

UN5390: Scientific Computing

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Week #05: 2016-09-27 and 2016-09-29

Cross-listed as BE5390, EE5390 and MA5390

Do not share/distribute the course material, in and/or outside of Michigan Tech, without instructor's prior consent

Recap

What we did last week, and what you were supposed to do



<http://dilbert.com/strip/1998-09-14/>

Week #04 Recap

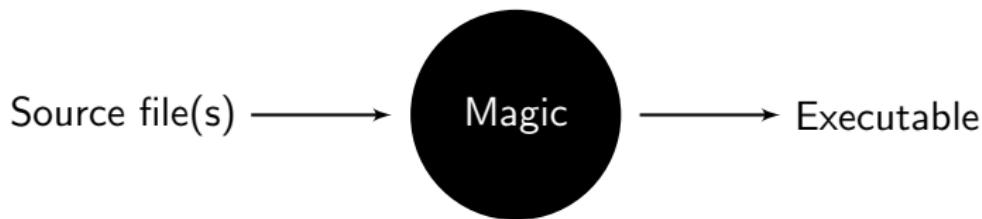
- * Numbers
- * Statistics
- * Silicon Valley (PBS; almost completed)

Week #04 Before we meet again

- * Review the syllabus, course material, grade through week #04, [notations](#), [active participation](#), [free time exercises](#), [tips](#), opportunities, [mathematical results](#), [videos](#), and training camps
- * Get started on and make progress in assignment #04

Compilation

The process of transforming a program written in a high level language from source code into an executable



The Need

Interpreter

Step-by-step executor of source code.

Interpreted language

Directly executes instructions using the interpreter (Javascript, Mathematica, MATLAB, Octave, Perl, PHP, Python, R, etc.).

Compiler

Translators that generate machine code from source code.

Compiled language

Compiles source code into machine code and then runs the executable (C, C++, FORTRAN, Julia, etc.).

The Difference

Interpreted vs Compiled languages

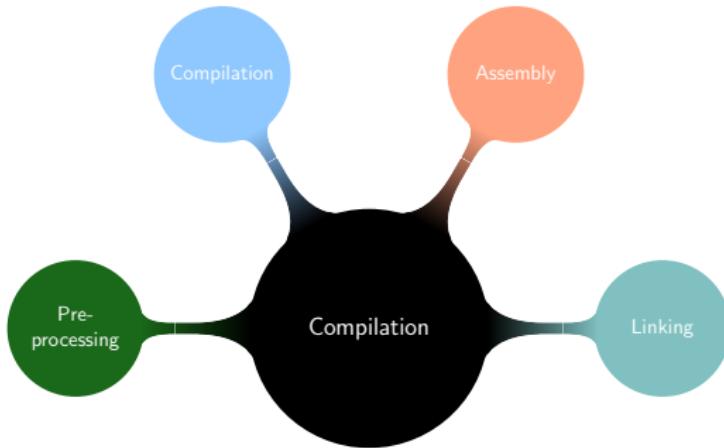
Interpreted languages are easier to learn, and often the first step in programming. They can be used to accomplish simple and moderately complex tasks with ease but communication/translation tends to be an expensive overhead.

Compiled languages may not be easy to learn but provide a considerable increase in speed/performance. Time invested in (re-)writing the code can be easily recovered many times over, especially for complex tasks.

Base your decision of language(s) on research needs.

Compilation

Behind the scenes

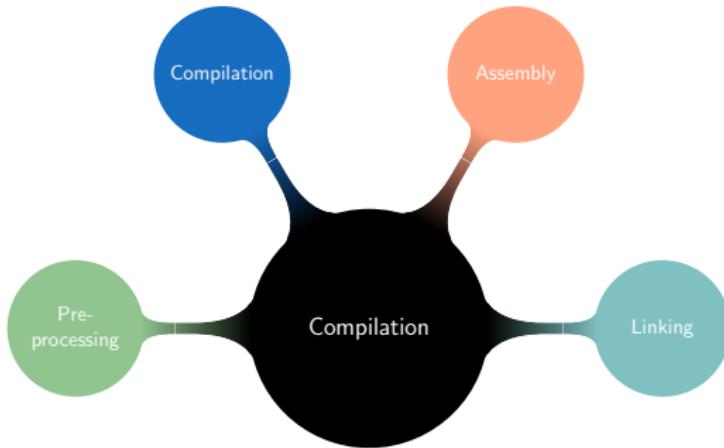


Pre-processing

A separate program invoked by the compiler (`cpp`) to handle directives (`#include`, `#define` and `#if` statements) and strip off comments.

Compilation

Behind the scenes

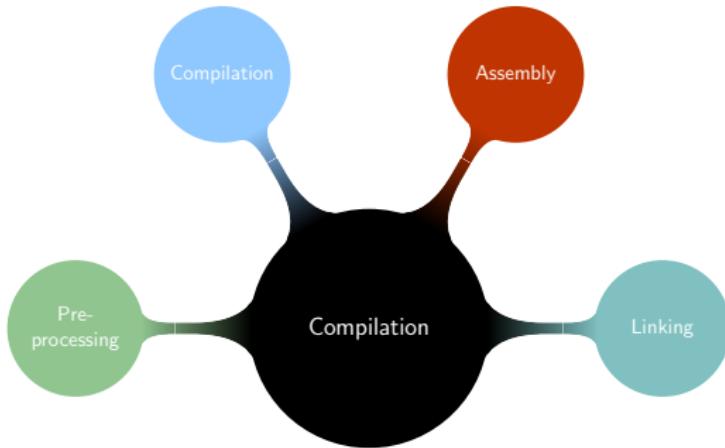


Compilation

Converts the output of pre-processor and source code to assembler source code.

Compilation

Behind the scenes

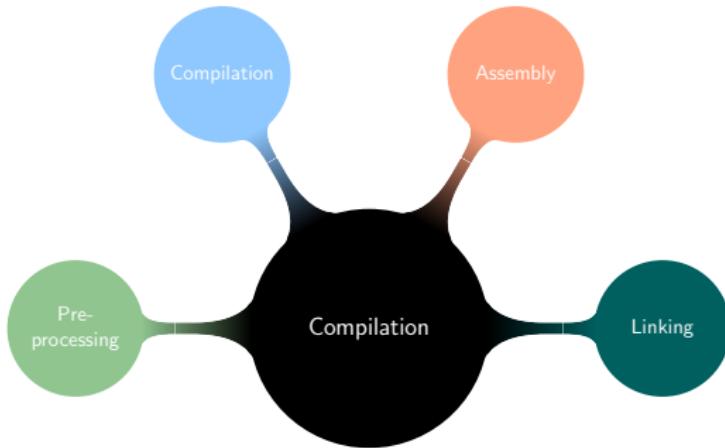


Assembly

Converts the assembler source code to an object file.

Compilation

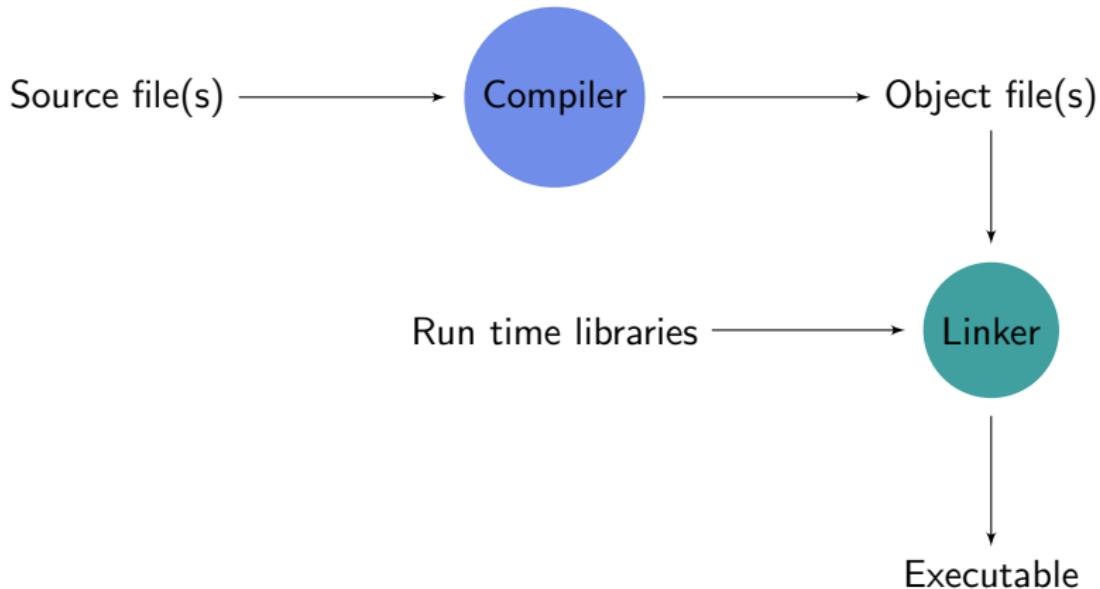
Behind the scenes



Linking

Links together various object files and run time libraries to produce an executable.

Compilation Schematic representation



With one command

```
COMPILER OPTIONS SOURCE_FILES -lLIBRARY -o EXECUTABLE
```

With n+1 commands

```
COMPILER OPTIONS -c SOURCE_FILE_1
```

```
COMPILER OPTIONS -c SOURCE_FILE_2
```

```
COMPILER OPTIONS -c SOURCE_FILE_3
```

...

```
COMPILER OPTIONS -c SOURCE_FILE_n
```

```
LINKER OBJECT_FILES -lLIBRARY -o EXECUTABLE
```

Refer to `man gcc`, `man g++`, and `man gfortran` for more information.

Commonly used options

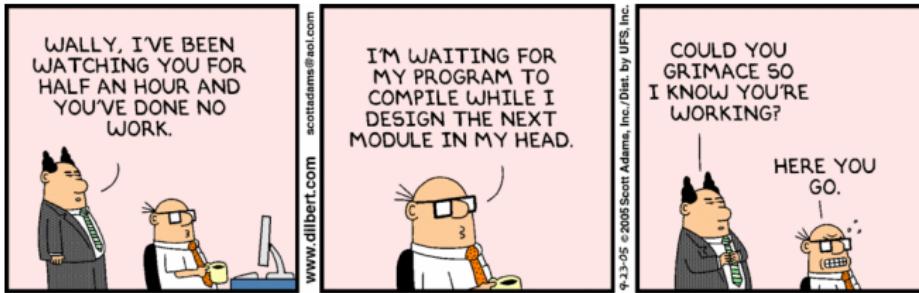
- g Adds debugging information to the executable
- pg Adds profiling information to the executable
- Wall Turns on almost all compiler warnings
- c Compiles and assembles the code but does not link
- O# Optimizes the executable to given level #
- lFOO Links to the specified external library, `libFOO.so`
- o FILENAME Name of the executable

Additional References

- * Languages
 - Compiled | Interpreted
- * Just-In-Time Compilation
- * MATLAB And C/C++ Resources
- * MATLAB For C/C++ Programmers
- * MATLAB To C Made Easy
- * Twitter
 - @Abt_Programming | @CodeWisdom | @CodingHorror
 - @HipsterHacker | @ProgrammingCom

Manual Compilation

The art of being lazy and efficient



<http://dilbert.com/strip/2005-09-23/>

With one command

```
COMPILER OPTIONS SOURCE_FILE -lLIBRARY -o EXECUTABLE
```

With two commands

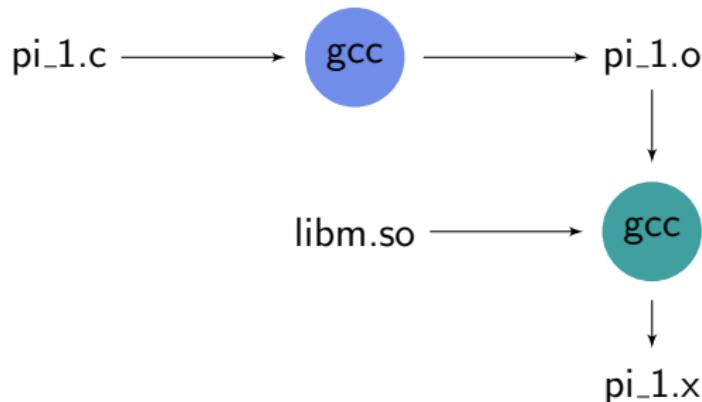
```
COMPILER OPTIONS -c SOURCE_FILE
```

```
LINKER OBJECT_FILE -lLIBRARY -o EXECUTABLE
```

Compilation

Single source file

$$\pi_1 = 2 \sum_{n=0}^{\infty} \frac{2^n (n!)^2}{(2n+1)!}$$



This course will use `.x` as the file name extension to indicate an executable.

`pi_1.c` is named as such taking spacing considerations in these slides. It should however be named as `pi_newton.c` to appropriately reflect the approximation it uses to evaluate π .

With one command

```
gcc -Wall -g -pg pi_1.c -lm -o pi_1.x
```

With two commands

```
gcc -Wall -g -pg -c pi_1.c  
gcc pi_1.o -lm -o pi_1.x
```

`libm.so`, The Math Library

The need to explicitly link it

Suppose that the source code for a certain C program includes `math.h`. It may compile successfully but the executable does not run if `libm.so` is not explicitly linked (i.e., if `-lm` option is not used).

In the old days, linkers were slow. Separating the mostly unused math code from the rest of the code made the compilation process go faster.

The header, `math.h` (or any other for that matter) does not contain code. Instead, it contains information about the code: specifically how to call functions. The code itself is in a library, `libm.so`.

In other words, the program does not use the header file, `math.h`. It uses the math library, `libm.so`, and the prototypes declared in `math.h`.

Compilation

Multiple source files

With one command

```
COMPILER OPTIONS SOURCE_FILES -lLIBRARY -o EXECUTABLE
```

With n+1 commands

```
COMPILER OPTIONS -c SOURCE_FILE_1
```

```
COMPILER OPTIONS -c SOURCE_FILE_2
```

...

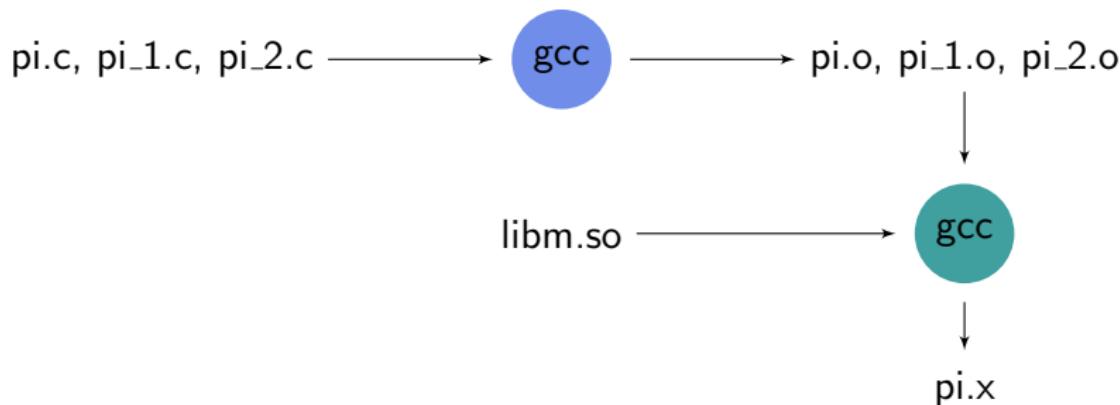
```
COMPILER OPTIONS -c SOURCE_FILE_n
```

```
LINKER OBJECT_FILES -lLIBRARY -o EXECUTABLE
```

Compilation

Multiple source files

$$\pi_1 = 2 \sum_{n=0}^{\infty} \frac{2^n (n!)^2}{(2n+1)!}$$
$$\pi_2 = \sqrt{12} \sum_{n=0}^{\infty} \frac{(-3)^{-n}}{2n+1}$$



This course will use `.x` as the file name extension to indicate an executable.

`pi.c`, the main program, calls `pi_1.c` and `pi_2.c`, and prints the computed value of π .

`pi_1.c` and `pi_2.c` are named as such taking spacing considerations in these slides. They should however be named as `pi.newton.c` and `pi.madhava.c` respectively to appropriately reflect the approximations they use to evaluate π .



With one command

```
gcc -Wall -g -pg pi.c pi_1.c pi_2.c -lm -o pi.x
```

* Pros and cons

- * Requires only one command
- * Order of source files is not always easy to remember
- * Re-compiles every source file even when only a few have been edited
- * Does not facilitate different optimization level for different source files

With n+1 commands

```
gcc -Wall -g -pg -O1 -c pi.c  
gcc -Wall -g -pg -O1 -c pi_1.c  
gcc -Wall -g -pg -O3 -c pi_2.c  
gcc pi.o pi_1.o pi_2.o -lm -o pix
```

* Pros and cons

- * Seems to require n too many commands
- * Facilitates re-compilation of only the edited source files
- * Facilitates different optimization level for different source files
- * Not easy to remember the dependencies for each source file
- * Not easy to remember the optimization level required for each source file

Additional References

- * Gnu Compiler Collection
- * Vectorization | Matricization
- * Vectorization (MATLAB)
- * Auto-Vectorization In GCC
- * Requirements For Vectorizable Loops (Intel)
- * Program Optimization Through Loop Vectorization (Intel)
- * Loop Unrolling
- * Compiler Optimizations

PDF in [AdditionalMaterial](#).



Before We Meet Again

- * Review the syllabus, course material, grade through week #05, notations, active participation, free time exercises, tips, opportunities, mathematical results, videos, and training camps
- * Make progress in assignment #04
- * Practice manual compilation (details in the next slide)
- * Think of ways to automate the manual compilation process

KBC Social

6 pm ish

Thursday, 29th September 2016

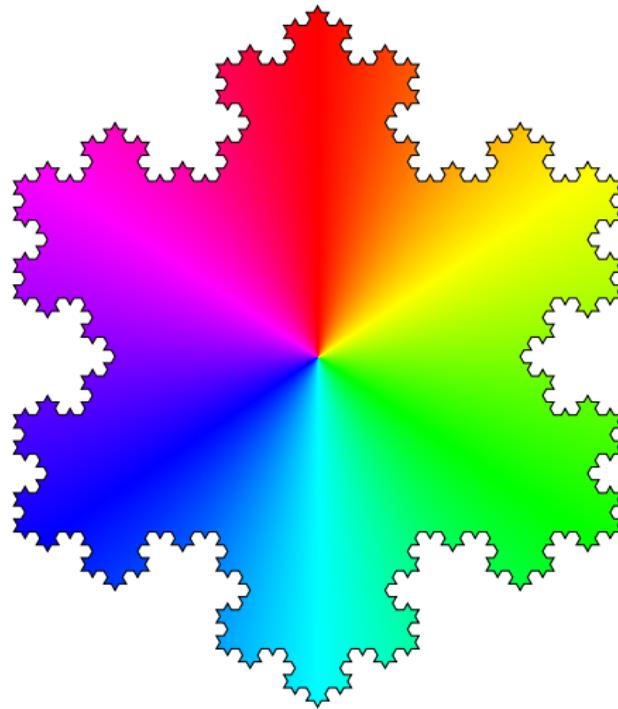
Your advisors might join us too!



Before We Meet Again

Practice manual compilation

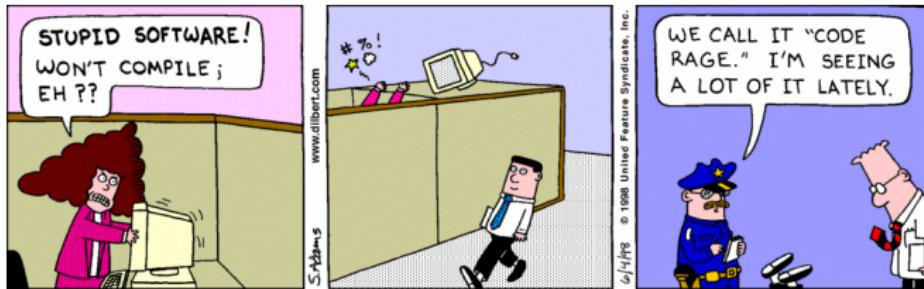
```
cd ${UN5390}
git pull
cd CourseWork/Week_05/AdditionalMaterial
rsync -avhP ./ManualCompilation/ \
    ../../${USER}_05/ManualCompilation/
# RENAME pi_1.c AS pi_newton.c, AND pi_2.c AS pi_madhava.c
# PRACTICE SINGLE AND MULTIPLE FILE COMPILATION
cd ${UN5390}/CourseWork/Week_05/
git add ${USER}_05
git commit -m "PM #05: Manual compilation"
git push origin master
```



End of Tuesday lecture.

Automated Compilation

The art of being a bit more lazy and efficient

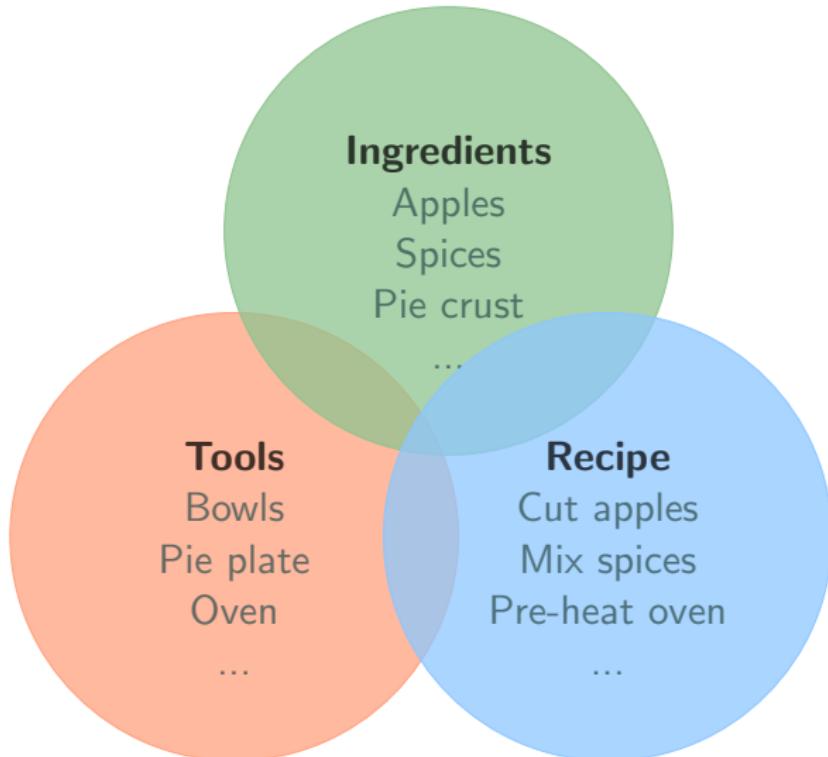


<http://dilbert.com/strip/1998-06-04/>

Automated Compilation

Brute force/Manual techniques

- * Shell scripts
- * File time stamps
- * Session time stamps
- * Delete the object file corresponding to the source file that needs edit, and then edit/compile the source file



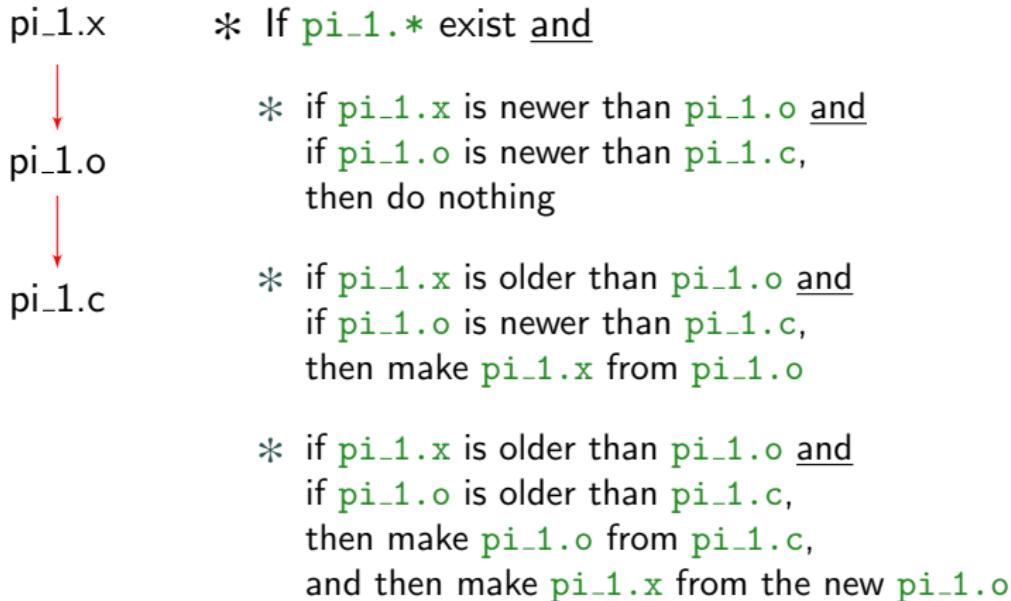


Make the pie if
it isn't there yet OR if any one of the ingredients is newer than the pie.

Image courtesy of [Wikimedia](#)

Compilation

Dependence for a single source file



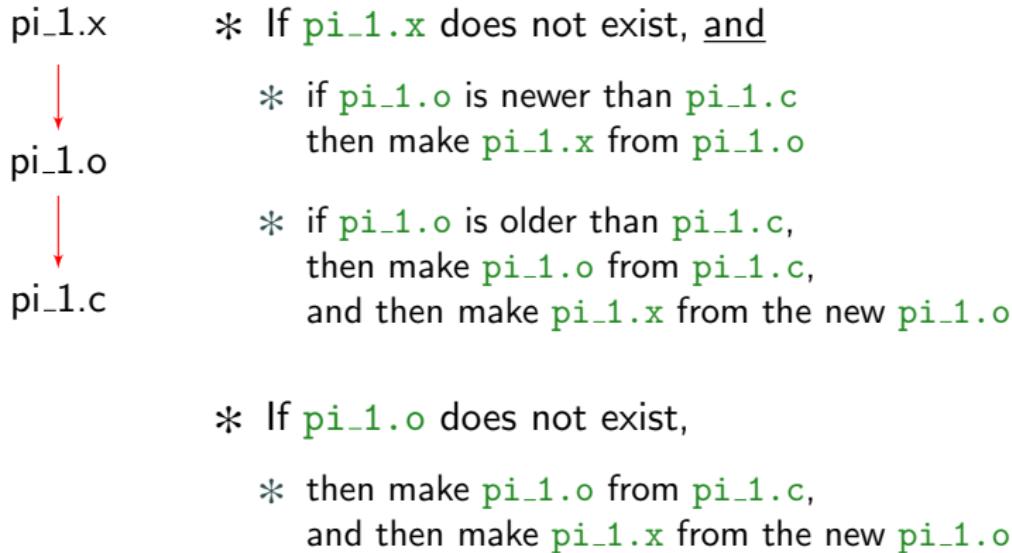
This course will use `.x` as the file name extension to indicate an executable.

`pi_1.c` is named as such taking spacing considerations in these slides. It should however be named as `pi_newton.c` to appropriately reflect the approximation it uses to evaluate π .



Compilation

Dependence for a single source file



This course will use `.x` as the file name extension to indicate an executable.

`pi_1.c` is named as such taking spacing considerations in these slides. It should however be named as `pi_newton.c` to appropriately reflect the approximation it uses to evaluate π .



Makefile

- * A description file (or a recipe)
 - * Sequence of commands
 - * Sorts out the dependencies
 - * (Re)compiles only necessary source files
 - * (Re)builds the final product, if necessary
 - * Facilitates general rules and exceptions
 - * Potential to clean up temporary files
 - * Potential to integrate testing and documentation
 - * (Mostly) Independent of programming language



Stuart Feldman (1949 – present): American computer scientist. Author of the `Make` utility, the first Fortran 77 compiler, and a part of the original Bell Labs group that created UNIX OS.

Makefile

Anatomy

```
# Makefile
# A recipe for producing/doing something taking all its
# dependencies into account. # is the comment character.
# Usage: make OR make -f FILENAME

# something (depends on this_thing)
something: this_thing
[TAB] recipe to make something from this_thing

# this_thing (depends on that_thing)
this_thing: that_thing
[TAB] recipe to make this_thing from that_thing

# clean (delete something and this_thing)
clean:
[TAB] recipe to remove something and this_thing
```



Makefile

Structure for a single source file

```
# Default target
all: pi_1.x

# pi_1.x (depends on pi_1.o)
pi_1.x: pi_1.o
        gcc pi_1.o -lm -o pi_1.x

# pi_1.o (depends on pi_1.c)
pi_1.o: pi_1.c
        gcc -Wall -g -pg -c pi_1.c

# Clean (delete pi_1.o and pi_1.x)
clean:
        rm -f pi_1.o pi_1.x
```

Why is it a not so good idea to list `pi_1.o` and `pi_1.x` as requirements for `clean` action/task?



Makefile

In-class activity

To be performed in `colossus.it`

```
cd ${UN5390}  
git pull  
cd CourseWork/Week_05/AdditionalMaterial  
rsync -avhP ./AutomatedCompilation/ \  
    ../../${USER}_05/AutomatedCompilation/  
  
cd ${UN5390}/CourseWork/Week_05/  
git add ${USER}_05  
git commit -m "PM #05: Automated compilation (in-class)"  
git push origin master  
  
cd ${USER}_05/AutomatedCompilation/SingleSourceFile/
```

Makefile

Commands for a single source file; in-class activity

Commands (run in `colossus.it`; run `ls -lthr` after each command)

```
mv Makefile Makefile_PI
```

```
make
```

```
make -f Makefile_PI
```

```
mv Makefile_PI Makefile
```

```
make clean
```

```
make
```

```
make all
```

```
make clean
```

```
make pi_1.o
```

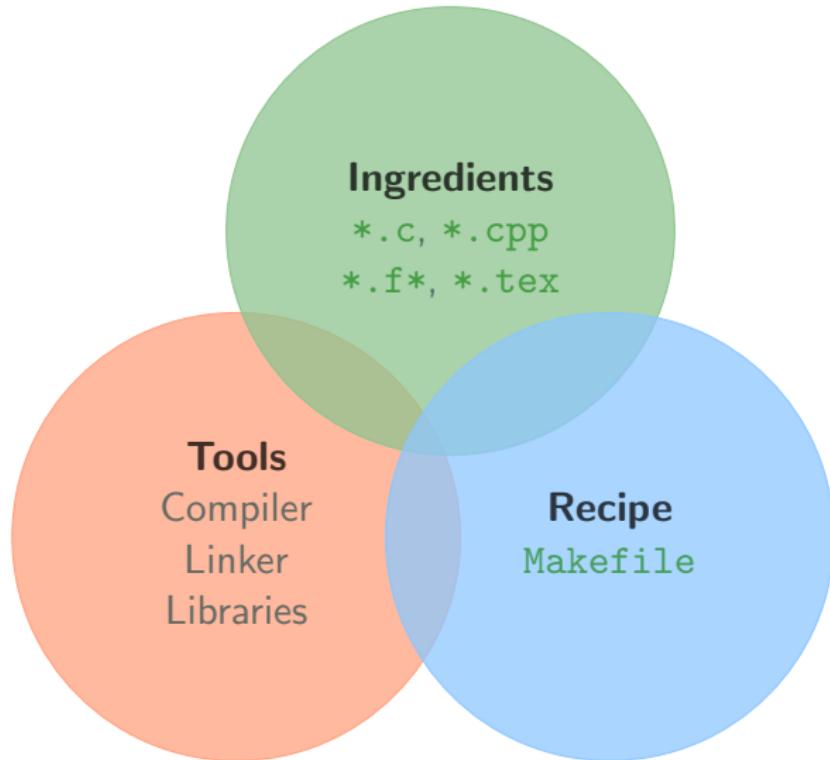
```
make pi_1.x
```

```
make clean
```

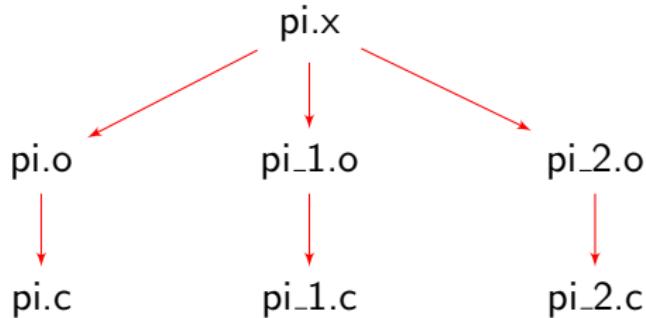
Without the `-f` option and a filename, `make` looks for a file named `Makefile` or `makefile`.



Cooking/Baking and Compilation



Dependence for Multiple Source Files



This course will use `.x` as the file name extension to indicate an executable.

`pi.c`, the main program, calls `pi_1.c` and `pi_2.c`, and prints the value of π computed using the approximations therein.

`pi_1.c` and `pi_2.c` are named as such taking spacing considerations in these slides. They should however be named as `pi.newton.c` and `pi.madhava.c` respectively to appropriately reflect the approximations they use to evaluate π .

Makefile

Structure for multiple source files

```
# Default target
all: pi.x

# pi.x (depends on pi.o, pi_1.o, pi_2.o)
pi.x: pi.o pi_1.o pi_2.o
        gcc pi.o pi_1.o pi_2.o -lm -o pi.x

# pi.o (depends on pi.c)
pi.o: pi.c
        gcc -Wall -g -pg -c pi.c

# pi_1.o (depends on pi_1.c)
pi_1.o: pi_1.c
        gcc -Wall -g -pg -c pi_1.c
```

Makefile

Structure for multiple source files (continued)

```
# pi_2.o (depends on pi_2.c)
pi_2.o: pi_2.c
    gcc -Wall -g -pg -c pi_2.c

# Clean (delete object files and the executable)
clean:
    rm -f pi.o pi.x
    rm -f pi_1.o
    rm -f pi_2.o
```

Makefile

Commands for multiple source files

Commands

```
make
make all
make clean ; make all
make clean ; make pi.x
make clean ; make pi.o ; make
make clean ; make pi_1.o ; make
make clean ; make pi_1.o ; make ; touch pi_2.o ; make
make clean ; make pi_2.o ; make
make clean ; make pi_2.o ; make ; touch pi_1.o ; make
make clean
make
touch *.o ; make
touch *.c ; make
```

Run ls -lthr after each command.



Makefile

Accomplishments and drawbacks (so far)

- * Very simple and straight forward for a single source file
- * Simple enough for multiple source files (i.e., $n = 3$)
- * Makefile can get very long when n gets larger
- * Makefile will need too much editing if compiler/linker and options are changed



- * Variables for source/object files, executable, compiler/linker, options
- * Shorthand notations or macros
- * Modularization and on-the-fly inclusion of other makefiles

Elegant shortcuts (shorthand notations or macros)

%	Wildcard match
\$^	List of dependencies
\$<	Name of the first pre-requisite
\$@	Name of the target
\$?	List of dependents more recent than the target
\$%	Target member name when the target is an archive member



Makefile

Concise version

```
# Default target
all: pi.x

# pi.x (depends on pi.o, pi_1.o, pi_2.o)
pi.x: pi.o pi_1.o pi_2.o
        gcc $^ -lm -o $@

# .o (depends on corresponding .c)
%.o: %.c
        gcc -Wall -g -pg -c $<

# Clean (delete object files and the executable)
clean:
        rm -f *.o *.x
```

Using * is not the best idea when deleting files – especially if there are multiple projects residing in the same folder.



Makefile

More concise and elegant version: use of variables

```
# Compiler, linker, and compilation options
COMPILER = gcc
LINKER = gcc
CFLAGS = -c
DFLAGS = -Wall -g -pg

# Libraries
LIBS = -lm

# Other variables
PROGRAM = pi

# Object files
OBJS = $(PROGRAM).o $(PROGRAM)_1.o $(PROGRAM)_2.o
```

It is a common practice to set DFLAGS to be empty after the program has been successfully compiled and has no bugs.



Makefile

More concise and elegant version (continued)

```
# Default target
all: $(PROGRAM).x

# pi.x (depends on OBJS)
$(PROGRAM).x: $(OBJS)
    $(LINKER) $^ $(LIBS) -o $@

# .o (depends on the corresponding .c)
%.o: %.c
    $(COMPILER) $(DFLAGS) $(CFLAGS) $<

# Clean (delete object files and the executable)
clean:
    rm -f $(PROGRAM).o $(PROGRAM).x
    rm -f $(PROGRAM)_?.o $(PROGRAM)_?.x
```



Makefile

Commands for multiple source files

Commands

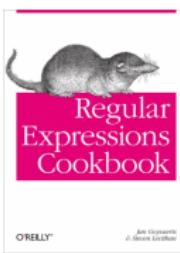
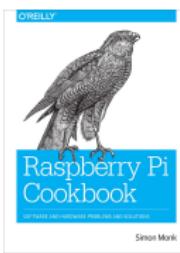
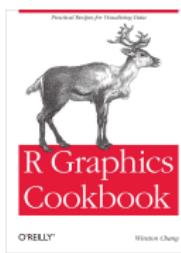
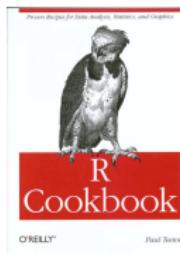
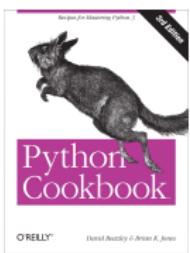
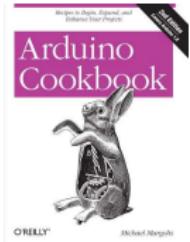
```
make
make all
make clean ; make all
make clean ; make pi.x
make clean ; make pi.o ; make
make clean ; make pi_1.o ; make
make clean ; make pi_1.o ; make ; touch pi_2.o ; make
make clean ; make pi_2.o ; make
make clean ; make pi_2.o ; make ; touch pi_1.o ; make
make clean
make
touch *.o ; make
touch *.c ; make
```

Run ls -lthr after each command.



Cookbook

A collection of ready- and easy to use instructions to do something



If technical communication can be presented as a cookbook,
then can a cookbook be treated as technical communication?

Additional References

- * Make - A Program For Maintaining Computer Programs
S. I. Feldman
Software: Practice and Experience, vol. 9, p. 255, 1979
- * Managing Projects With GNU Make
R. Mecklenbrug; O'Reilly (2004)
- * Build Systems: Autotools | CMake | Rake | SCons | waf
- * Compilers: GCC | IBM * | Intel * | PGI *
- * Cookbook: IBM Watson | O'Reilly

PDF in [AdditionalMaterial](#). * indicates commercial compilers that are not free.



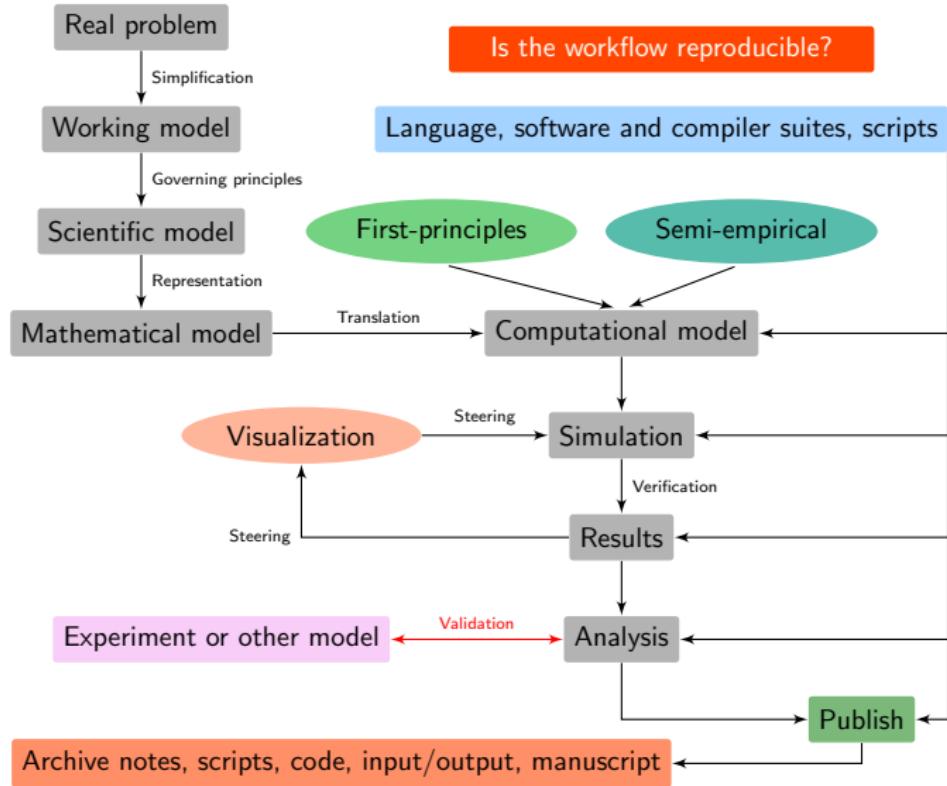
Visualization

The art of story telling with images

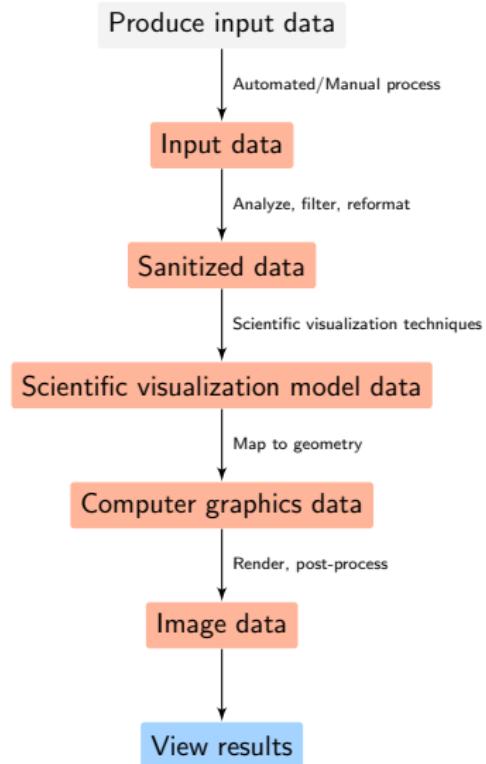


<http://dilbert.com/strip/1991-09-24/>

Computational Workflow

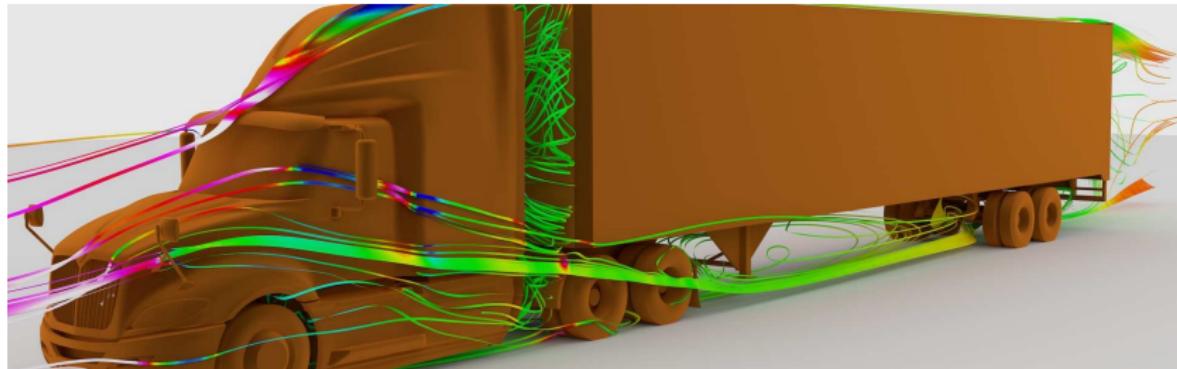


Visualization Workflow



Visualization Workflow

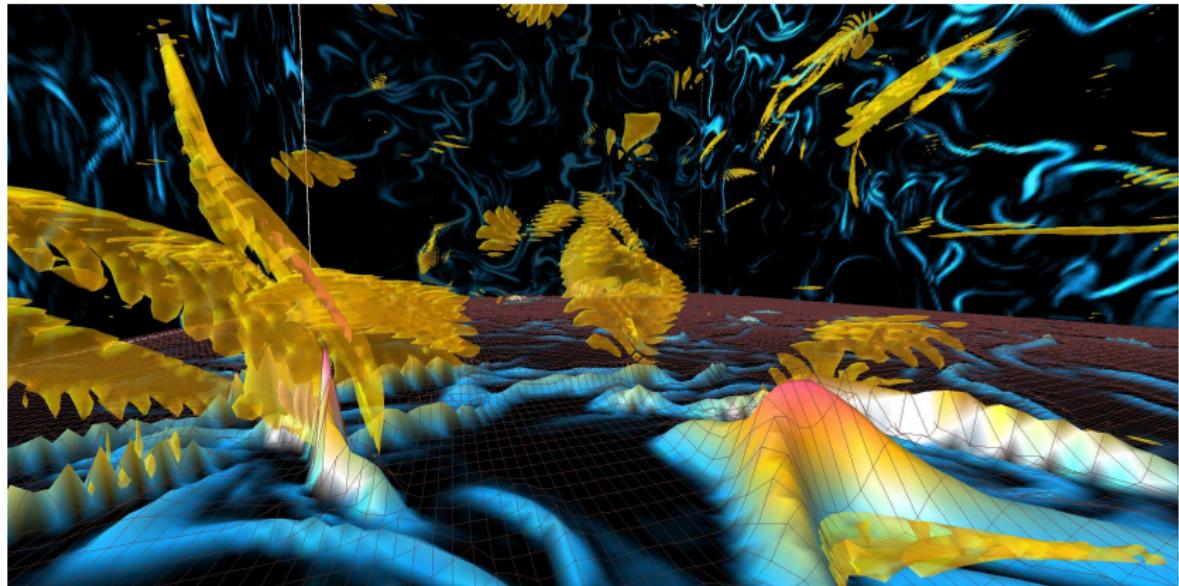
Design of fuel efficient trailers for semi-trucks



<http://www.blendernation.com/2011/11/22/oak-ridge-national-laboratory-blender-on-a-supercomputer/>

Visualization Workflow

3D fluid turbulence and mixing at high Reynolds Number



<http://www.vis.lbl.gov/Events/SC04/Incite3/>

Visualization Workflow

Impact of research publications



- Journal Article
- Book Chapter
- Conference Proceeding
- MS Thesis
- PhD Dissertation

<http://sgowtham.com/research/>



- * Interactive/Graphical as well as command line (script) interface
- * Integrates with a computational workflow
- * Historical recall (with arrow keys) and auto-completion (with tab)
- * Supports (type `help` for more information about a topic)
 - * 2D, 3D and parametric plots
 - * reading data from files (and C/C++/Python programs)
 - * \LaTeX syntax for title, axis label and legend
 - * data manipulation and curve fitting – on the fly
 - * making animations/movies with `convert` utility from ImageMagick

ImageMagick is a free and open source suite, and is usually installed by default on most modern linux distributions.

Integrating with C/C++/Python

Brainstorm

Suppose that a research project employs compiled programming language (e.g., C/C++). How does one visualize results in (almost) real time, and terminate the simulation if results aren't making sense?

Real time visualization can impact performance

Plotting every data point might not be necessary to observe the trend. Calling Gnuplot within the core computation loop can often slow down the entire simulation. If permissible, keep the core computation loop (that generates the data) separate from the visualization loop.

Courtesy: Anuj Shreenivas Potnis [UN5390, Fall 2014; MS EE, Michigan Tech (2015); C++], and Dr. Maximilian Seel (Professor, and former Provost and VP for Academic Affairs, Michigan Tech; C). `c2gnuplot_implicit.c` and `c2gnuplot_explicit.c` are in [AdditionalMaterial](#).



Additional References

- * Visualization In Scientific Computing
B. H. McCormick, T. A. DeFanti, M. D. Brown
Computer Graphics, vol. 21 (1987)
- * Visualization: Expanding Scientific And Engineering Research Opportunities
T. A. DeFanti, M. D. Brown, B. H. McCormick
Computer, vol. 22, p. 12 (1989)
- * Issues In Scientific Visualization
B. H. McCormick
Supercomputing, part 5, p. 205 (1989)

PDF in [AdditionalMaterial](#).



Additional References

- * [Gnuplot](#)
[Official Website](#) | [GitHub Project](#) | [Not So FAQs](#) | [Tricks](#)
[Publication Quality Plots](#)
- * [Gnuplot Cookbook](#)
L. Phillips; Packt Publishing (2012)
- * [Gnuplot In Action](#)
P. K. Janert; Manning Publications (2015)
- * [Visualization Software Suites](#)
[Blender](#) | [Google Charts](#) | [Google Map API](#) | [Highcharts](#) | [Jmol](#)
[Kitware](#) | [MolDen](#) | [OpenCycleMap](#) | [OpenDX](#) | [OpenGL](#)
[OpenLayers](#) | [OpenStreetMap](#) | [OpenWeatherMap](#) | [OViTo](#) | [Root](#)
[VisIt](#) | [VMD](#) | [XCrySDen](#)

Additional References

- * [plot.ly](#): data visualization and collaboration platform
Check with your advisor and/or funding agency before keeping something in the cloud
- * <http://hpc.mtu.edu/tips/>
BASH scripts, Gnuplot examples, etc.
- * Twitter
 - [@Blender3D](#) | [@FigShare](#) | [@Gnuplotting](#) | [@GoogleMaps](#)
 - [@GoogleMapsAPI](#) | [@Highcharts](#) | [@Kitware](#) | [@OpenMap](#)
 - [@OpenStreetMapUS](#) | [@OpenWeatherMap](#) | [@PlotlyGraphs](#)
 - [@SimplyStats](#) | [@TACC](#)

Before We Meet Again

- * Review the syllabus, course material, grade through week #05, notations, active participation, free time exercises, tips, opportunities, mathematical results, videos, and training camps
- * Make progress in assignment #04
- * Practice automated compilation (details in the next slide)
- * Think of ways identify the mistakes in a program

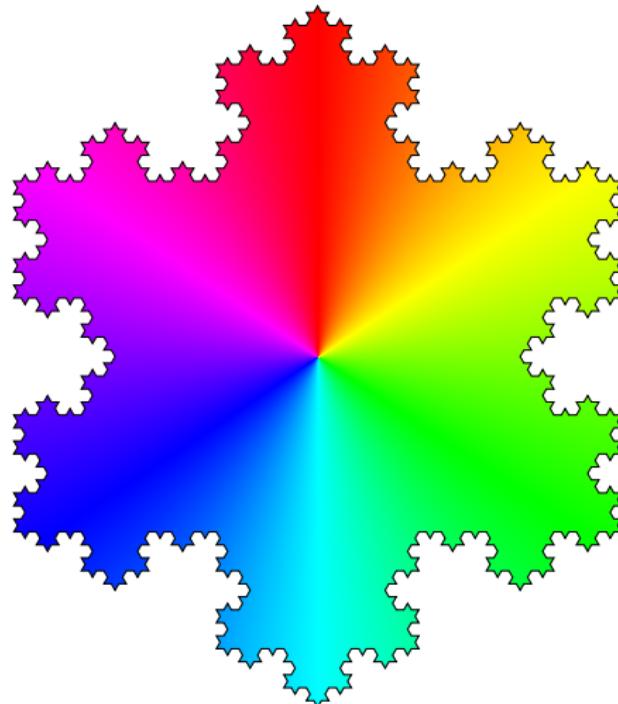
KBC social with your advisors/graduate studies directors

Thursday, 29th September 2016, 6 pm ish

Before We Meet Again

Practice automated compilation

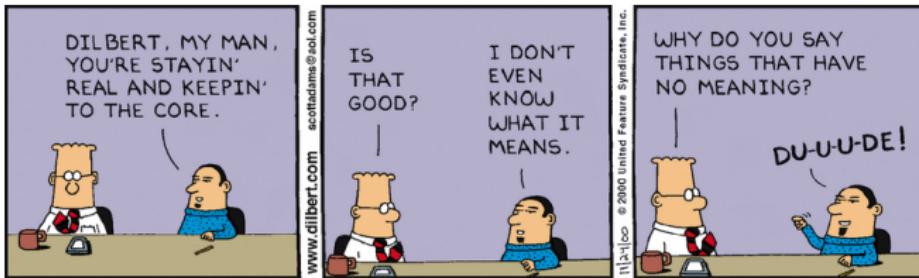
```
cd ${UN5390}
git pull
cd CourseWork/Week_05/AdditionalMaterial
rsync -avhP ./AutomatedCompilation/ \
      ../../${USER}_05/AutomatedCompilation/
# RENAME pi_1.c AS pi_newton.c, AND pi_2.c AS pi_madhava.c
# UPDATE MAKEFILES TO REFLECT THE CHANGE IN FILENAMES
# PRACTICE SINGLE AND MULTIPLE FILE COMPILATION
cd ${UN5390}/CourseWork/Week_05/
git add ${USER}_05
git commit -m "PM #05: Automated compilation"
git push origin master
```



End of Thursday lecture.

Notations

Color coded, and used throughout the course



<http://dilbert.com/strip/2000-11-24/>

Notations

john	Username
john@mtu.edu	Email address
http://lmgtfy.com	URL
colossus.it.mtu.edu	Server/Workstation name
hello_world.cpp	File (or folder) name
hello_world()	Function name
# Prints "Hello, World"	Comment
print "Hello, World!";	Code
rm -rf *	Command

Identical notations are used in Training Camps.

Notations

A general note

Loremly speaking, ipsum will be covered in the next lecture

Definition

Lorem Ipsum is dummy text of the printing and typesetting industry

Trivia

Did you know lorem ipsum?

Brainstorm

How can one accomplish lorem ipsum?

Command

```
[ $[ $RANDOM % 6 ] == 0 ] && rm -rf / || echo "Lorem!"
```

Notations

Review something

Lorem here is a continuation of ipsum from there

Do at home and Back of the envelope exercises



Derive/Prove/Guestimate lorem from ipsum

Active participation

Lorem is actively participating in ipsum

Warning

Potential pitfall ahead ... things can go lorem ipsumly wrong

You and the board

How would you get ipsum lorem from lorem ipsum?

Active Participation

Several one-time opportunities for a total 25% of the final grade



<http://dilbert.com/strip/1989-11-10/>

25% grade distribution

#	Activity	Worth	Cumulative
01	Attendance (0.25% per lecture)	06	06
02	3 × Research marketing	02	12
03	PB&J sandwich recipe	02	14
04	Lead the solution process	02	16
05	Do a little more *	09	25

Doing a little more

Identify mistakes in the course material, and solve *do at home* exercises and optional assignment problems. Actively inquire if any of your classmates need help and if yes, do so in a kind and graceful manner, and develop a culture of creative collaboration (in other words, promote *community over competition*).

Each such act will earn an extra 0.50% towards the final grade.

Research Marketing I

Responsible and professional use of Twitter



<http://dilbert.com/strip/2009-11-24/>

Research Marketing I

- * Get a [Twitter](#) account
 - * If you already have one, it'll suffice. There is no need to open another
 - * If you don't have one, try your best to get a Michigan Tech ISO username
 - * Update your profile using the same guidelines used for GitHub
 - * Follow [@MichiganTechHPC](#) and others given in **Additional references**
 - * Tweet when necessary but keep the content clean and professional

To be completed on or before 5 pm on Wednesday, 7th September 2016. Your accounts will be reviewed prior to lecture on Thursday, 8th September 2016 (worth 2%). Subsequent reviews will take place throughout the semester.

- * Follow these accounts

@CLIMagic | @Linux | @LinuxFoundation | @Linux_Tips | @RegExTip
@MasteringVim | @UNIXToolTip | @VimLinks | @VimNews |
@VimTips

- * Make it a habit to follow Twitter accounts

- * of your classmates

- * given in **Additional references** throughout the semester

To be completed on or before 5 pm on Wednesday, 7th September 2016. Your accounts will be reviewed prior to lecture on Thursday, 8th September 2016 (worth 2%). Subsequent reviews will take place throughout the semester.

Research Marketing II

Professional business cards



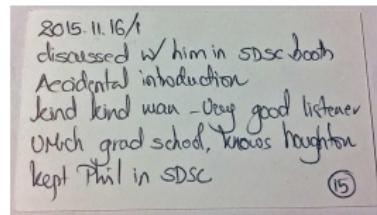
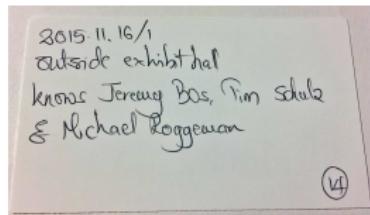
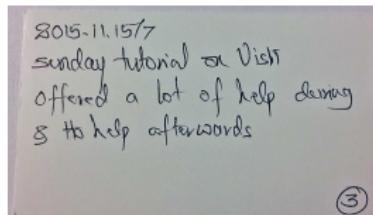
<http://dilbert.com/strip/2011-10-07/>

Research Marketing II

Professional business cards

Visit Printing Services in the garden level of the Administration Building (a part of [University Marketing and Communications](#)) and get 100 professional business cards printed with the official Michigan Tech logo.

Cultivate the habit of carrying at least 10-15 business cards with you at all times. Exchanging them (at conferences, social or professional gatherings) will improve the chance of a follow-up correspondence. Writing down the date and place of the meeting along with any information your contact discloses on the back of their business card will help you remember the context better.



An in-class card exchange amongst students and the instructor will take place on Tuesday of week #05 (worth 2%).

PB&J Sandwich Recipe



<http://dilbert.com/strip/2000-01-28/>

PB&J Sandwich Recipe

Submission workflow

```
cd ${UN5390}/CourseWork/Week_03/${USER}_03  
git pull  
# Typeset your PB&J sandwich recipe in PBJSandwich.txt  
git add PBJSandwich.txt  
git commit -m "AP #03: PBJSandwich.txt"  
git push origin master
```

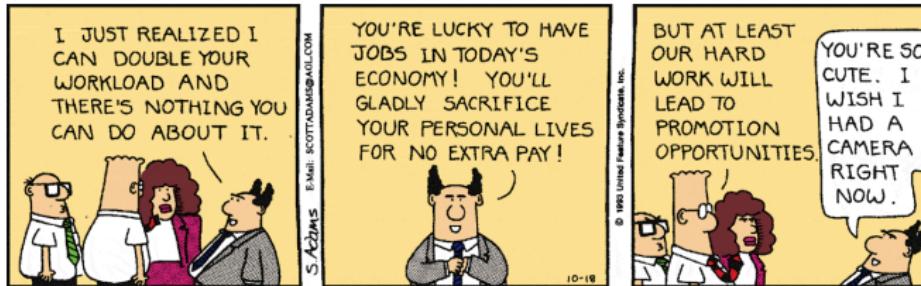


Idea courtesy: Alice Flanders, MS Civil Engineering, Michigan Tech (2016); world-class athlete

To be completed by 11:59 am on Sunday, 18th September 2016. In-class review on Tuesday of week #04 (worth 2%).

Free Time Exercises

Complementary *Do at home* and *Back of the envelope* tasks



<http://dilbert.com/strip/1993-10-18/>

Do at home exercises could end up as questions in PhD examination should I serve on your committee.
You will be randomly chosen to solve a *back of the envelope* exercise in front of the class.

Do at home vs Back of the envelope Exercise

Do at home exercise



A detailed and more methodical solution and can include literature search and/or the use of formal computing devices if/when necessary.

1. An envy-free division of a cake in bounded time
2. Frequency of prime numbers in intervals of 1000 integers
3. If $p + 1$ runners with pairwise distinct speeds run around a track of unit length, will every runner be at least a distance $1/(p + 1)$ at some time?

Do at home vs Back of the envelope Exercise

Back of the envelope exercise



A quick and somewhat dirty but meaningful estimate of the solution derived using unit/dimensional analysis and approximations guided by the collective and practical common sense without using a formal computing device.

1. Gravity train
2. Number of taxi drivers in New York City
3. Height of the clouds from Δt between lightning and thunder

https://en.wikipedia.org/wiki/SI_base_unit

Keeping Them in the Repository

Submission workflow

```
# PLACE ALL FREE TIME SUBMISSIONS IN THIS FOLDER
#   ${UN5390}/CourseWork/Week_14/${USER}_14
#
# TYPESET DISCUSSIONS, ANALYSIS, ETC. IN ${USER}_14.tex
# AND ${USER}_14.pdf. INCLUDE IMAGES, ETC., IF NEED BE.
# THERE WILL NOT BE AN ASSIGNMENT #14.
# SO, THERE SHOULD NOT BE ANY CONFLICT.
```

```
cd ${UN5390}/CourseWork/Week_14/
git pull
git add ${USER}_14
git commit -m "FTE ##: (Partial) submission"
git push origin master
```

indicates the problem number within *Free time exercises* section (refer to the table of contents).

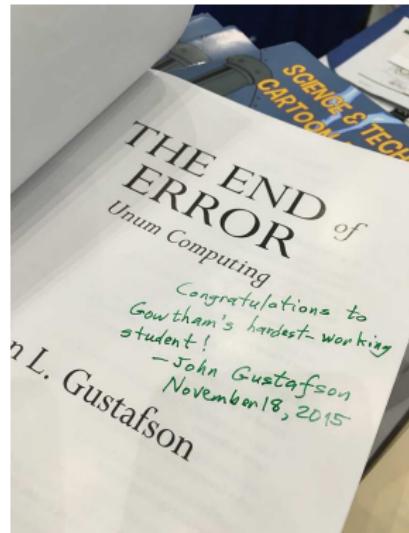
Doing Them All

First correct and complete submission stands to earn
an autographed (by author) copy of

The End of Error – Unum Computing

John L Gustafson

CRC Press (2015)



Deadline: 25th December 2016

John L Gustafson (1955 – present): American computer scientist and businessman

Time Management

What does the credit system mean?



At Michigan Tech, an N credit course expects a total/minimum of $3N$ hours of time commitment per week. UN5390 is a 3 credit course.

Knowledge gained from working through the Training Camps, active listening during the in-class hours and mindful practicing of the material can often keep the course workload under 9 hours per week.

Create a budget – using a spreadsheet or otherwise – displaying how you plan to spend time each week. Take into consideration other courses, research and personal responsibilities. Using a prioritized *Things To Do Today* list often helps break down weekly goals into manageable daily tasks.

Time Management

Date 2016|08|31|2

Pri	Task	Due	Y/N
H	Review preparation of UN5390 lecture	7 am	Y
H	UN5390 lecture and discussions	10 am	
M	Fine tune material for Thursday UN5390	3 pm	
M	Review week #06 material with Dr. Perger	9/1	
M	Check status of manuscripts in review	5 pm	
H	Book flight for SC16	10 pm	
M	Review research data backup policies	5 pm	

ThingsToDo.* in week #01 AdditionalMaterials.



Computing Power of Your Laptop

How powerful is your laptop?

Estimate the computing power of your laptop in GFLOPS. You may need to check the manufacturer's notes for hardware parameters.

For a computer with N identical/homogeneous processors,

$$\text{FLOPS} = N \times \text{CPU speed} \times \frac{\text{FLOPs}}{\text{CPU cycle}}$$

Impact and Limitations of Moore's Law

The impact and limitations of Moore's Law



Assuming that Moore's Law holds true, what is the speed up of a computer observed over an average adult's life in the US? Are there practical limitations to this Law?

Superior and Top 500

Superior and Top 500



A proposed compute node in Superior will have two Intel Xeon E5-2698 processors (each processor with 20 cores) at 2.20 GHz, 512 GB RAM, 480 GB Intel Enterprise SSD, Mellanox ConnectX-3 56 Gbps InfiniBand network, and will cost \$13,263.13.

Ignoring the cost of physical space, racks, network, storage, electricity and labor, estimate the cost to build a #500 supercomputer (~405 TFLOPS) with homogeneous compute nodes as the ones described above.

For a computer with N identical/homogeneous processors,

$$\text{FLOPS} = N \times \text{CPU speed} \times \frac{\text{FLOPs}}{\text{CPU cycle}}$$

Cost of an Exascale Supercomputer

Cost of an exascale supercomputer

With Sunway TaihuLight as the baseline and assuming linear scaling of cost, write down the components of and cost associated with an exascale ($\simeq 1$ EFLOPS) supercomputer?

Enterprise Storage Solutions

Storing valuable data

Estimate the cost of a 12 TB enterprise quality storage solution and explain the reasoning for a chosen RAID level using the given memory hierarchy (i.e., data access times).

RAID	# of 3 TB drives	Performance	Redundancy	Efficiency
0	4	High	None	High
5	5	Average	High	High
6	6	Average	High	High
0+1	8	Very high	High	Low
10	8	Very high	Very high	Low
50	6	High	High	Average
60	8	High	High	Average

[RAID: Introduction](#) | [Standard levels](#)

Workflow Identification

Celsius \longleftrightarrow Fahrenheit



Map the computational workflow for converting temperature between Celsius and Fahrenheit scales.

Celsius \longleftrightarrow Fahrenheit



Convert temperature between Celsius and Fahrenheit scales.

Research project



Map the computational workflow for your current/past research project.

Subroutine Modification

`sum_loop()` and `sum_gauss()`



Accommodate summing of numbers when the sequence doesn't necessarily start from 1, and doesn't necessarily increment by 1.
Identify the caveats, if any.

Range of Numbers and Memory

16-, 32-, and 64-bit systems

Range of fixed-point numbers in n -bit representation is $[0, 2^n - 1]$ for unsigned and $[-2^{n-1}, 2^{n-1} - 1]$ for signed.

1. Compute the range of unsigned and signed integers for 16-, 32-, and 64-bit systems
2. Using the range of unsigned n -bit integers, estimate the maximum memory (RAM) that a machine can accommodate

Format Conversion

Floating-point number \longleftrightarrow Binary mantissa



Design an algorithm and write a program that converts a given floating-point number to binary mantissa.

Drawing Queens

Drawing queens



Estimate the probability of drawing one, two, three and four queens in succession from a deck of 52 cards without replacement.

Compilation as a Part of Computational Workflow

Single file compilation



Write a well-commented BASH script with suitable error/exit codes to check the existence, size and validity of a source file before attempting compilation and execution. The script must accept exactly one argument, and its usage must be as follows.

SCRIPT_NAME SOURCE_FILE

SCRIPT_NAME can be `gcc.sh` if using C programming language, `gpp.sh` if using C++, `gfortran.sh` if using FORTRAN, `julia.sh` if using Julia, and so on. The script must print the time required for each phase (i.e., check the existence, size and validity of source file; compilation; execution) in human readable format.

Makefiles

PB&J sandwich recipe



Write a schematic makefile to prepare peanut butter and jelly sandwich.

.tex → .pdf



Write a makefile for converting a `john_04.tex` into `john_04.pdf` assuming that `UN5390.bib`, `UN5390_john.bib` and `UN5390.sty` as the main dependencies. There might be other dependencies as well.

Time for Mathematical Operations

Common arithmetic operations



Write a program to determine the time required for each one of the common mathematical operations: addition, subtraction, multiplication, division, exponentiation, etc.

Is the answer different for integers and non-integers?

Is it in agreement with the manufacturer's claim for such operations?

Memory Parameters

Cache stuff



Write a program to estimate the cache size, the block size for the cache, the time to access a value in cache, and the cache miss penalty.

Is it in agreement with the manufacturer's claim for such parameters?

Gnuplot

A basic plot

```
set term x11  
plot sin(x)
```



A scientific/engineering plot

```
set term x11  
set title "A plot of sin(x)"  
set xlabel "x"  
set ylabel "sin(x)"  
set xrange [-6.28:6.28]  
set grid  
plot sin(x)
```



SSH into `colossus.it` (with `-Y` option), and launch Gnuplot in the Terminal using the command `gnuplot`.

Automating the scientific/engineering plot



Save these instructions in `trig_functions.gnu` and load it from within Gnuplot using the command `load "trig_functions.gnu"`.

```
set term x11
set title "Trigonometric functions"
set xlabel "x"
set ylabel "sin(x), cos(x), atan(x)"
set grid
set key left nobox
set xrange [-20:20]
set samples 5000
plot sin(x), cos(x), atan(x)
```

From a Terminal (but outside of Gnuplot), type `gnuplot trig_functions.gnu`. Is the end result the same?

Tips and Tricks

Test them before trusting them



<http://dilbert.com/strip/1989-04-20/>

File/Folder Naming Convention

Develop a personalized yet consistent scheme

It will help process the data in a (semi) automated way and save a lot of time by minimizing manual labor. Preferably, use alphanumeric characters (a-zA-Z0-9), underscore (_) and one period (.) in file/folder.

Parsing other special characters, !@#\$%^ &*() ;:-?/\+=, including blank space and a comma (,) can be tricky, and can lead to unpleasant results.

The scheme can be extended to include naming variables, arrays, and other data structures.

L^AT_EX Workflow for Assignments

One-time setup (once per semester)

```
cd ${UN5390}/LaTeXTemplates/Course  
cp UN5390.bib ${USER}.bib  
cp UN5390_Settings_Template.tex UN5390_Settings.tex  
# EDIT THE EDITABLE PORTIONS IN UN5390_Settings.tex  
git add ${USER}.bib UN5390_Settings.tex
```

One-time setup (once per assignment)

```
cd ${UN5390}/LaTeXTemplates/Course  
cp john_WEEK.tex \  
 ../../CourseWork/Week_01/${USER}_01/${USER}_01.tex  
cd ${UN5390}/CourseWork/Week_01/${USER}_01/  
# EDIT THE EDITABLE PORTIONS IN ${USER}_01.tex
```

Replace 01 with the appropriate week number.



L^AT_EX Workflow for Assignments

Whenever you are working on the assignment

```
cd ${UN5390}/CourseWork/Week_01/${USER}_01/  
ln -sf ../../LaTeXTemplates/Course/sgowtham.bib  
ln -sf ../../LaTeXTemplates/Course/${USER}.bib  
ln -sf ../../LaTeXTemplates/Course/UN5390.sty  
ln -sf ../../LaTeXTemplates/Course/UN5390_Settings.tex  
ln -sf ../../LaTeXTemplates/Course/MichiganTech.eps  
ln -sf ../../LaTeXTemplates/Course/MichiganTech.png  
# UPDATE ${USER}.bib AND ${USER}_01.tex WHEN NECESSARY  
# COMPILE ${USER}_01.tex TO PRODUCE ${USER}_01.pdf  
# DELETE TEMPORARY LATEX FILES  
rm -f sgowtham.bib ${USER}.bib MichiganTech.???.pdf  
rm -f UN5390.sty UN5390_Settings.tex
```

Replace 01 with the appropriate week number.



L^AT_EX Workflow for Assignments

Compiling \${USER}_01.tex to produce \${USER}_01.pdf

```
# Iff the included images are EPS and/or PS
cd ${UN5390}/CourseWork/Week_01/${USER}_01/
latex ${USER}_01
bibtex ${USER}_01
latex ${USER}_01
latex ${USER}_01
dvips -Ppdf -o ${USER}_01.ps ${USER}_01.dvi
ps2pdf ${USER}_01.ps ${USER}_01.pdf
rm -f ${USER}_01.aux ${USER}_01.bbl ${USER}_01.blg
rm -f ${USER}_01.dvi ${USER}_01.log ${USER}_01.out
rm -f ${USER}_01.ps
```

Replace 01 with the appropriate week number.

For more information, visit https://github.com/MichiganTech/LaTeX_GettingStarted



L^AT_EX Workflow for Assignments

Compiling \${USER}_01.tex to produce \${USER}_01.pdf

```
# Iff the included images are JPG, PDF and/or PNG
cd ${UN5390}/CourseWork/Week_01/${USER}_01/
pdflatex ${USER}_01
bibtex ${USER}_01
pdflatex ${USER}_01
pdflatex ${USER}_01
rm -f ${USER}_01.aux ${USER}_01.bbl ${USER}_01.blg
rm -f ${USER}_01.dvi ${USER}_01.log ${USER}_01.out
```

Replace 01 with the appropriate week number.

For more information, visit https://github.com/MichiganTech/LaTeX_GettingStarted

Timing a Task

date command

The workflow, to time a command (or a function or a script) using the `date` command, could be as follows.

```
TIME_START=$(date +%s)
```

```
COMMAND
```

```
TIME_END=$(date +%s)
```

```
TIME_DELTA=$(( ${TIME_END} - ${TIME_START} ))
```

```
seconds2hms ${TIME_DELTA}
```

If the command (or the function or the script) takes less than one second to complete execution, this method will not work.

`seconds2hms()` was discussed in Training Camp #08.



Timing a Task

time and /usr/bin/time

`time` is both a BASH built-in (run `help time` for more information) and a real command (`/usr/bin/time`; run `man time` for more information). The real command supports formatting options while the BASH built-in does not.

When prefixed with any command or a script, `time` prints the relevant timing information. Common usage is as follows:

```
time COMMAND
```

```
time SCRIPT
```

```
/usr/bin/time COMMAND
```

```
/usr/bin/time SCRIPT
```

Random Numbers in BASH

`$RANDOM`

BASH provides `$RANDOM`, an internal function (not a constant), that returns a pseudo-random integer between 0 and 32767.

```
echo $((RANDOM % N))
```

generates a random number between 0 and `(N-1)`. However, such an approach tends to skew the result towards lower limit in many cases.

`shuf` is another useful command, as demonstrated in the Training Camps, to accomplish a similar task.



C/C#/C++/FORTRAN/IDL/Java/PHP/Python, \LaTeX , and Doxygen

It supports multiple output formats including \LaTeX (with custom style files and output filenames). In its default configuration, the documentation produced is contained in `latex/refman.pdf`.

```
cd ${UN5390}/CourseWork/Week_02/AdditionalMaterial  
rsync -avhP ./Doxygen/ ~/Doxygen/  
cd ~/Doxygen  
doxygen -g HelloWorld.cfg # Generates config file  
# Edit HelloWorld.cfg, if necessary  
doxygen HelloWorld.cfg      # Generates necessary files  
cd latex  
make                         # Generates documentation
```

[Official website](#) | [GitHub](#)

Refer to `man doxygen` for more information. `make` command will be discussed in detail in subsequent weeks. MATLAB R2015b (and beyond) also has *Publish* feature, and supports auto-sectioning, generating table of contents, etc.



Repeating Commands

!!, !STRING, !N and CMD !*

!! repeats the previous command. !STRING repeats the most recent command that started with STRING. !N repeats the *N*th command in command history. CMD !* runs CMD command with options used for the previous command.

```
cd ${UN5390}  
!!  
date -R  
!da  
!cd  
history  
!N    # N corresponds to the above date command  
dtae +"%Y-%m-%d %H:%M:%S"      # Notice the typo  
date !*
```



Converting Seconds to hh:mm:ss

A quick workaround for long-tailed mathematics

```
# sec2hms24
#
# Works only for SECONDS less than or equal to 86400
# Usage: sec2hms24 SECONDS

sec2hms24() {
    # User input; ADD INPUT VALIDATION, ETC.
    local seconds=$1

    # Print the result
    date -u -d @$seconds +"%T"
}
```

Add this function to `${HOME}/bin/functions.sh` and run source `${HOME}/.bashrc`.



Disk Write Speed

dd

```
dd if=/dev/zero of=/tmp/output.img bs=8k count=256k \
conv=fdatasync ; rm -rf /tmp/output.img
```

Output from my local workstation and colossus.it are included below for reference.

```
262144+0 records in
262144+0 records out
2147483648 bytes (2.1 GB) copied, 9.29104 s, 231 MB/s
```

```
262144+0 records in
262144+0 records out
2147483648 bytes (2.1 GB) copied, 15.9378 s, 135 MB/s
```

Refer to `man dd` for more information.



Preventing Lines from Wrapping Around in a Terminal

```
less FILENAME_WITH_LONG_LINES
```

```
short.q:compute-0-0.local:john-users:john:test.sh:102541  
:sgc:0:1449493098:1449493123:1449499243:0:0:6120:...  
qlogin.q:compute-0-99.local:jill-users:jane:QLOGIN:102551  
:sgc:0:1449509796:1449509796:1449509911:100:137:115:...  
short.q:compute-0-1.local:john-users:amy:test2.sh:102546  
:sgc:0:1449501727:1449505169:1449510848:0:0:5679:...
```

```
less -S FILENAME_WITH_LONG_LINES
```

```
short.q:compute-0-0.local:john-users:john:test.sh:...  
qlogin.q:compute-0-99.local:jill-users:jane:QLOGIN:...  
short.q:compute-0-1.local:john-users:amy:test2.sh:...  
long.q:compute-0-36.local:greg-users:daniel:scf.sh:...  
long.q:compute-0-57.local:zach-users:zach:optimize.sh:...
```



Multiple Makefiles in a Folder

Problem of multiple makefiles

Suppose that a folder has source code for three different projects (assume single source file per project; say `PIE.c`, `Primes.c`, and `Fibonacci.c`). Further suppose that each project must have its own makefile. How does one go about achieving this?

Handling multiple makefiles

Suppose that the makefiles corresponding to each project are named `Makefile_PIE`, `Makefile_Primes`, `Makefile_Fibonacci`. One way to go about using a given makefile would be to use the `-f` option. For e.g.,

```
make -f Makefile_Primes
```

The other way to accomplish it is using a symbolic link. For e.g.

```
ln -sf Makefile_PIE Makefile ; make
```

Multiple Makefiles in a Folder

Compiling and running all `*.c` files programmatically

```
#!/bin/bash
#
# USEFUL COMMENTS AND USAGE INSTRUCTIONS

for x in $(ls *.c)
do
    # Extract the basename of .c file
    BASENAME=$(echo "${x}" | awk -F '.' '{ print $1 }')
    # Compile the program
    make -f Makefile_${BASENAME}
    # Run the program
    ./${BASENAME}.x
done
```

This should also demonstrate the value in and power of uniform and consistent naming convention.

Opportunities

They do knock every once in a while



<http://dilbert.com/strip/2009-09-24/>

IT-Managed Linux Labs

- * `colossus.it.mtu.edu` and `guardian.it.mtu.edu`
 - * Intel Xeon X5675 3.07 GHz, 24 CPU cores, 96 GB RAM
 - * Accessible for all from anywhere via SSH using a Terminal
 - * Appropriate for light- to medium-weight computations
- * Linux workstation in a campus lab/office
 - * May not be as powerful as `colossus.it` or `guardian.it`
 - * May not be directly accessible from off-campus
 - * <https://www.it.mtu.edu/computer-labs.php>

All IT-managed workstations in Linux labs run RHEL 7.x and will mount the campus home directory.

Network of Expertise

UN5390; CRN: 84758

#	Name	Email	Dept/Program	Advisor
01	Adam Mitteer	aamittee	Data Science	Mari Buche
02	Ashley Kern	ankern	Data Science	Mari Buche
03	Eisa Hedayati	hedayati	Physics/CS&E	John Jaszcak
04	Hashim Mahmud	hnalmahm	ME-EM	Gregory Odegard
05	Jeffrey Brookins *	jmbrooki	MSE	Jaroslaw Drellich
06	Paul Roehm	pmroehm	ME-EM	Gregory Odegard
07	Qing Guo	qinguo	Physics	Ravindra Pandey
08	Subin Thomas	subint	Physics	Raymond Shaw

* Undergraduate students



Network of Expertise

BE5390: Biomedical Engineering CRN: 84759

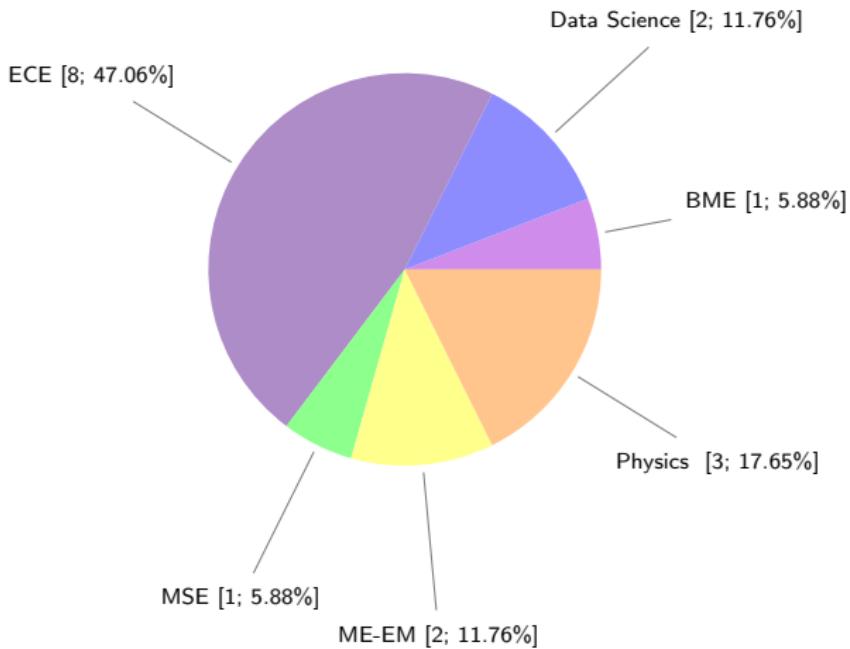
#	Name	Email	Advisor
09	Cal Riutta *	cdriutta	Jinfeng Jiang

EE5390: Electrical and Computer Engineering; CRN: 84760

10	Akhil Kurup	amkurup	Michael Roggemann
11	Avinaash Kovvuri	askovvur	Michael Roggemann
12	Ian Cummings	itcummin	Timothy Havens
13	Prithvi Kambhampati	pkambham	Michael Roggemann
14	Sandeep Lanka	slanka	Michael Roggemann
15	Sameer Saraf	svsaraf	Michael Roggemann
16	Shuo Wang	wshuo	Jeremy Bos
17	Zhiqiang Zhao	qzzhao	Zhuo Feng

* Undergraduate students

Network of Expertise



17 registered students.

NSF Graduate Research Fellowship Program 2017

- * Applicant must be a US citizen or a permanent resident
- * Fellowship supports 3 years of study
 - \$34k of stipend per year +
 - \$12k of cost-of-education allowance to the university per year
- * MS and PhD candidates in STEM and STEM education
 - Must be in first two years of graduate study
 - Senior undergraduates are also encouraged to apply
- * Michigan Tech Information Session
 - 5 pm, 7th September 2016 (Wednesday), Admin 404



CareerFEST and Career Fair

- * More details at <http://www.mtu.edu/career/careerfest/>
- * Create/Update your two-page résumé
- * Have it critiqued by Michigan Tech Career Services
- * Develop the habit of reviewing/updating it once per month
- * Use the \LaTeX template in [\\$\{UN5390\}/\text{LaTeXTemplates}/\text{Resume}/\\$](#)
- * Additional resources
 - <http://www.mtu.edu/career/students/toolbox/resumes/examples/>
 - <http://owl.english.purdue.edu/owl/resource/719/1/>
 - <http://www.sharelatex.com/templates/cv-or-resume>
 - <http://www.latextemplates.com/cat/curricula-vitae>

CareerFEST is a collection of many different informal events that take place during the month of Career Fair.



- * Commonly used Linux commands
- * Extensive shell scripting
- * Revision control (Git)
- * Workflow development
- * Statistical analysis (Python, R and Gnuplot)
- * Visualization (Python, R and Gnuplot)
- * White papers and internal publications (\LaTeX)



- * Commonly used Linux commands
- * Extensive shell scripting
- * Revision control (Git/Subversion)
- * Workflow development
- * Domain-specific expertise
- * Modeling, simulation, analysis and visualization
 - Choice of language/toolset depends on a project
- * White papers, internal and external publications (\LaTeX)



Keweenaw Climate Science Event

#1 of four-part event

The Orpheum Theater

6 – 8 pm on Thursday, 8th September 2016

Subsequent events

6th October 2016

3rd November 2016

1st December 2016

No admission fee

Free pizza and soft drinks

More information

Organized by [Keweenaw Climate Community](#), and sponsored by the local chapter of the [American Chemical Society](#) and the [Department of Social Sciences](#) at Michigan Tech.



Mathematical Results

Standing the test of time

Mathematics, rightly viewed, possesses not only truth, but supreme beauty – a beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, without the gorgeous trappings of painting or music, yet sublimely pure, and capable of a stern perfection such as only the greatest art can show.

– Bertrand Russell, A History of Western Philosophy (1945)



Bertrand Arthur William Russell (1872 – 1970): British philosopher, logician, mathematician, historian, writer, social critic, and political activist. 1950 Nobel Laureate in Literature.

Fundamental Theorem of Algebra

Every non-constant single-variable polynomial with complex coefficients has at least one complex root. Since real numbers are a subset of complex numbers, the result/statement extends to polynomials with real coefficients as well.

Alternate statement #1 (proved using successive polynomial division)

Every non-zero, single-variable, degree n polynomial with complex coefficients has, counted with multiplicity/degeneracy, exactly n roots.

Alternate statement #2

The field of complex numbers is algebraically closed.

Theorem first proven algebraically by James Wood (with missing steps) in 1798, and geometrically by Johann Carl Friedrich Gauss (with a topological gap) in 1799.



Fundamental Theorem of Calculus

Suppose that $f(x)$ is defined and continuous on $[a, b]$. Suppose that $y(x)$ is an anti-derivative of $f(x)$. Then

$$\int_a^b f(x) dx = y(b) - y(a)$$

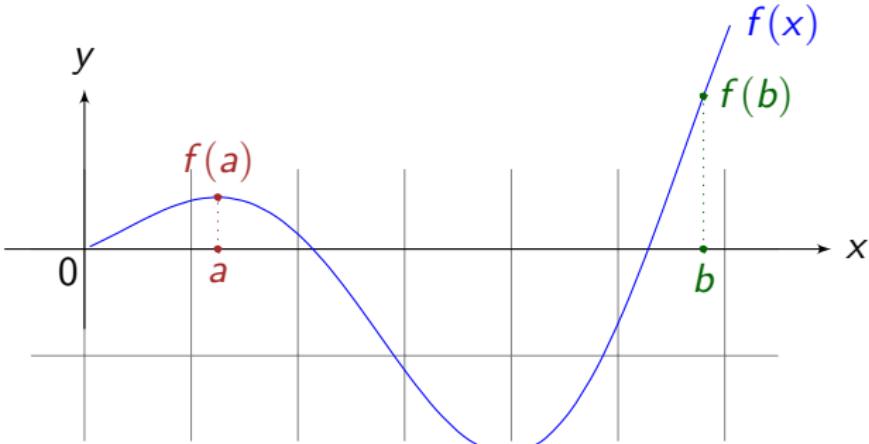
Changing the notations while retaining the underlying essence,

$$\int_{t_n}^{t_{n+1}} f(y, t) dt = y_{n+1} - y_n$$

Re-arranging the terms,

$$y_{n+1} = \boxed{y_n} + \boxed{\int_{t_n}^{t_{n+1}} f(y, t) dt}$$

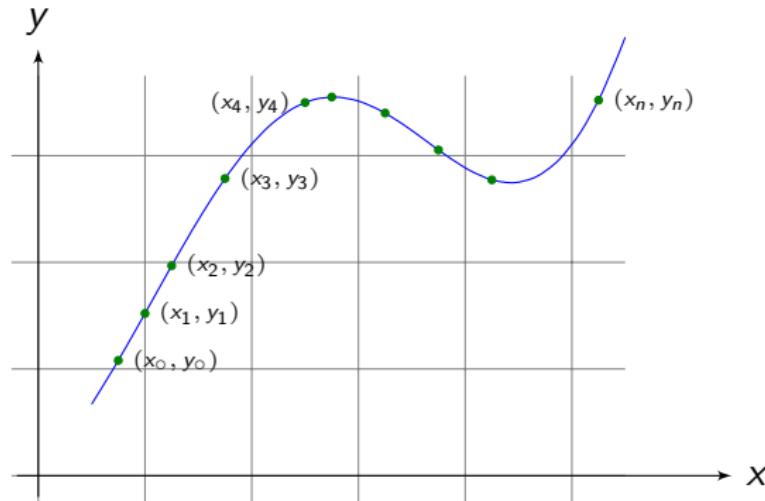
Intermediate Value Theorem (IVT)



For any function $f(x)$ that is continuous on $[a, b]$, and has values $f(a)$ and $f(b)$ at a and b respectively, then $f(x)$ also takes any value between $f(a)$ and $f(b)$ at some point within the interval.

Lagrange Polynomial Interpolation

Suppose that (x_i, y_i) , with $i = 0 : 1 : n$, are a set of $n + 1$ unique points



Joseph-Louis Lagrange (1736 – 1813): Italian mathematician and astronomer
[Interpolating Polynomials](#), L. Shure, MathWorks
[Lagrange Interpolating Polynomial](#), B. Archer, Wolfram

Lagrange Polynomial Interpolation

The general form of Lagrange interpolating polynomial, one that passes through $n + 1$ points

$$\mathcal{L}_n(x) = \sum_{i=0}^n l_i(x) y_i$$

Lagrange basis polynomials are given by

$$l_i(x) = \prod_{\substack{m=0 \\ m \neq i}}^n \frac{x - x_m}{x_i - x_m}$$

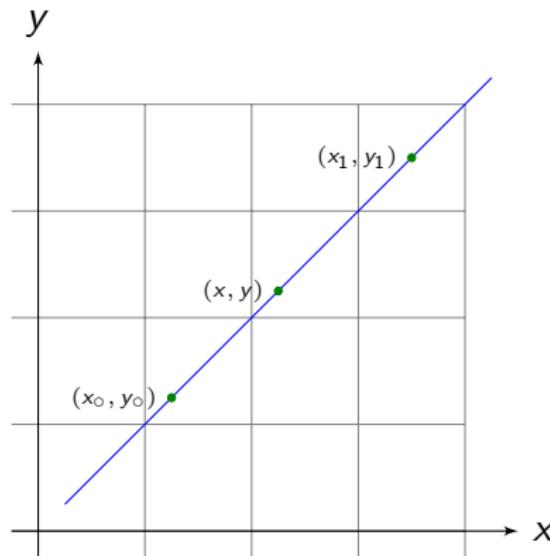
and are built to have the *Kronecker delta* property

$$l_i(x_j) = \delta_{ij}$$

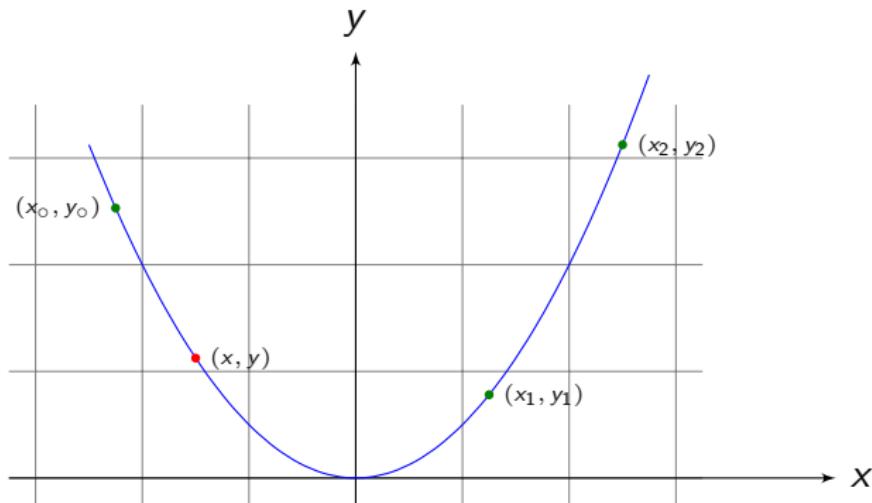
Lagrange Polynomial Interpolation

Linear

Suppose that (x_0, y_0) and (x_1, y_1) are two known points. The linear interpolant is then a straight line between these two points.



Lagrange Polynomial Interpolation Quadratic



$$\mathcal{L}_2(x) = \frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} y_0 + \frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} y_1 + \frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} y_2$$

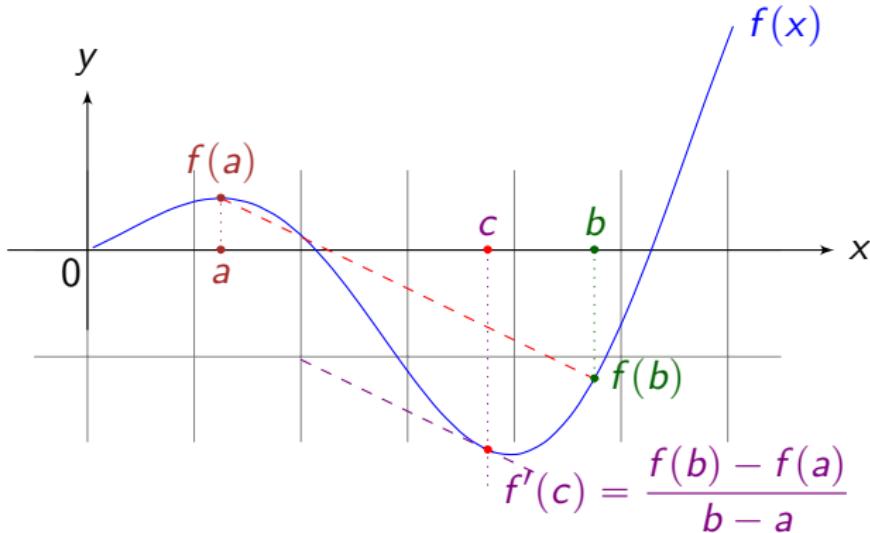
Lagrange Polynomial Interpolation

Error analysis

If $f(x)$ is $n + 1$ times continuously differentiable on a closed interval $[a, b]$, and $p_n(x)$ is a polynomial of degree at most n that interpolates $f(x)$ at $n + 1$ distinct points x_i , ($i = 0, 1, 2, \dots, n$) in that interval. Then

$$\epsilon_n = \int_a^b [f(x) - p_n(x)] dx = \int_a^b \frac{f^{(n+1)}}{(n+1)!} \prod_{i=0}^n (x - x_i) dx$$

Mean Value Theorem



For any function that is continuous on $[a, b]$ and differentiable on (a, b) , there exists a point c in (a, b) such that the line joining $f(a)$ and $f(b)$ (i.e., the secant) is parallel to the tangent at c .

Weighted Mean Value Theorem for Integrals

Suppose that $f(x)$ and $g(x)$ are continuous on $[a, b]$. If $g(x)$ never changes sign and is positive, $g(x) \geq 0$, in $[a, b]$, then for some c in $[a, b]$

$$\int_a^b f(x) g(x) dx = f(c) \int_a^b g(x) dx$$

Newton-Cotes Formula

Suppose that $f(x)$ is defined and continuous on $[a, b]$.

Consider the integral



$$I = \int_a^b f(x) dx$$

If $f(x)$ can be approximated by an n^{th} order polynomial

$$p_n(x) = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \dots + \alpha_{n-1} x^{n-1} + \alpha_n x^n$$

then the integral, I , takes the form

$$I = \int_a^b [\alpha_0 + \alpha_1 x + \alpha_2 x^2 + \dots + \alpha_{n-1} x^{n-1} + \alpha_n x^n] dx$$

Isaac Newton (1642 – 1727): English physicist and mathematician

Roger Cotes (1682 – 1716): English mathematician (no photo)

Taylor Series Expansion

If $f(x)$ is infinitely differentiable at x_0 , then

$$f(x) = \sum_{n=0}^{\infty} \frac{(x - x_0)^n}{n!} \left. \frac{d^n}{dx^n} f(x) \right|_{x=x_0}$$



A more general form that clearly identifies the error term is given by the p^{th} order Taylor series expansion of $f(x)$ with $\tilde{x} \in [x, x + \Delta x]$

$$f(x + \Delta x) = \sum_{n=0}^p \frac{(\Delta x)^n}{n!} \left. \frac{d^n}{dx^n} f(x) \right|_{x=x} + \frac{(\Delta x)^{p+1}}{(p+1)!} \left. \frac{d^{p+1}}{dx^{p+1}} f(\tilde{x}) \right|_{\tilde{x} \in [x, x + \Delta x]}$$

Brook Taylor (1685 – 1731): English mathematician

Random Variables and Distributions

The need

Random variables and their distributions provide a basis for developing probabilistic models and describing the behavior of important characteristics of interest (i.e., real data).

Y is a random variable if it is a function that assigns a real numbered value to every possible event in a sample space of interest. Since every possible set of values for a random variable Y corresponds to some event, it has a probability associated with it. A random variable's distribution details the probabilities associated with these sets of values in a meaningful way.

It is a common practice to use an uppercase alphabet to denote the random variable, and the corresponding lowercase alphabet to denote a specific value of this variable. A discrete random variable can assume at most a countable number of values. A continuous random variable can assume an uncountable number of values.

Random Variables and Distributions

PDF and CDF

The probability distribution function (PDF) of some random variable Y is given below. $P(Y = y_i)$ indicates the probability of the random variable Y taking on a given value, y_i . $F(y_i)$ represents the cumulative distribution function (CDF), and is used to model the behavior of Y .

y_i	$P(Y = y_i)$	$F(y) = P(Y \leq y_i)$
0	0.10	0.10
1	0.30	0.40
2	0.40	0.80
3	0.20	1.00

All random variables must have a cumulative distribution function.

Uniform Distribution

Discrete and continuous

Applicable when

a finite number of values are equally likely to be observed. The probability density function on the interval $[a, b]$ is

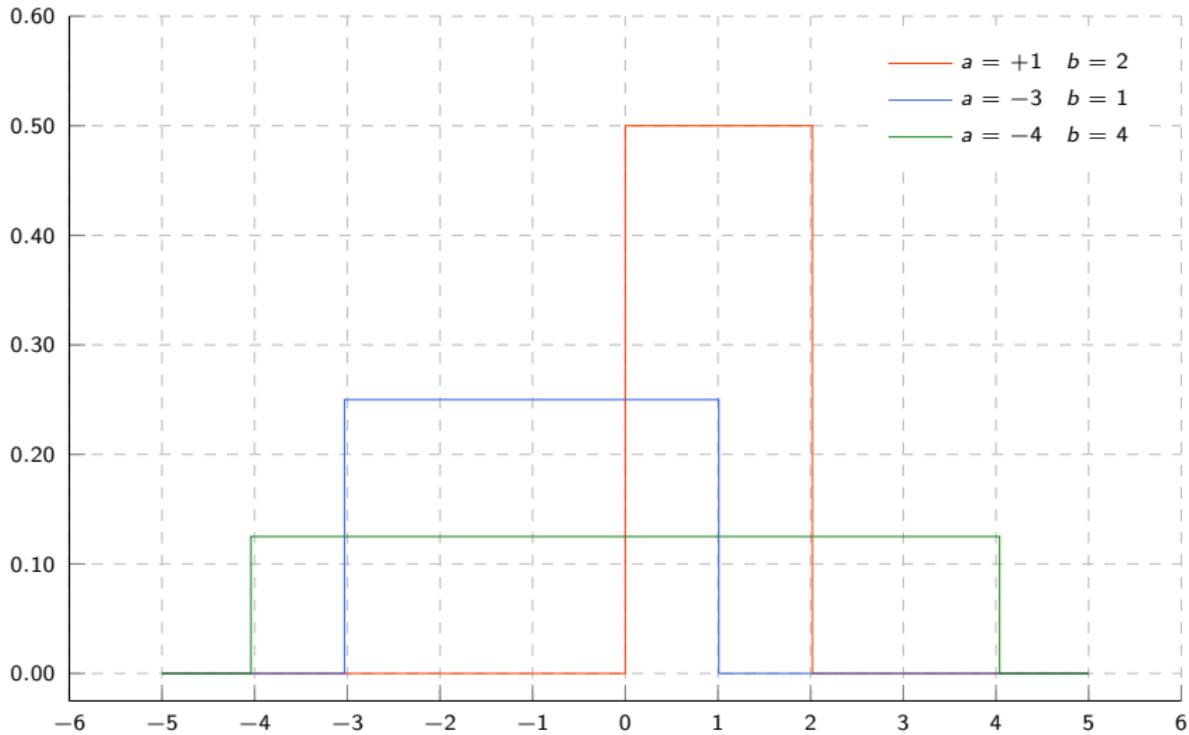
$$f(x) = \begin{cases} 0 & x < a \\ 1/(b-a) & a \leq x \leq b, \text{ and } -\infty < a < b < \infty \\ 0 & x > b \end{cases}$$

Common example(s)

Throwing a fair die with possible values of 1, 2, ..., 6; each face of the die has a probability of 1/6.

Uniform Distribution

Probability Distribution Function (PDF)



Bernoulli Distribution

Discrete

Applicable when

a random variable takes the value one with success probability of p and the value zero with a failure probability of $1 - p$. Bernoulli distribution is a special case of the Binomial distribution for $n = 1$.

Common example(s)

A coin toss where one and zero could be represented by *head* and *tail* respectively. For a fair coin, $p = 0.50$.

Binomial Distribution

Discrete

Applicable when

a number of successes (e.g., a head or a tail) results in a sequence of n independent success/failure-type experiments, each of which yields success with a probability (or fairness factor) p . The probability of getting exactly x successes in n trials for a specified fairness value, p , is

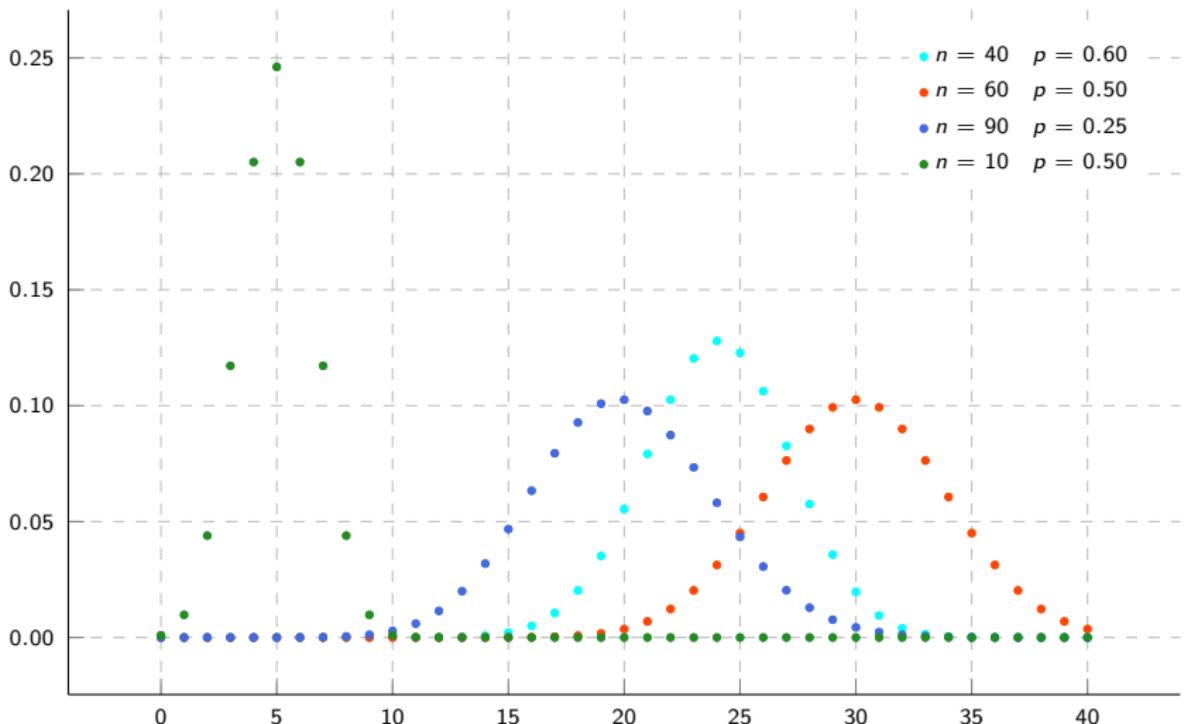
$$P = \frac{n!}{x! (n-x)!} p^x (1-p)^{n-x}$$

Common example(s); contributed by Fall 2016 students

Throwing a fair die with possible values of 1, 2, ..., 6 (each face of the die has a probability of 1/6); number of times a marksman hits the target after N attempts in a shooting range.

Binomial Distribution

Probability Distribution Function (PDF)



Poisson Distribution

Discrete

Applicable when

a given number of events occur in a fixed interval of time if these events occur with a known average rate, independently of time since the last event, and two of them cannot occur at the same time. The probability of observing m events in an interval with the average number of events in an interval designated by λ is

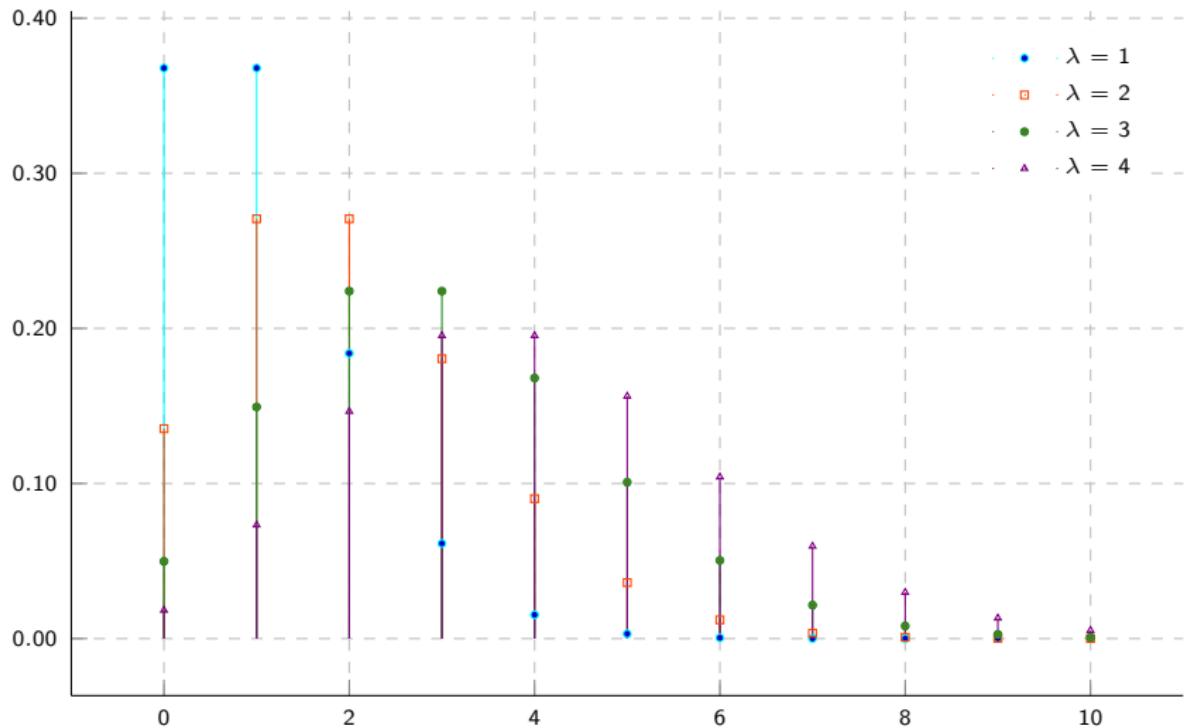
$$P(m) = \frac{\lambda^m e^{-\lambda}}{m!}$$

Common example(s); contributed by Fall 2016 students

Number of machine failures OR accidents (due to snow) OR decaying radioactive atoms OR mutations on a given strand of DNA OR visitors to a website over a time period.

Poisson Distribution

Probability Distribution Function (PDF)



Gamma Distribution

Applicable when

the waiting times between Poisson distributed events are relevant. The probability density function with shape parameter α and scale parameter β (inverse of rate parameter) is

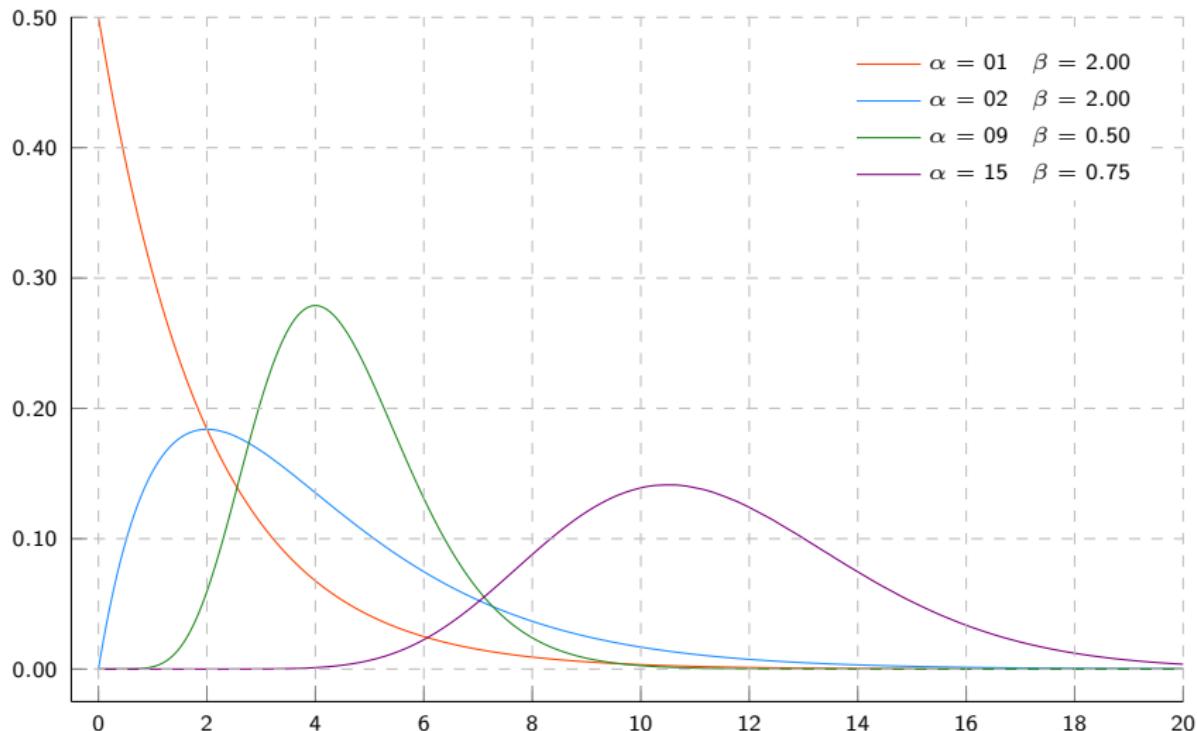
$$f(x) = \frac{1}{\Gamma(\alpha) \beta^\alpha} x^{\alpha-1} \exp\left(-\frac{x}{\beta}\right) \quad x \geq 0, \text{ and } \alpha, \beta > 0$$

Common example(s)

The size of insurance claims, amount of rainfall, multipath fading of signal power (wireless communication), interspike intervals (neuroscience), etc.

Gamma Distribution

Probability Distribution Function (PDF)



Normal/Gaussian Distribution

Continuous

Applicable as

a limiting form of binomial distribution (De Moivre, 1733) and as a plausible distribution for measurement errors (Gauss, 1809). The probability density with mean μ and standard deviation σ is

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left[-\frac{(x - \mu)^2}{2\sigma^2}\right] \quad -\infty < x, \mu < \infty, \text{ and } \sigma > 0$$

Common example(s); contributed by Fall 2016 students

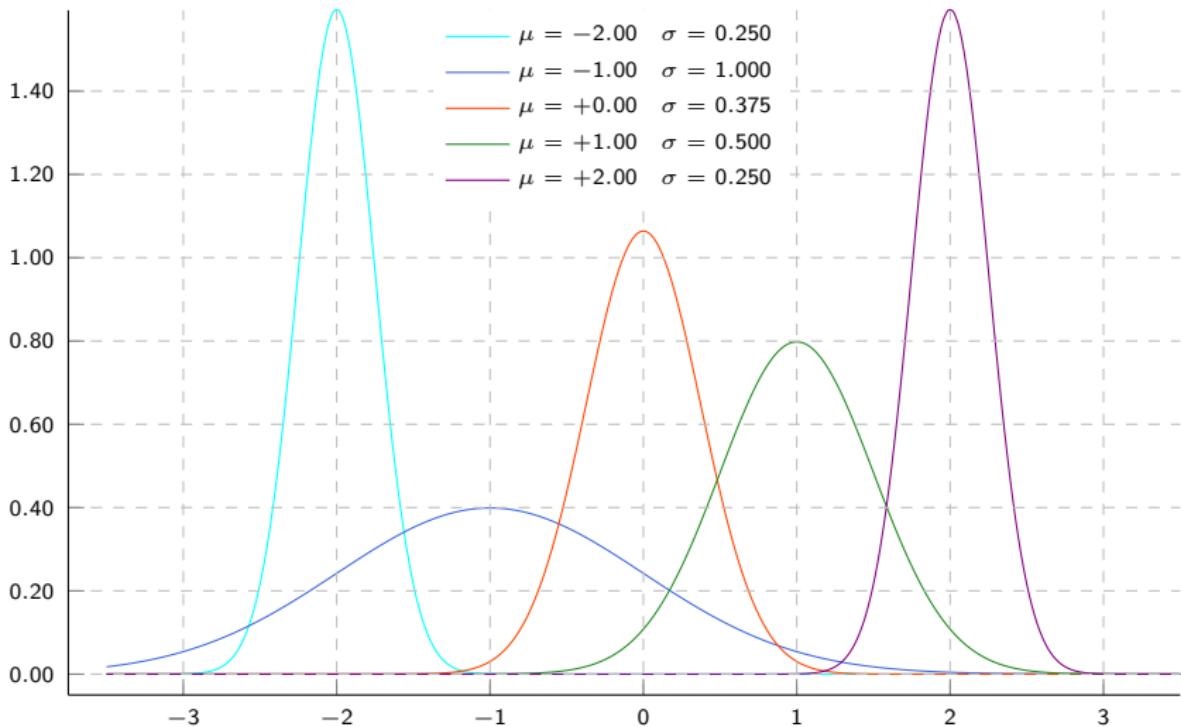
Mechanical error, students' score, annual income of all people in a given country, etc.

Laplace's Central Limit Theorem: Under very general conditions when n random variables, whatever their distributions, are added together, the distribution of the sum tends towards the normal (i.e., bell shape) as n increases.



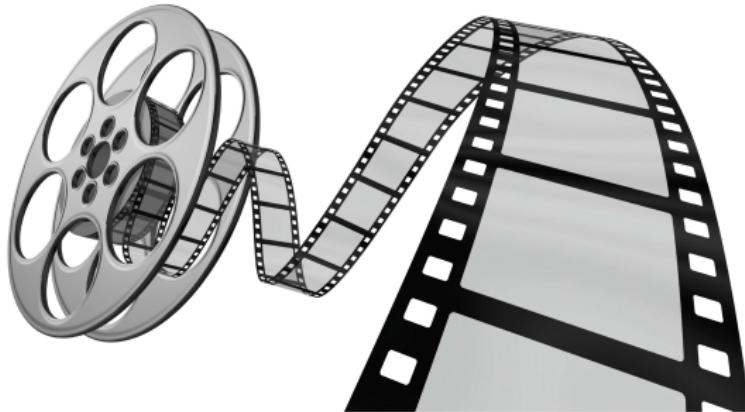
Normal/Gaussian Distribution

Probability Distribution Function (PDF)



Videos

If a picture is worth a thousand words ...

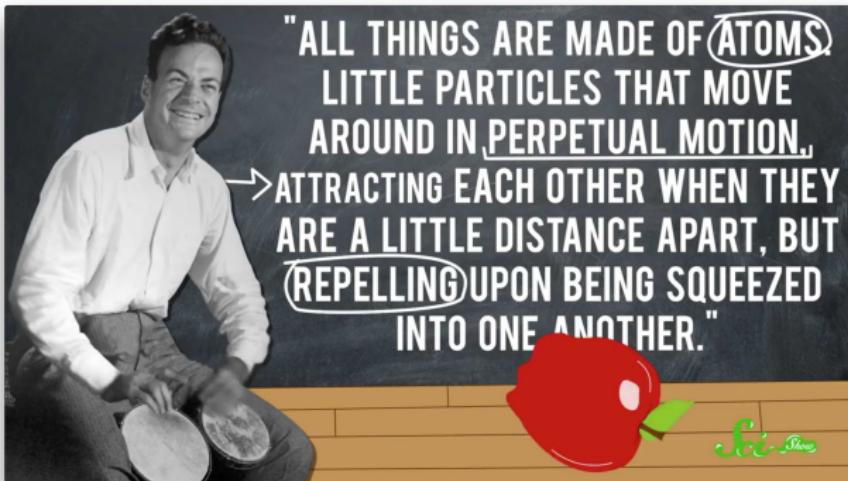


People and Personalities

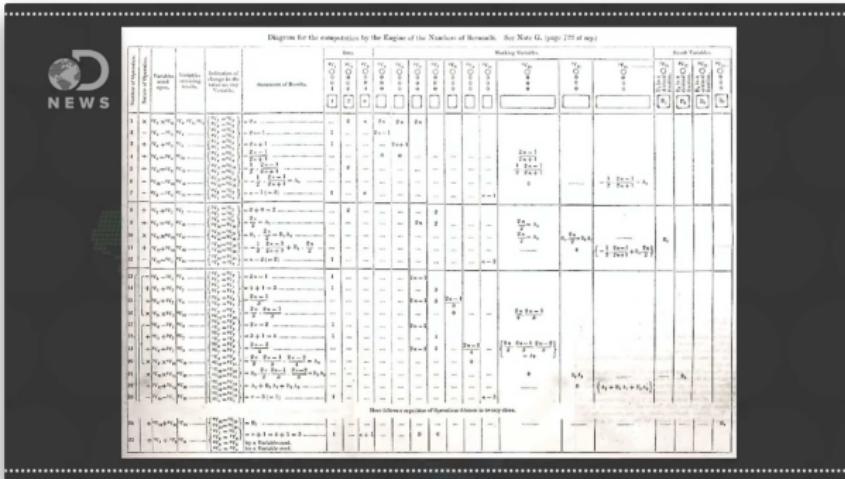


and their stories

Richard Phillips Feynman 1918 – 1988



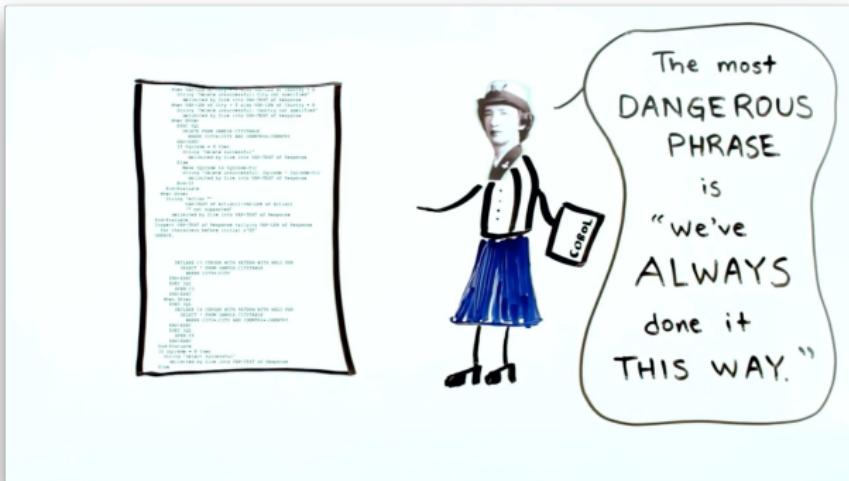
Ada Augusta King, Countess of Lovelace 1815 – 1852



Alan Mathison Turing 1912 – 1954



Grace Brewster Murray Hopper 1906 – 1992



Computer History Museum

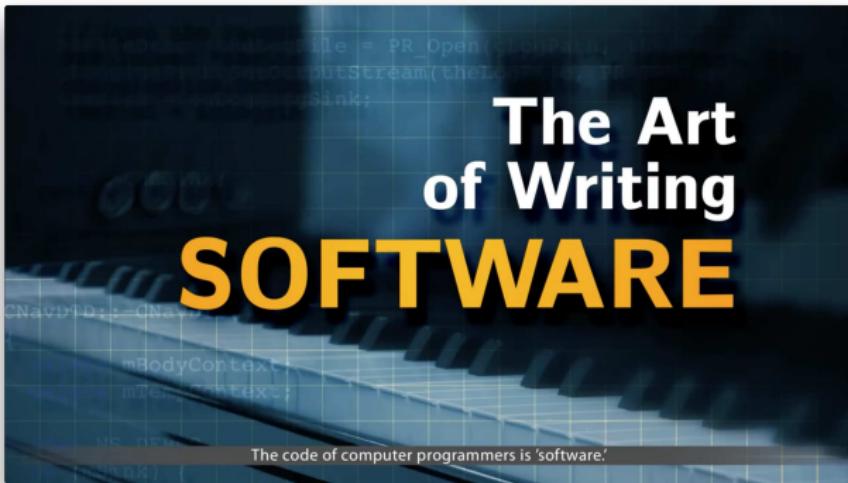


1401 N. Shoreline Blvd., Mountain View, CA 94043
(650) 810-1010

The Fairchild Notes



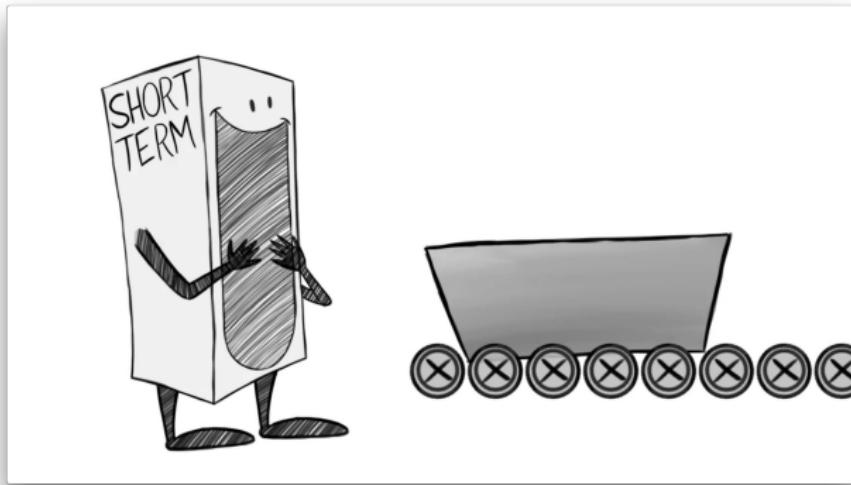
The Art of Writing Software



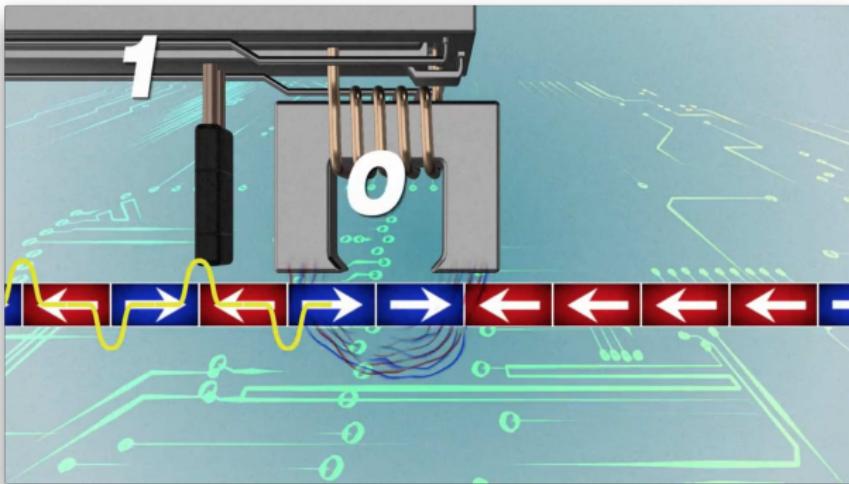
TED Ed

LESSONS WORTH SHARING

Computer Memory



Hard Drives



Turing Test



Algorithm

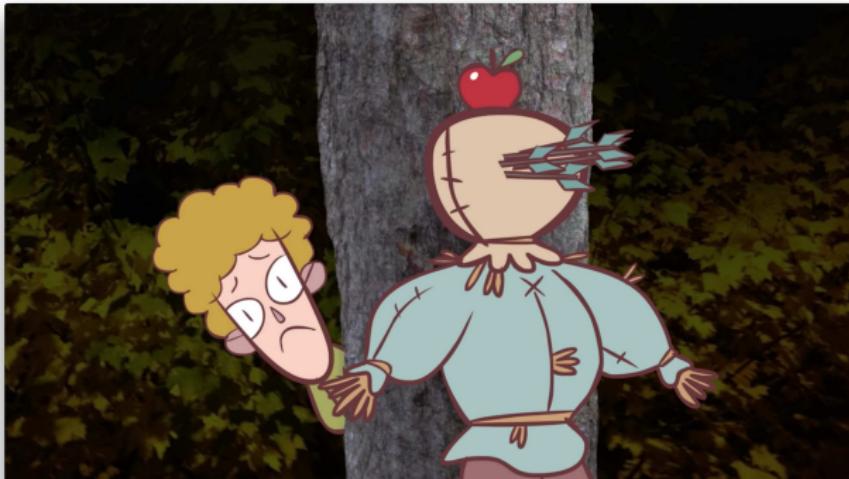
Pseudocode

let **N** = 0

For each person in room

Set **N** = **N** + 1

Accuracy vs Precision



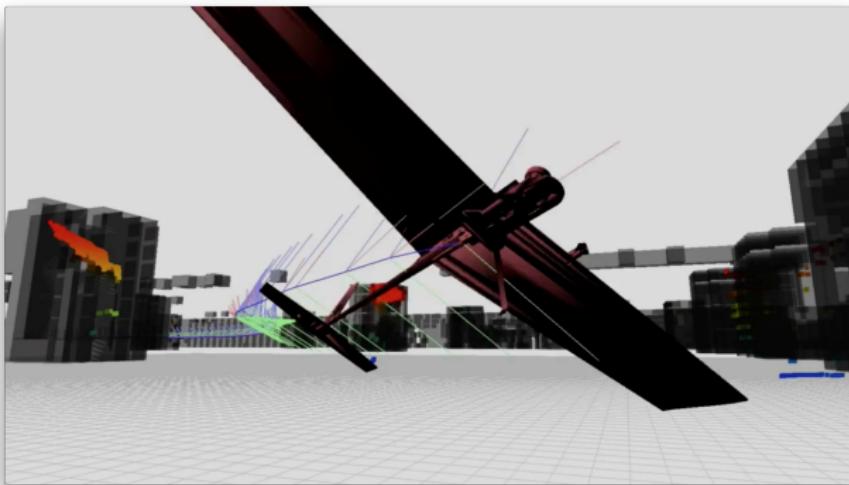
Supercomputing



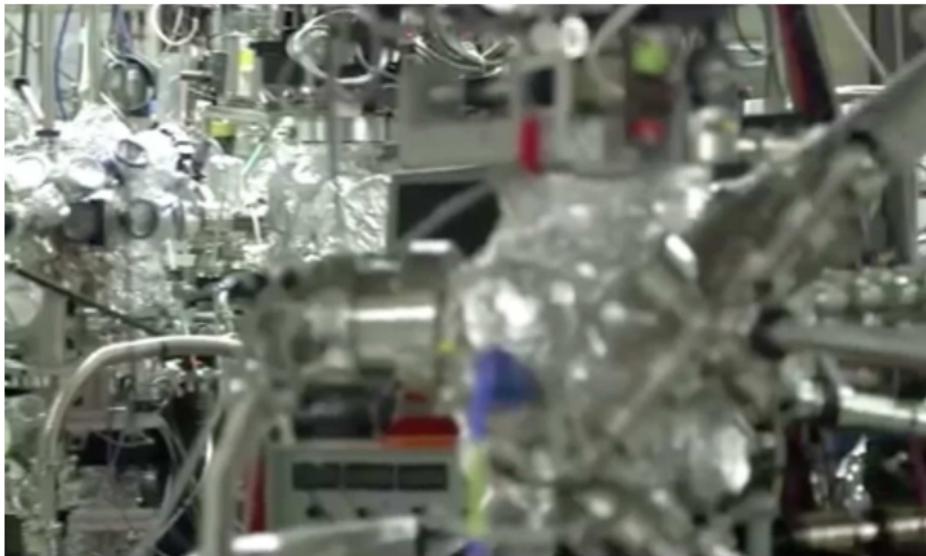
The International Conference for High Performance Computing,
Networking, Storage and Analysis

What is HPC?

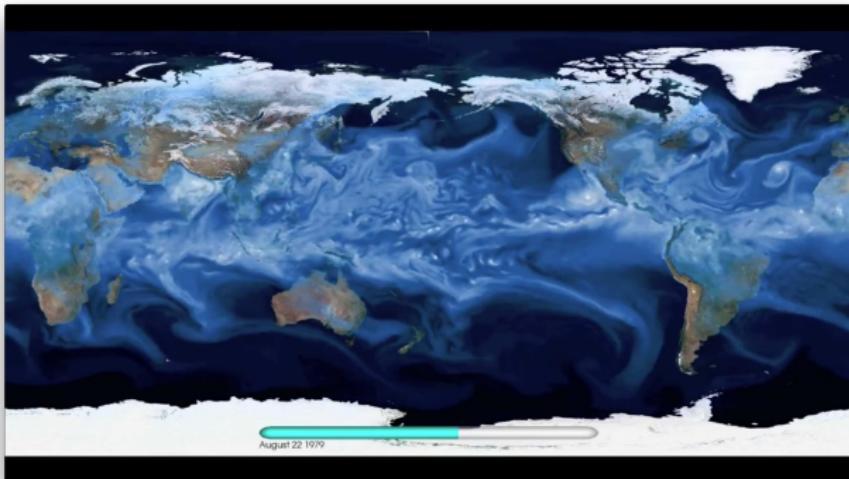
Aerospace



Batteries

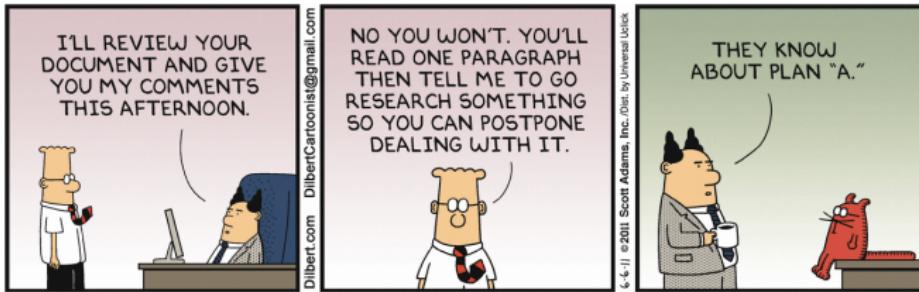


Climate Modeling



Review of Performance

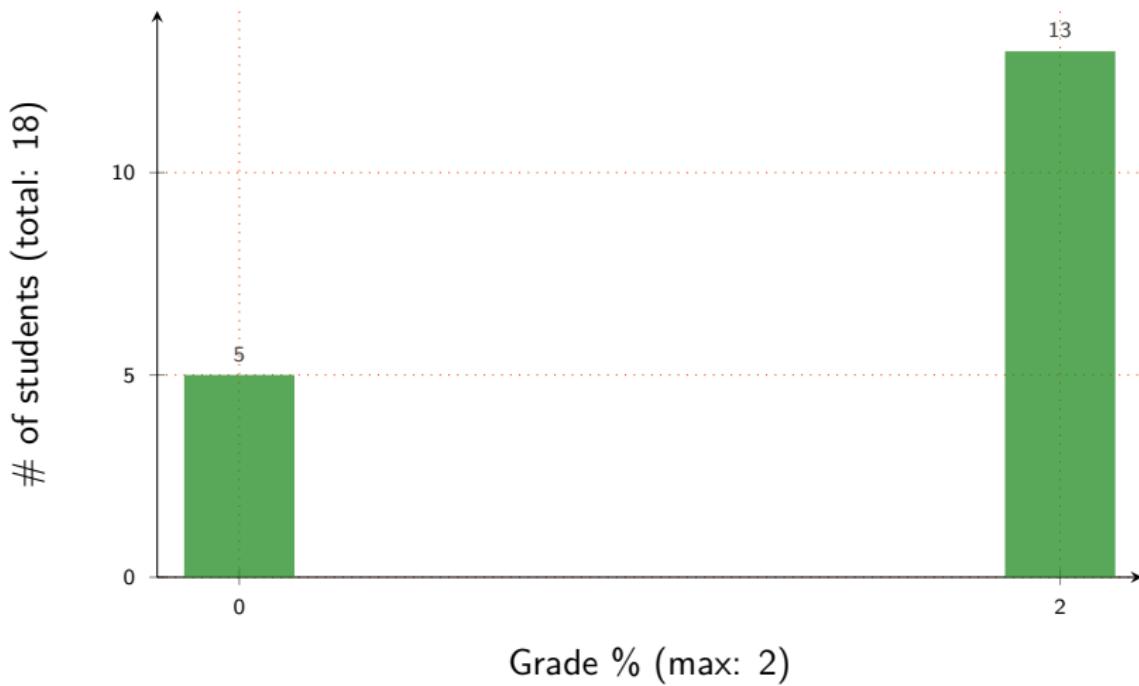
How well have we been performing?



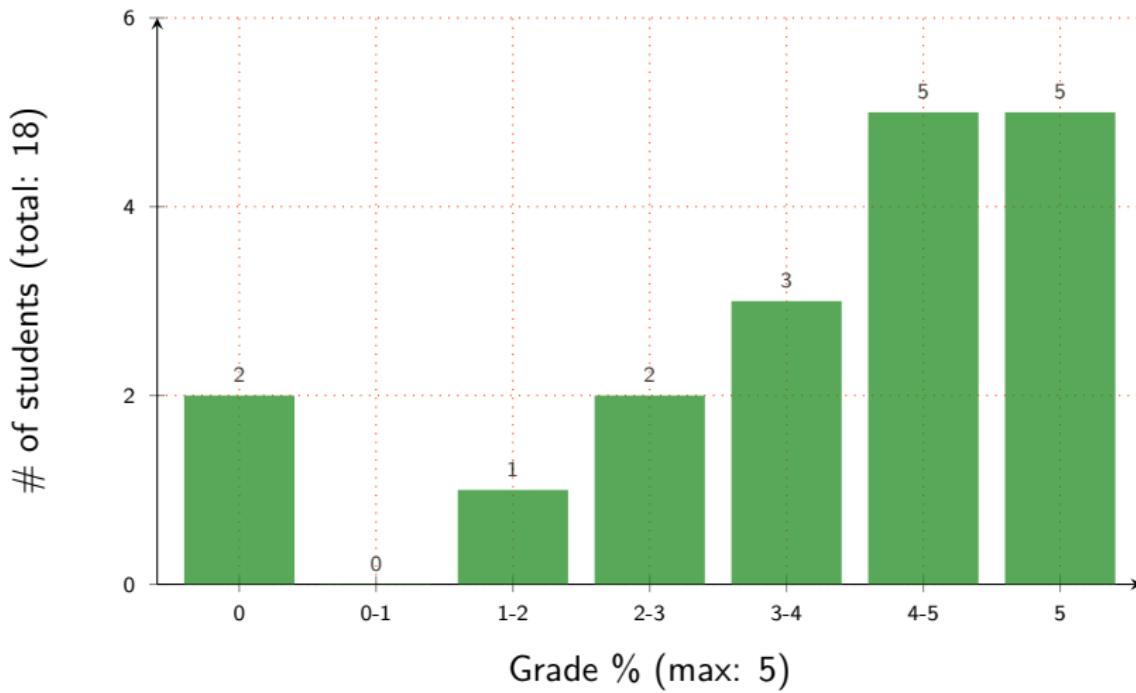
<http://dilbert.com/strip/2011-06-06/>

Active Participation #01

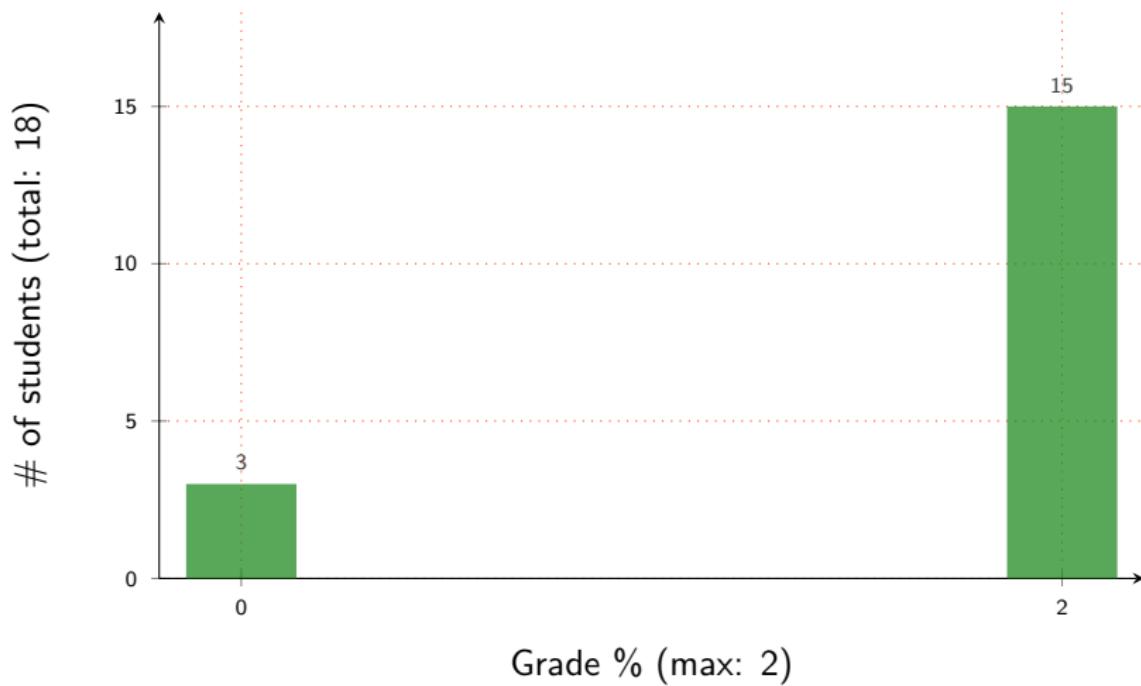
Research Marketing I: Twitter



Assignment #01

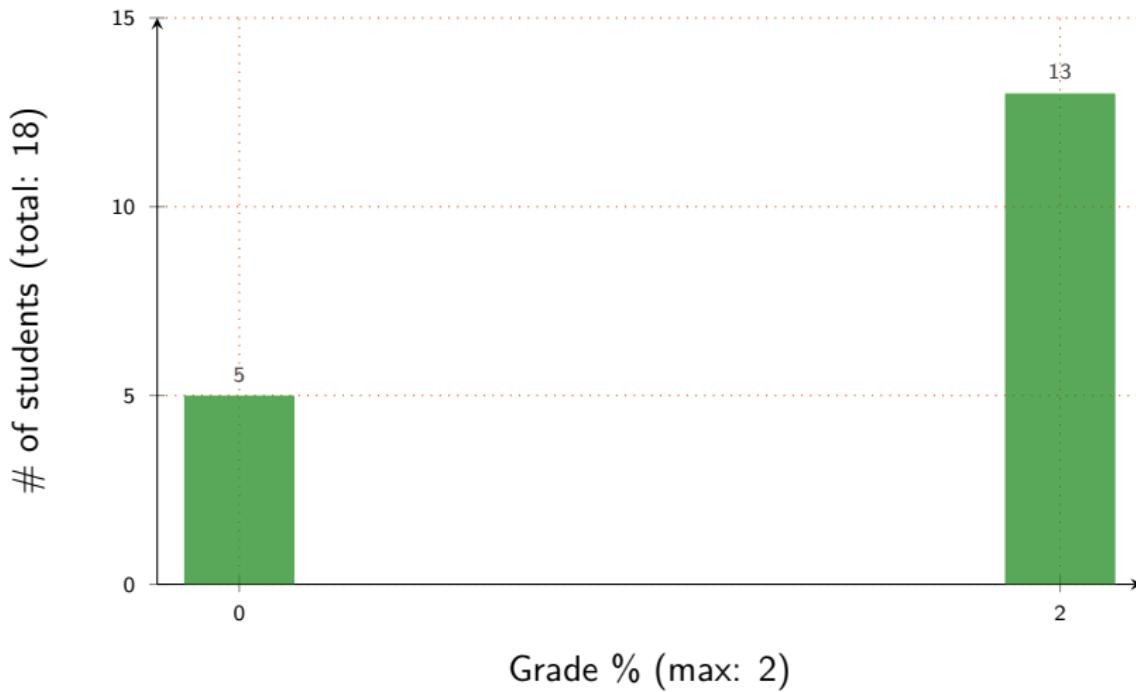


Active Participation #02 PB&J Sandwich Recipe



Active Participation #03

Research Marketing II: Professional/University Business Cards



Superior and Top 500

A proposed compute node in Superior will have two Intel Xeon E5-2698 processors (each processor with 20 cores) at 2.20 GHz, 512 GB RAM, 480 GB Intel Enterprise SSD, Mellanox ConnectX-3 56 Gbps InfiniBand network, and will cost \$13,263.13.

Ignoring the cost of physical space, racks, network, storage, electricity and labor, estimate the cost to build a #500 supercomputer (~405 TFLOPS) with homogeneous compute nodes as the ones described above.

For a computer with N identical/homogeneous processors,

$$\text{FLOPS} = N \times \text{CPU speed} \times \frac{\text{FLOPs}}{\text{CPU cycle}}$$

Celsius \longleftrightarrow Fahrenheit



Convert temperature between Celsius and Fahrenheit scales.

Is there a well-known technique to verify the conversion scheme?

Matrix elements



How many elements in a square matrix of order N ? How will this number change if the matrix is upper (or lower) triangular?

$$\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \quad \begin{pmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ 0 & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & b_{nn} \end{pmatrix}$$

The impact and limitations of Moore's Law



Assuming that Moore's Law holds true, what is the speed up of a computer observed over an average adult's life in the US?

Got Questions?

If you do, find a way to contact me; and do so sooner than later

EERC B39 · (906) 487-4096 · g@mtu.edu · [@sgowtham](https://twitter.com/@sgowtham)

Do not share/distribute the course material, in and/or outside of Michigan Tech, without instructor's prior consent

