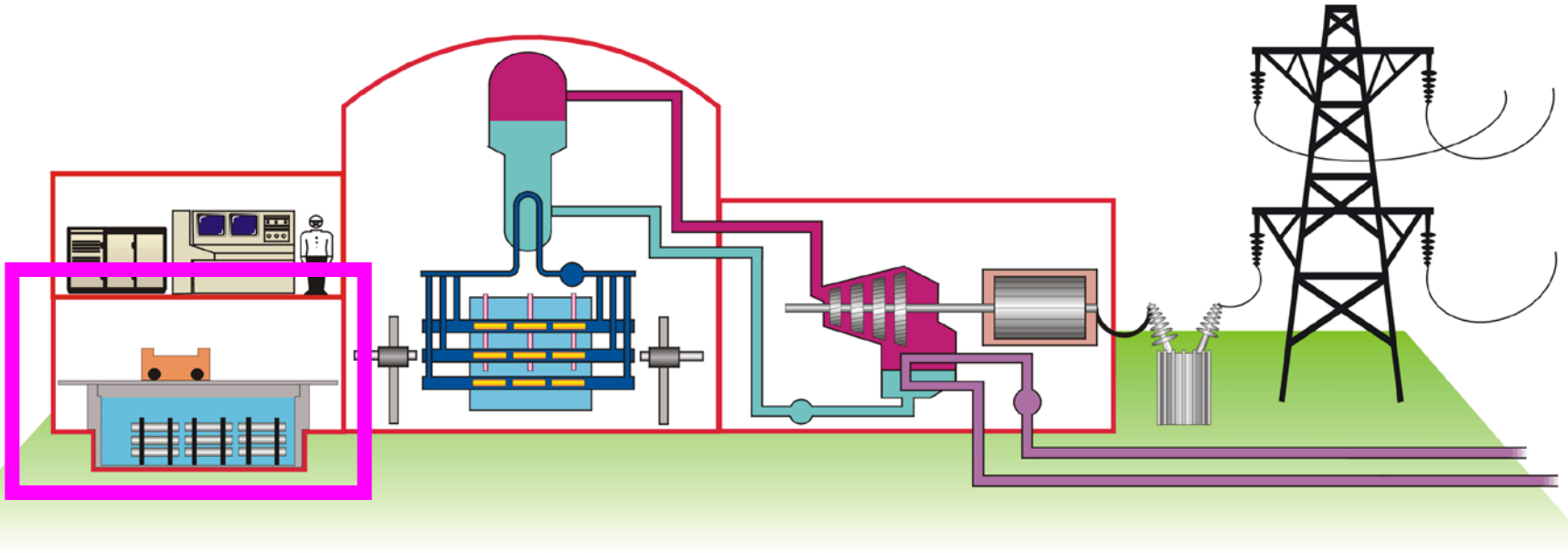



URANIUM
FUEL
HEAVY WATER (coolant)
HEAVY WATER (moderator)


CONTROL RODS
URANIUM FUEL
HEAVY WATER (coolant)
HEAVY WATER (moderator)

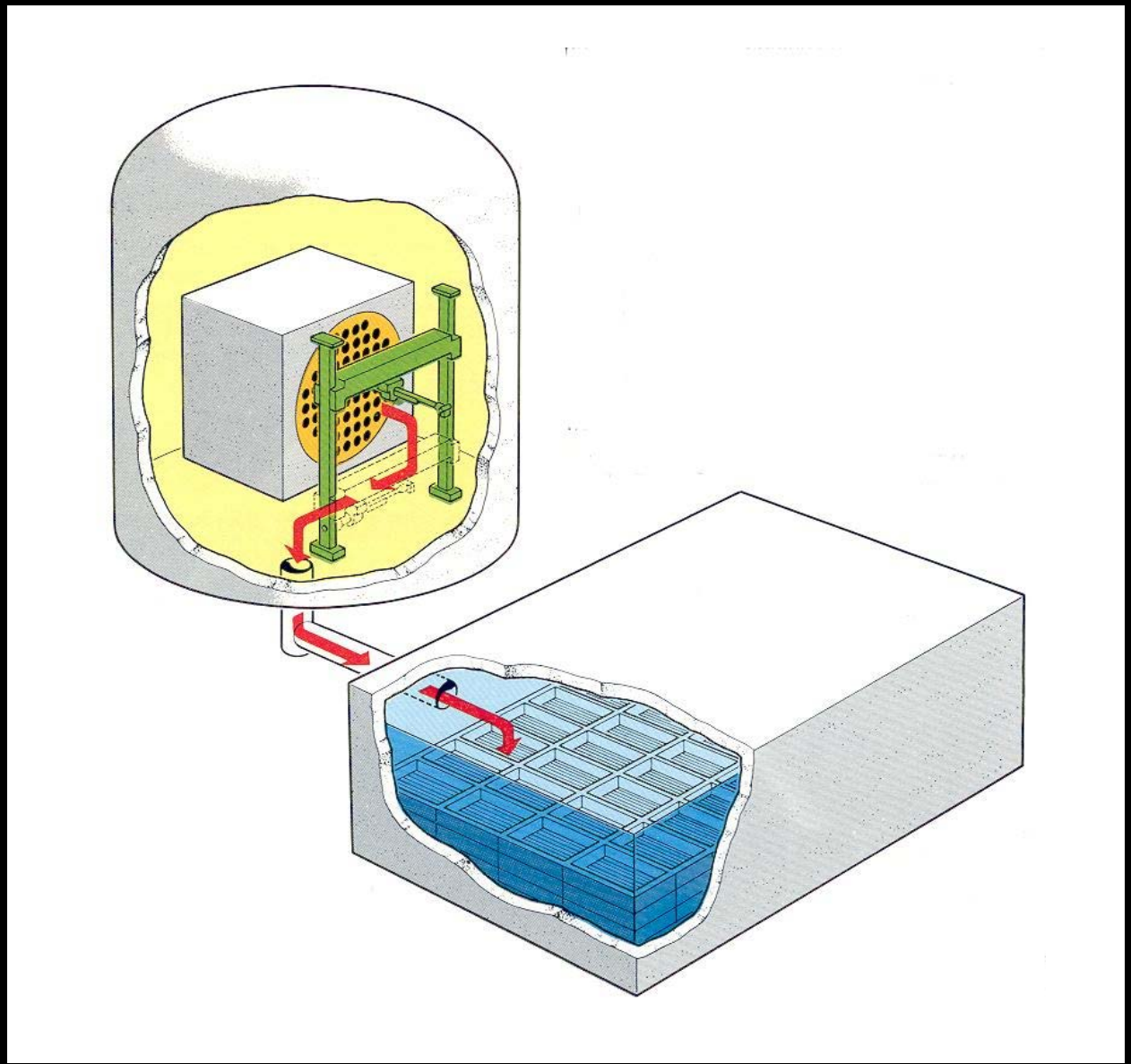
ENERGY CONVERSION



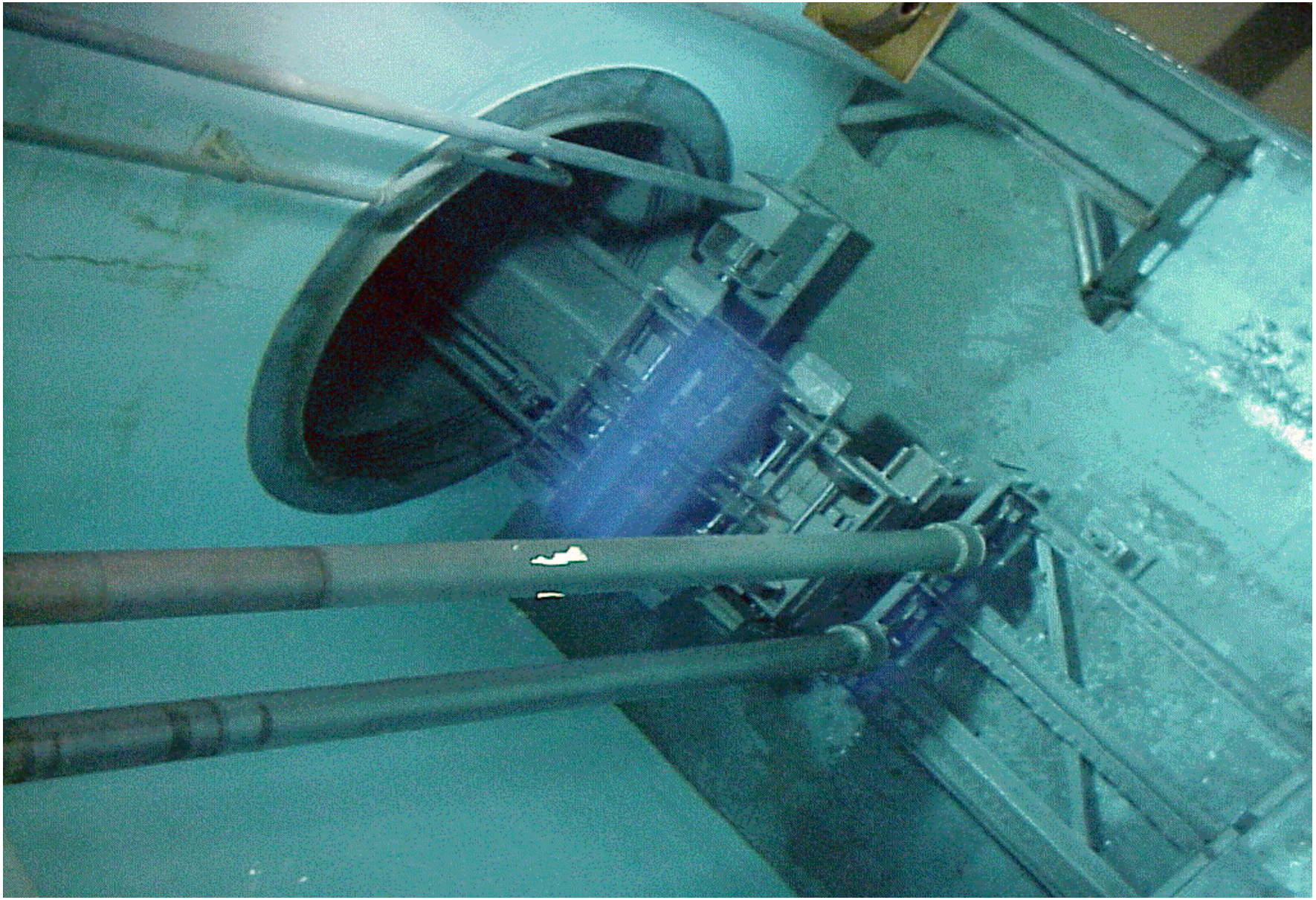


CANDU Spent-Fuel On-Site Storage:

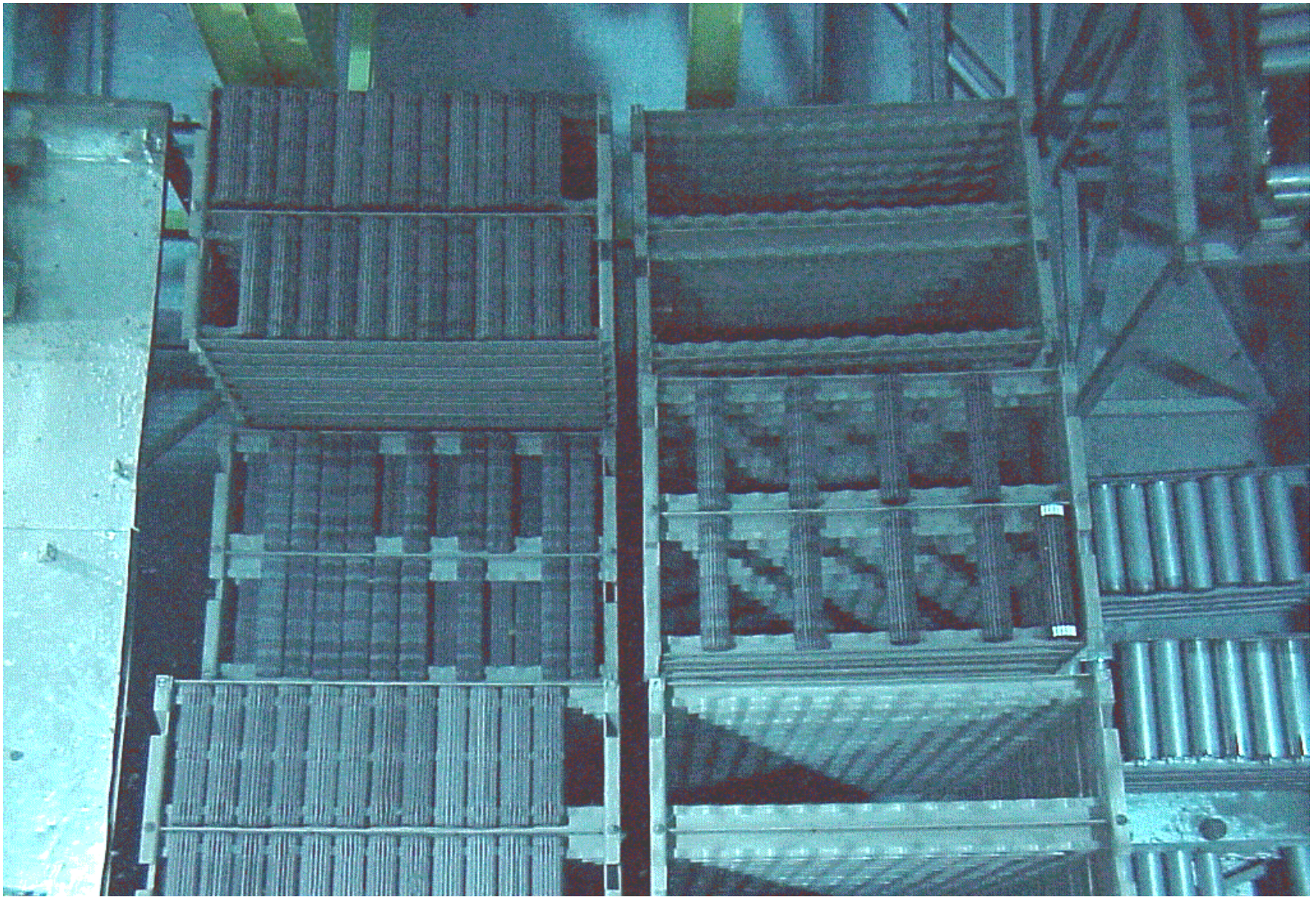
water-filled bays (short term)



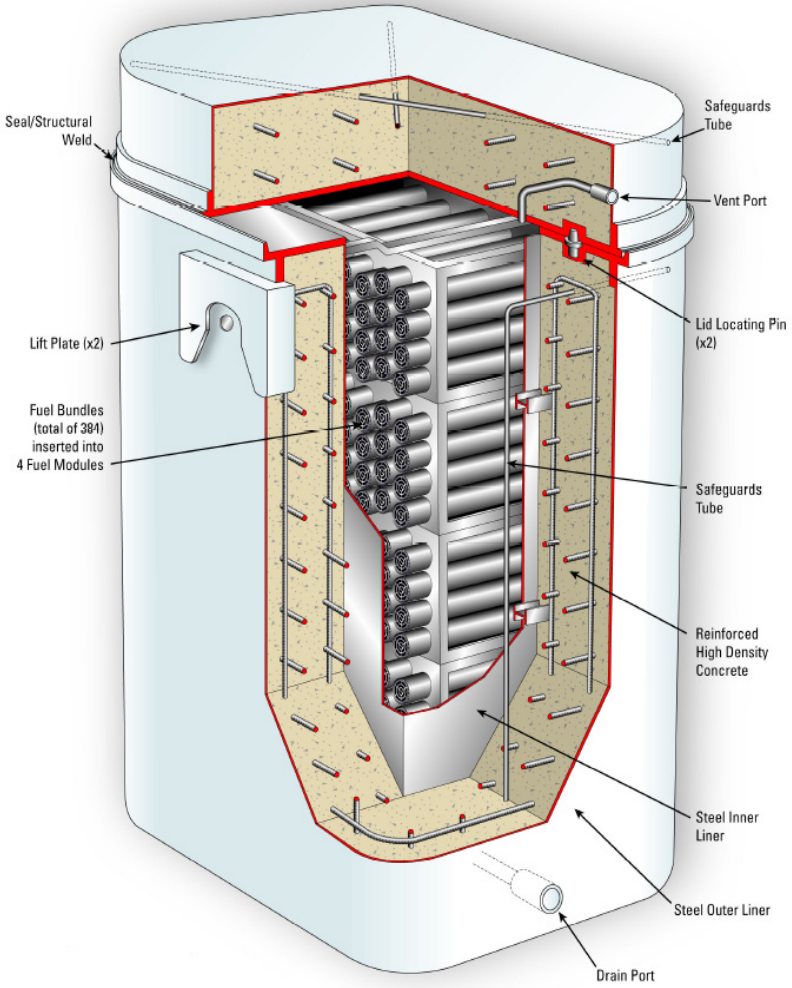
Transfer Canal



Reception Bay



OPG Dry Storage Container (DSC)



- 2 steel shells with concrete
- Welded lid
- 2.1 m x 2.4 m x 3.6 m
- 384 CANDU fuel bundle capacity
- 75 tonnes (loaded)
- 50+ year design life

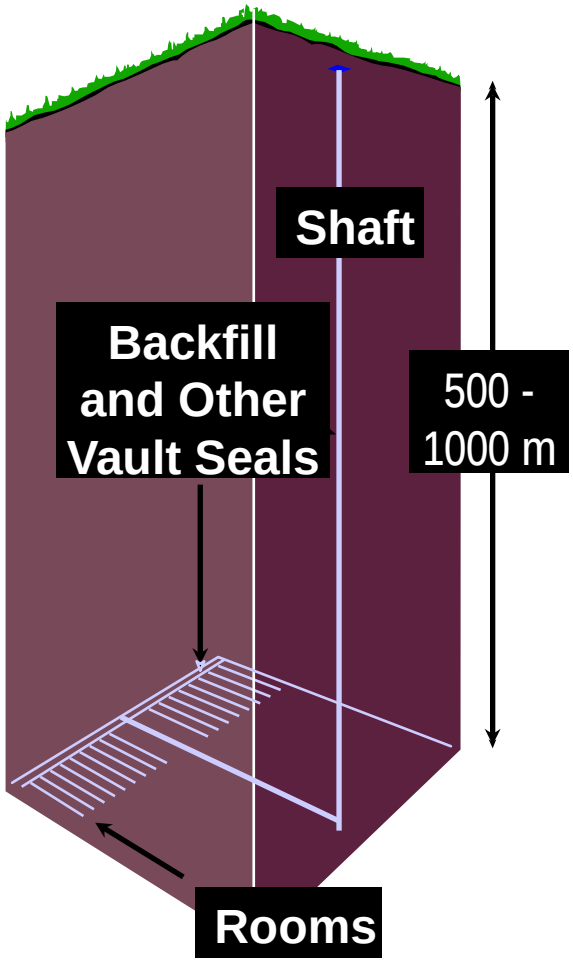
Dry Used Fuel Storage at Reactor Sites

Dry Storage Containers, Kincardine Ontario

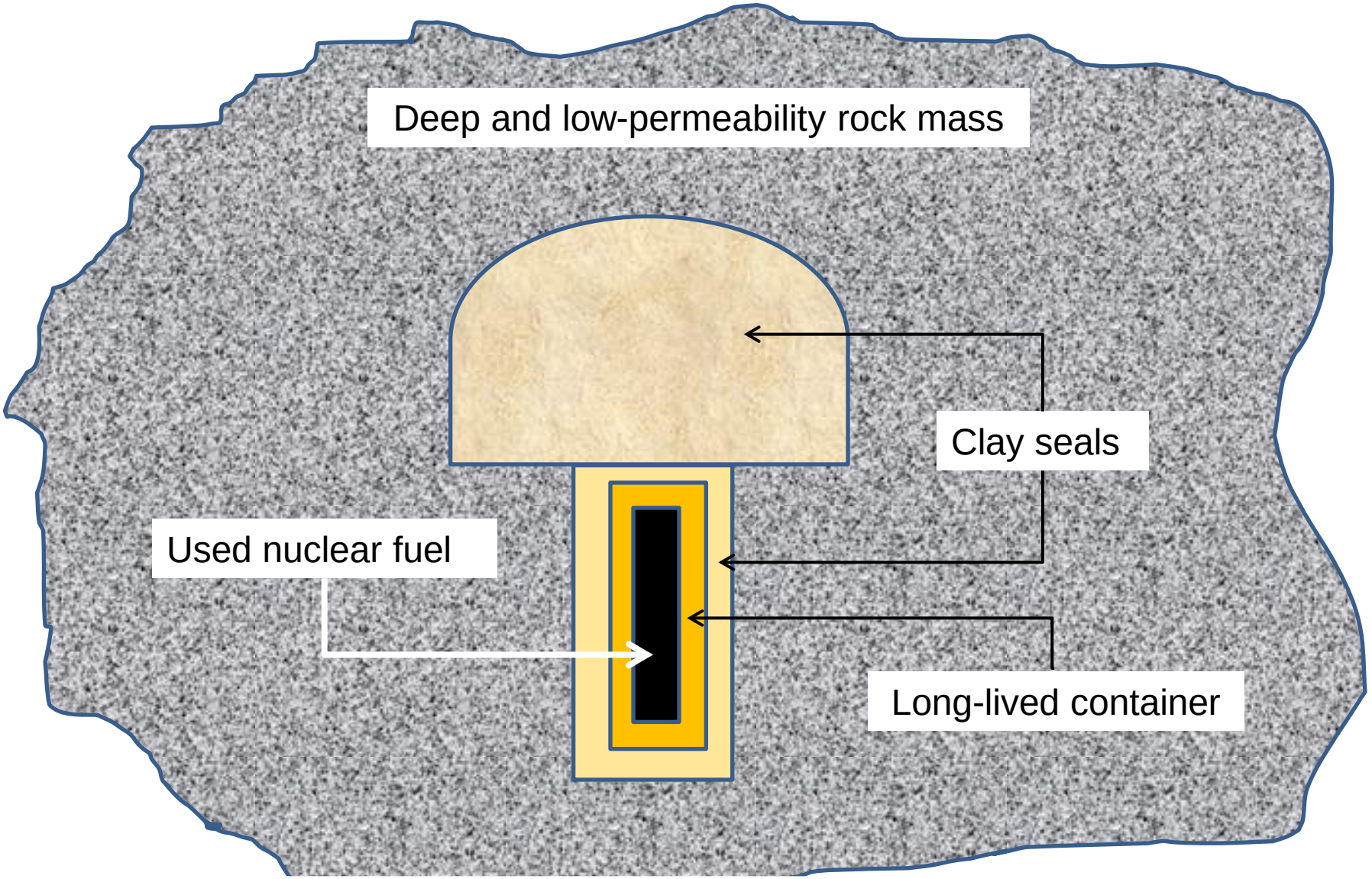
Dry Storage Facility, Kincardine Ontario

Permanent Disposal of Used Nuclear Fuel

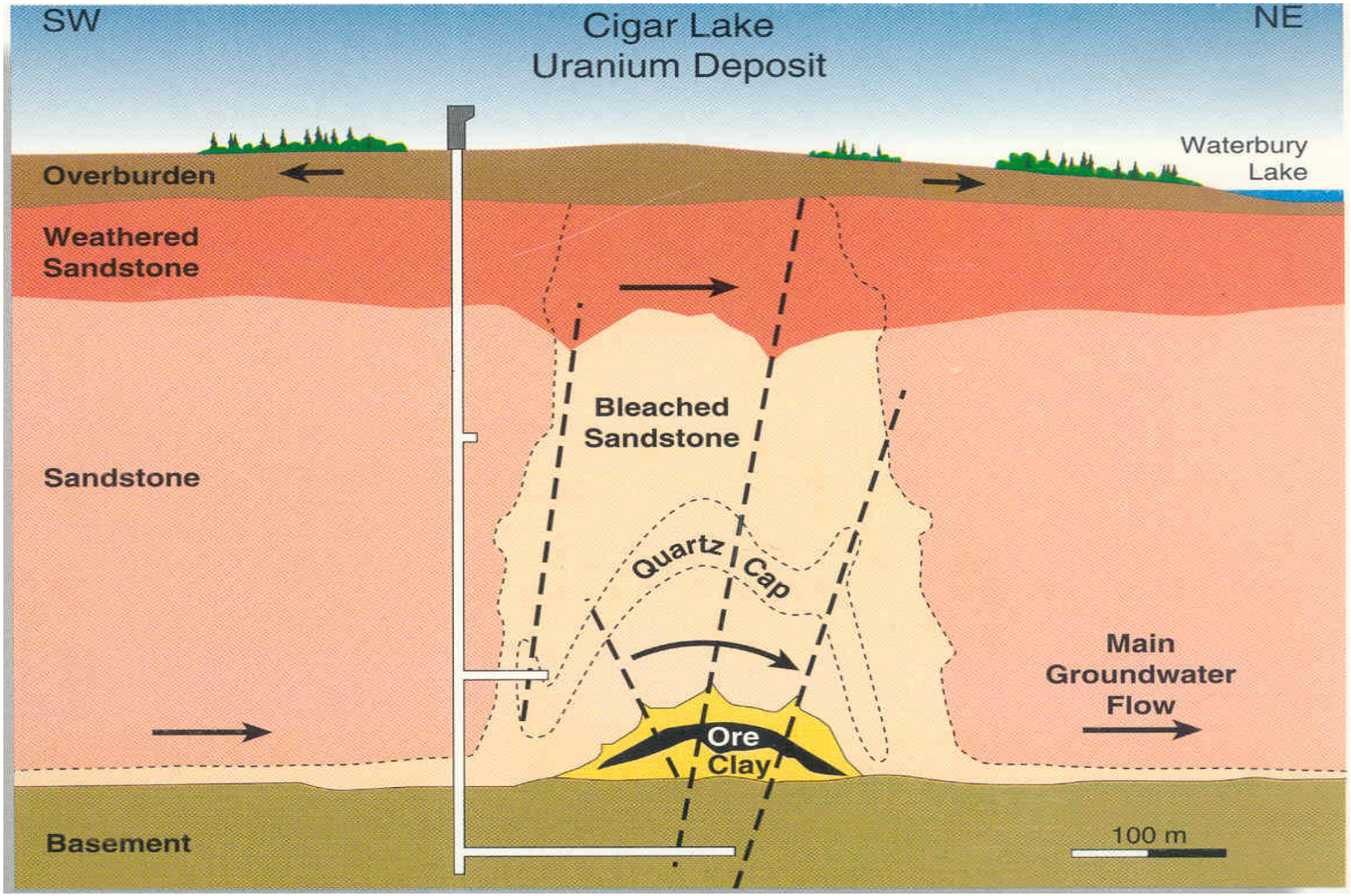
The Canadian Shield



Deep Geological Repository Concept
Multi-barrier System



Natural Analogue - Cigar Lake Uranium Ore Deposit



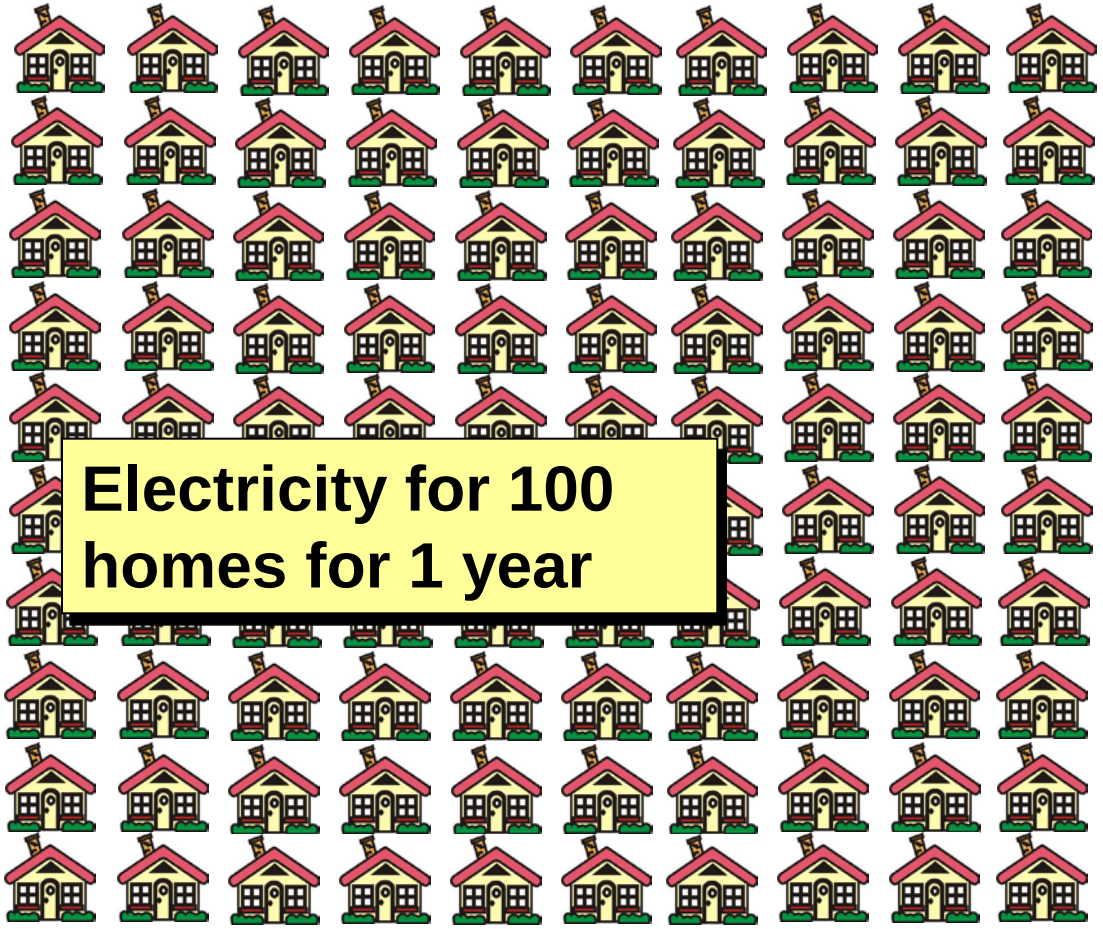
Uranium deposit is about 100,000 tonnes at depth of about 400 metres

Nuclear power

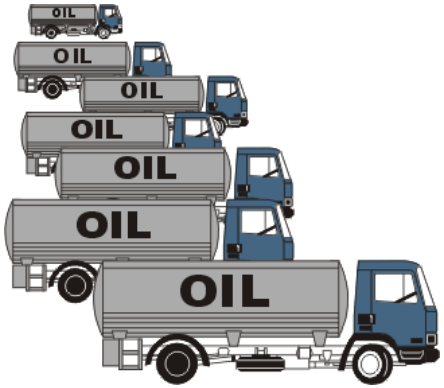
- All used fuel from 40 years of nuclear electricity generation in Canada could be stored in five hockey rinks up to the height of the boards

1 CANDU fuel bundle (50 cm long, 23 kg)

=



Electricity for 100 homes for 1 year



1 CANDU fuel bundle (50 cm long, 23 kg)

= 400 tonnes coal

↓

1000 tonnes CO_2
1 tonne particulates
8 tonnes acid gas

= 60,000 gal oil

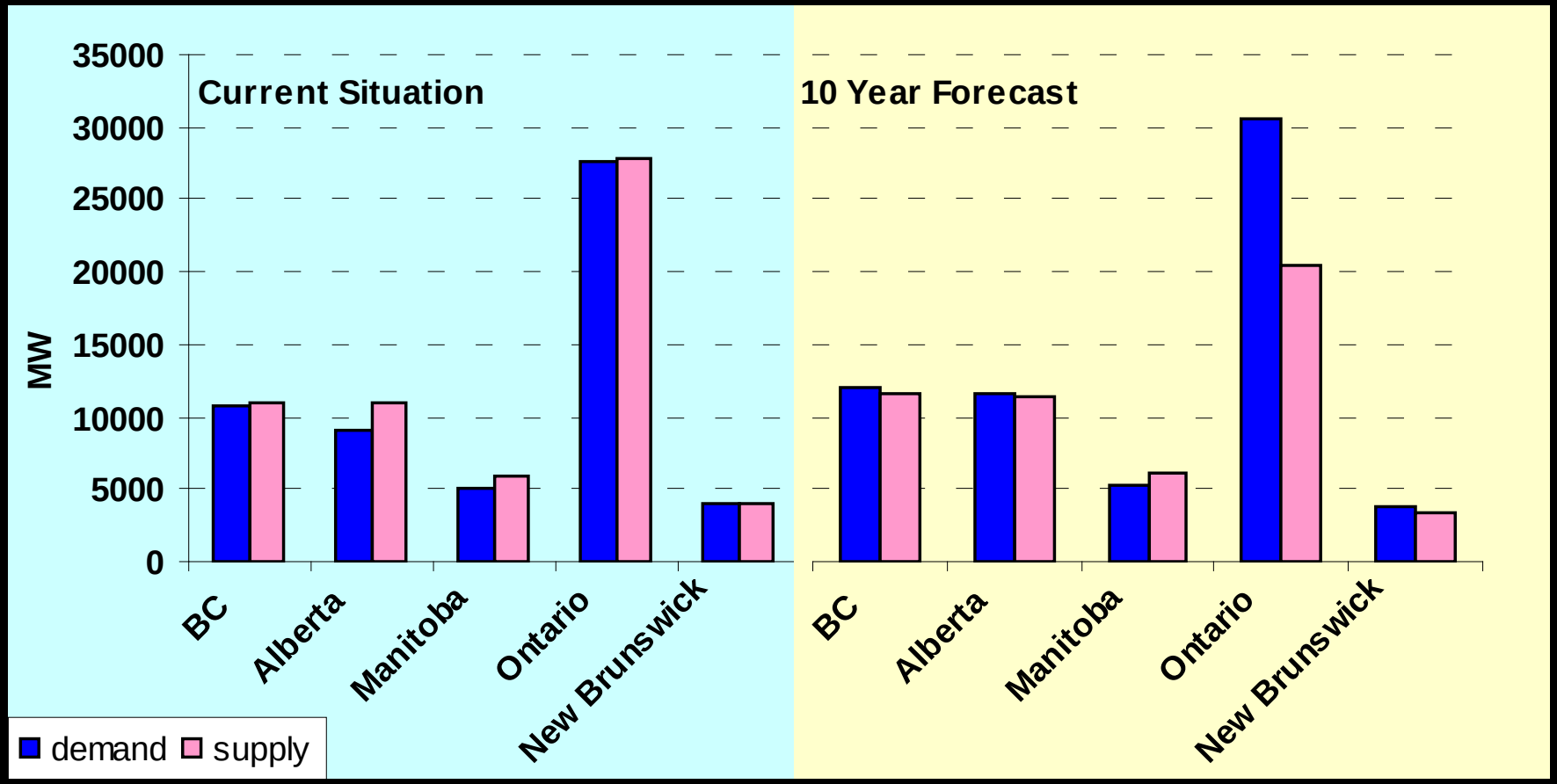
= 10 million ft^3 natural gas

↓

600 tonnes CO_2
1 tonne acid gas

- **Each year nuclear power in Canada avoids over 60 million tonnes CO_2, 0.5 million tonnes acid gases, 100,000 tonnes particulates, and up to 1000 deaths from respiratory illness**

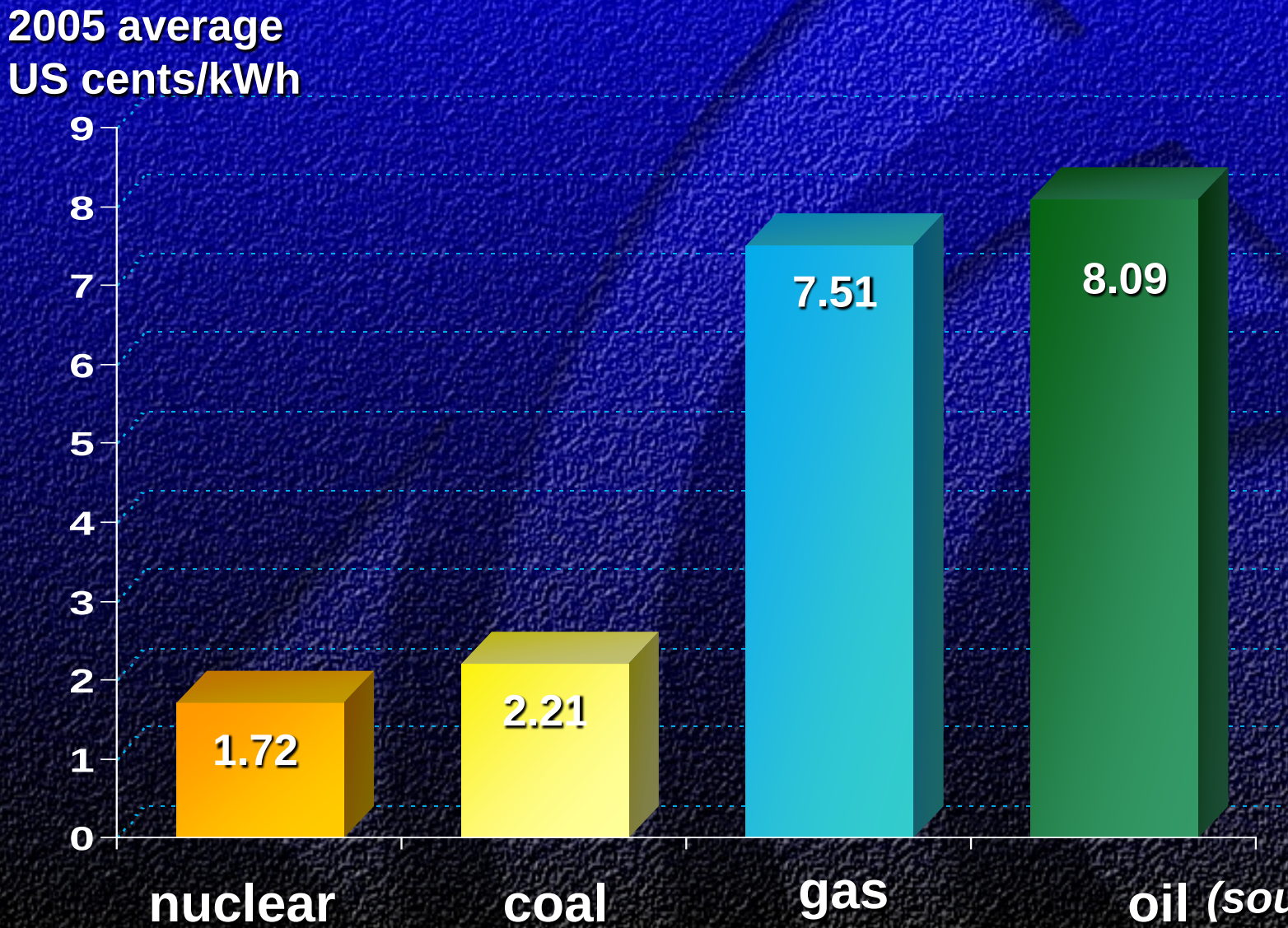
Electricity Supply & Demand in Canada



Source: provincial electricity system operators

Nuclear power

Is it economic?



(source: NEI)

Canadian Nuclear Industry:

150 private companies

1 gov't R&D company

4 electricity producers

26,000 jobs

$4 billion/year electricity sales

$1 billion/year exports

$1 billion/year savings from foreign exchange

Opportunity

- We need smart, skilled people

Not!

Nuclear power

This is who we're looking for!

- Good opportunities
- Many different kinds of jobs
- Good paying jobs

nuclear power is…

- Clean
- Safe
- Reliable
- Sustainable

Climate Change

You're dealing with long-term data sets when you're dealing with climate change. The increasing slope of the graph demonstrates the worry about the undeniable increase in global temperature, as we get closer to present day. It is telling us that in fact climate change is accelerating.

The concentrations (ppm) of greenhouse gases are gradually increasing. Not totally smoothly but undeniably getting higher. The graph of green house gas concentrations over a period of time will be zigzag with highs and lows. Maximum green house gas is during the winter whereas the dip is during the summer when the trees absorb carbon dioxide, etc.

IPCC was created to control the global debate about climate change, and to provide governments with easily accessible information about climate change. So far there are 4 IPCC reports, and there have been many legal documents and agreements from governments. Despite these efforts, problems continue to grow.

Why is it a problem? We have understood for many years something called the greenhouse effect. The fact that our atmosphere contains greenhouse gases, act like a blanket around the earth. It absorbs the radiation from the earth and keeps it within our terrestrial system. This leads to a warming of the atmosphere and eventually the ocean. If it weren't for these greenhouse gases, the earth would be 30-32 ˚C colder. The greenhouse effect is useful.

The fact that these gases warm the atmosphere lead you to understand, the more gases there are, the warmer the atmosphere. The more you warm the atmosphere, the more you change climate as a whole. The fact that we've increased the amount of CO_2 in the atmosphere and the fact given by physics, tells us that climate will change. It will change because of deforestation and fossil fuel burning.

The trend over the last 15 years or so of our greenhouse gas production as a result of burning fossil fuels is increasing. In the year 2000, issued a special report on emission scenarios. It was to look into the future to see what would happen to the planet. What will happen to emissions? What drives those emissions is population, energy use, technology, equity, etc. Projected emission levels all lie very close to the most extreme conditions that have been predicted. It may reach up to 900 ppm, and an increase of global temperature of 4 ˚C.

2008-2009, the economic recession caused a dip in carbon dioxide emissions. The next year, they started increasing again.

Climate change is not just global warming. Artic sea ice is has also been declining, and for 20 odd years already. We can see that there has been a decline of the

summer extent of sea ice. What happens is that when you melt the ice and expose it to the ocean, you're replacing what was a white reflective surface with a dark absorptive surface. Ocean warms when ice melts, and creates a positive feed back and is non-linear relation. The actual levels of sea ice are lower than the projected model.

Expect an increase of the frequency and the extent and severity of extremes such as hurricanes, droughts, precipitation and winds. There are many reasons. Statistically, imagine you've fit the temperatures under a normal-distribution curve. When you increase the temperature, you move the curve. The area under the new curve increases, and shows that the population of these events increase at a much faster rate.

Imagine a pot of water on the stove. For a long time nothing happens, then a few more bubbles. Then the bubbles get bigger. The higher you put the heat, the bigger the bubbles. You can see that as you go in time from 1950s to 2001s, there is a shift of the curve to higher temperatures. In addition, the curve gets broader.

The European heat wave in 2003 mainly affected France, but also affected many neighbouring countries. Another devastating heat wave was in 2010 in Russia. This was more destructive in Moscow than during the European heat wave. The heat waves lead to a lot of forest fires. Lots of air pollution problems were caused. In fact, it devastated the grain growth such that they banned grain exports. North America experienced a heat wave in 2012.

An extreme such as hurricanes, are changing too. We don't understand how they form and sustained, but have to do with sea surface temperatures. When you warm the sea surface, there is more heat to drive the hurricane. There are lots of other things we have predicted but do not know.

Before satellites, if a hurricane did not hit land it did not happen. With satellites, we have better record of hurricane occurrences. We can see that the strength of the hurricane (measured by central pressure drop). There should be more weak hurricanes under normal CO_2, but with higher CO_2, the hurricanes are stronger.

Temperatures are projected to rise. The observed temperature is demonstrating an order of 0.8 in the increase in temperature. According to IPCC, we can see that we are getting close and closer to the IPCC extreme scenarios. There is a scenario where at year 2000, all emissions stop. Despite the stop, temperature still increases due to inertia of the planet system. Since changes are inevitable, we must adapt. Although adaptation is necessary, we must lower the emissions.

There are four factors that determine carbon dioxide emissions, and we must lower all four of them. So far, our carbon intensity has decreased dramatically, but per capita GDP and population and wealth are increasing, and carbon emissions are still increasing. The IPCC projects that wealth and population will continue to grow.

We are not all equal in terms of per capita carbon emissions. Our energy intensity has been dropping. We are using less energy per unit of GDP, but there is a paradox. When our efficiency increases, we use energy more. Although refrigerators became more efficient, their size increases. We have been substituting new energy sources for old ones, and switched over time from one to another. What does it mean for emissions? As emissions increase, so do the concentrations.

You can see the effects of geographical events and their effects on carbon intensity and carbon dioxide emissions. Economic problems affect the emissions, but not the intensity. We must eventually stabilize concentrations (we must stabilize emissions). It is a matter of value that science can tell you about. But it can tell you that if we need to stabilize concentrations, we must lower emissions. The leave of stability is a political choice.

Climate-Engineering (a.k.a. Geo-Engineering) has two classes of approach. One is to remove greenhouse gases from the atmosphere. The second is to change the solar-radiation management.

To change solar radiation management is almost like putting mirrors up in the sky to reflect the radiation. We can also use aerosols to do that. There are some problems with that. A practical one is that they don't stay up very long meaning we must replenish them all the time. It may also change the temperature profile AND precipitation profile!

To remove the gasses from the atmosphere, you would either use big fans to reverse-suck the greenhouse gases. The other idea is to suck it out when it leaves the source, condense it and convert to a liquid and dump it back into the well.

ECOR1010-TSE7

Sustainability at Carleton University

Imagine a Carleton where

- Energy is provided by clean and renewable sources and is consume deficiently
- Every building is designed to emit zero carbon and emit low impact material
- People can leave their cars at home
- Students are prepared to respond and contribute to the unprecedented circumstances as professionals and citizens

Sustainability… Why?

- "Don't think of it as saving the fish, think of it as saving humanity, your kids, you"
    - In the past, its always been about saving specific things (animals, rainforest, etc.)
    - Nowadays, things such as climate change, etc. its about saving ourselves

Sustainability Defined

- 1987 Brundtland Report
- Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs
- Three major parts to sustainability
    - Environment
    - Economic
    - Society

Recycling Program Tune Up

- Numbers for 2011/2012
    - Diversion rate has increased to 56%
    - Waste contract means that we do not pay for collection of any recyclables
    - We get money back for large scrap metal
    - Large wood as well in the maintenance yard is recycled
    - Yard-type waste is composted on site
    - Collect organics in UC from kitchen areas

Special Waste Depots

- Objective is to divert various special wastes from the landfill
    - Established 4 depots around campus
    - More depots will be added

    - Collects batteries, printer toner cartridges and cell phones
    - Can bring from home as well

Vending Misers

- Objective is to reduce energy used by vending machines on campus
    - Working with Dining services installing misers on 195 machines
    - Average saving of 35-45%
    - Will save approximately $22700 a year in electricity costs
    - Pay back within 2 years

Benchmarking

- Objective is to establish a benchmark for all buildings on campus. Use it to identify possible improvements and measure the change
- Working with Green Globes (building assessment tool) to develop a tool for rating buildings in a campus environment
- First report produced January 2010
- Evaluation tool now to be used by universities across Canada (through APPA)

Waste Audits

- Objective: Waste audits were conducted of all academic buildings on campus
    - Conducted waste audits and education around campus this last summer
    - Dumpsters contained 68% waste and 32% recyclables
    - Working with stakeholders to improve and implement recommendations

Waste Reduction at Special Events

- Objective: to reduce the waste going to landfill at special events
    - CU invested in special recycling and composting containers for events
    - There are now available to be used for outdoor events such as Employee Appreciation Day
    - EAD with 1600 people produced one bag of waste

Water Audits

- Objective: A water audit was conducted of campus to identify areas we could reduce water consumption
    - Add aerators, changing urinals and toilets as renovations are done
        - Russell/Grenville set a new level for water conservation. Now implemented in the new residence as well

Green Construction

- All new construction and major renovations must achieve at least 3/5 globes using Green Globes.
- River Building achieved 4/5 and Canal Building 5/5.
- Both have green roofs, lots of daylight, sensor controlled lighting, etc.
    - Canal has a 10 kW solar array

2012-2013 in the Sustainability Office

- Ensure long term funding for Sustainability at Carleton U
- Begin implementing a strategic plan for operations at Carleton
- Continue work on waste reduction, as it is such a visible part of sustainability. Currently working with Dining Services to improve dining areas.

What Can You Do

- Make good personal choices – be conscious
- Learn more about climate change and act now
- Share what you learn but don't preach
- Get involved with sustainability – here at Carleton, at home, with ENGO's, etc.
- Consider working specifically on a Carleton focused sustainability project for your course work in a later year
- Make your job a "green" job
- Have fun and laugh

"Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed it's the only thing that ever has." – Margaret Mead

Sustainable Buildings and the Engineers Who Build Them

What is a sustainable building?

- A building that uses the least amount of **resources** to fulfill its intended **need**

What is LEED?

- Leadership in Environmental and Energy Design: A certification program
    - Sustainable sites
    - Water efficiency
    - Materials Resources
    - Energy and atmosphere
    - Interior Environmental Quality
- Not a guarantee of sustainability
    - You get something that is more sustainable than other buildings
- Not the same as high performance
    - Does not indicate a buildings' efficiency

What is a High Performance Building?

- It can be described as a building approaching a Net Zero Energy Building
- It goes way behind the minimum requirements of code
    - ASHRAE 90.1-#### (#### is the year)
- It is very, very efficient AND does not compromise on indoor air quality and comfort

Why aren't all buildings HP?

- Money
    - A capital dollar is always worth more than an operations dollar
        - Life cycle cost analysis
- Owners don't understand what they want
- Engineers and architects are not good enough
    - Not a technical competency issue
        - We are not good at selling our services and ideas
- Not a technology problem
    - Technology for HP have existed for long time

We need better engineers

- "Super engineers"
    - Not just those who are better at calculating stuff

Why a super-engineer today?

- Because projects don't fail (or achieve its right level of sustainability/performance) from a lack of technical knowledge by the engineer…
    - The engineers fail because of a lack of project management or communication skills

A quick anecdote…
- Big construction project
- LEED gold target
- Was sustainability consultant
- A LEED Charette was organized (all engineers and owners and architects were invited)
    - Engineer had nothing to say. They didn't want to comment until they see completed architectural drawings.

Today's projects depend on Integrated Building Design
- To work… IBD requires
    - Active participation by ALL
    - Accurate, competent, comments that are timely
    - An understanding of the entire process

A building simply cannot be sustainable without IBD

Without IBD
- No HP building
- No HP building systems
- No on-site renewables

Who is the super-engineer?
- Technically competent
- Environmentally Conscious
- Client-focused
- Driven/Ambitious
- Intellectually curious… seeks perfection

The Super-Engineer
- Follows a rigorous design process to get there

How to become a super-engineer
- Graduate
- Get involved in technical societies and other professional associations (ASHRAE, ASPE, USGBC, ASME, IEEE, …) AND volunteer actively
- Develop your soft skills
    - Read books
    - Teach/Coach
- Pick an employer that share your values

Aligned Values

- General Y employees really need to work for a firm whose values match their own
- Brand = Culture

In Summary…

- The super engineer is needed now to be an effective contributor to the new reality of the greener built environment
- The super engineer is the total package: knowledgeable good communicator and disciplined
- You can be a super engineer… read, volunteer and pick your employer well