EE5240: Computer Modeling of Power Systems

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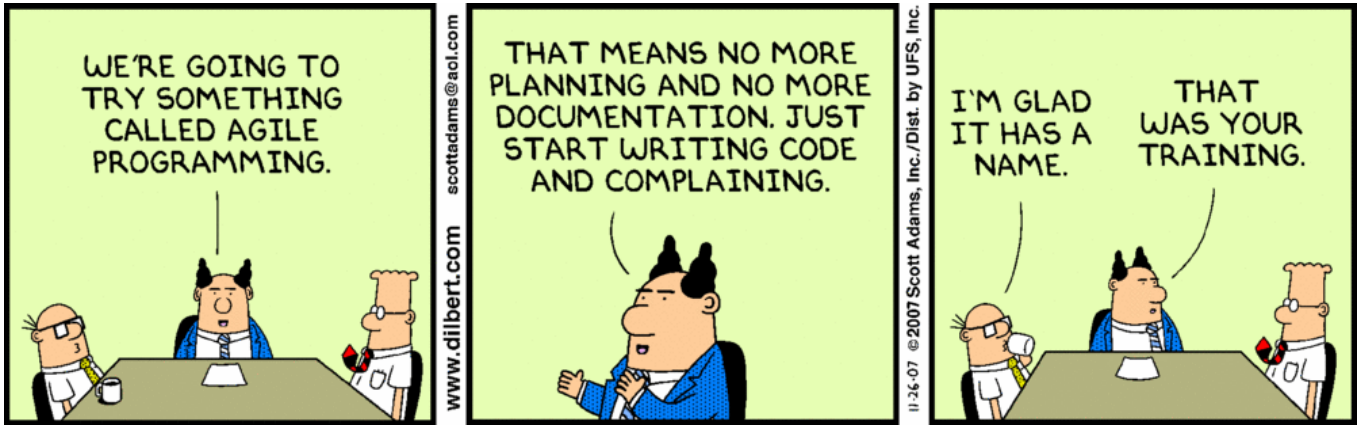
Week #08: 2017-02-27, 2017-03-01 and 2017-03-03

Structured Programming Tools

Coding a reflection of one's logic ... for the most part



http://dilbert.com/strip/2007-11-26/

Problem Definition

* Understand what is given
* Understand what is expected
* Understand what you have and what you don't have for resources

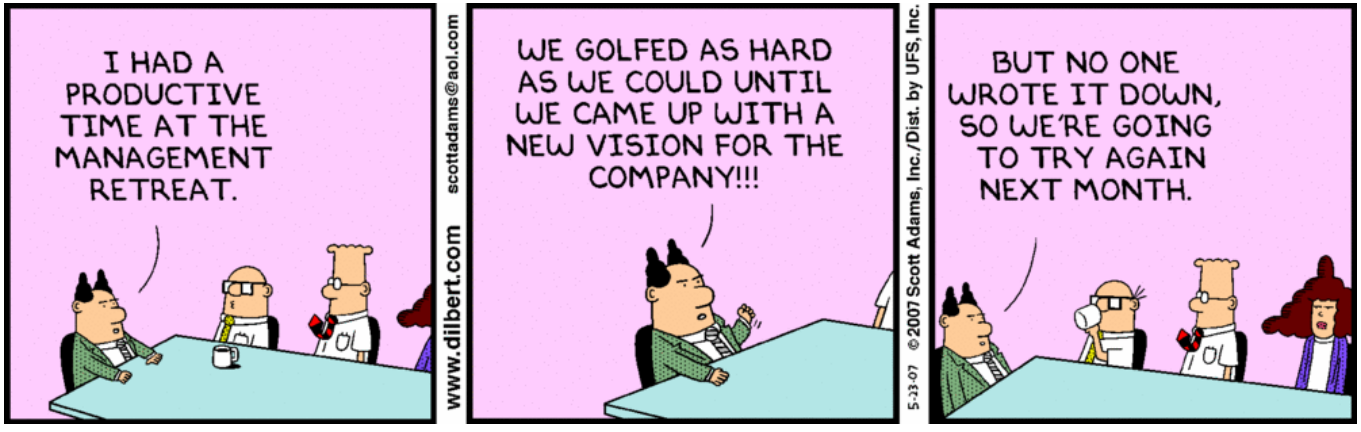
Literature Search

- Your own personal and/or friends'/colleagues' collection
- Computing literature

  GitHub | Stack Overflow
- Object-oriented learning

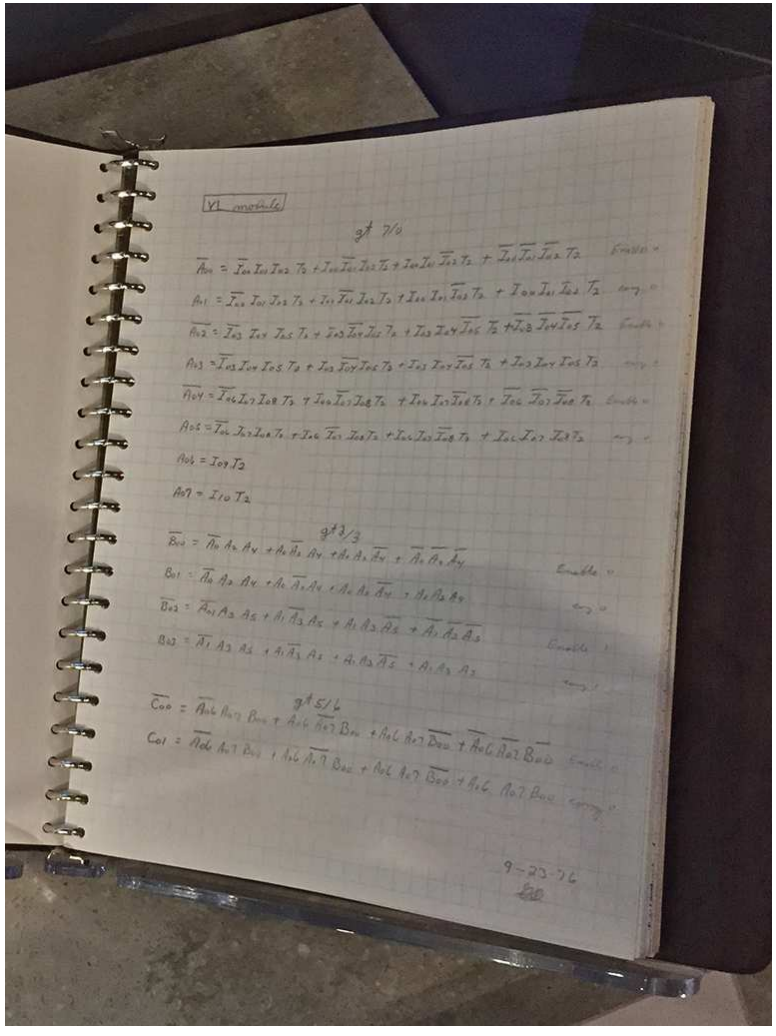
Notes

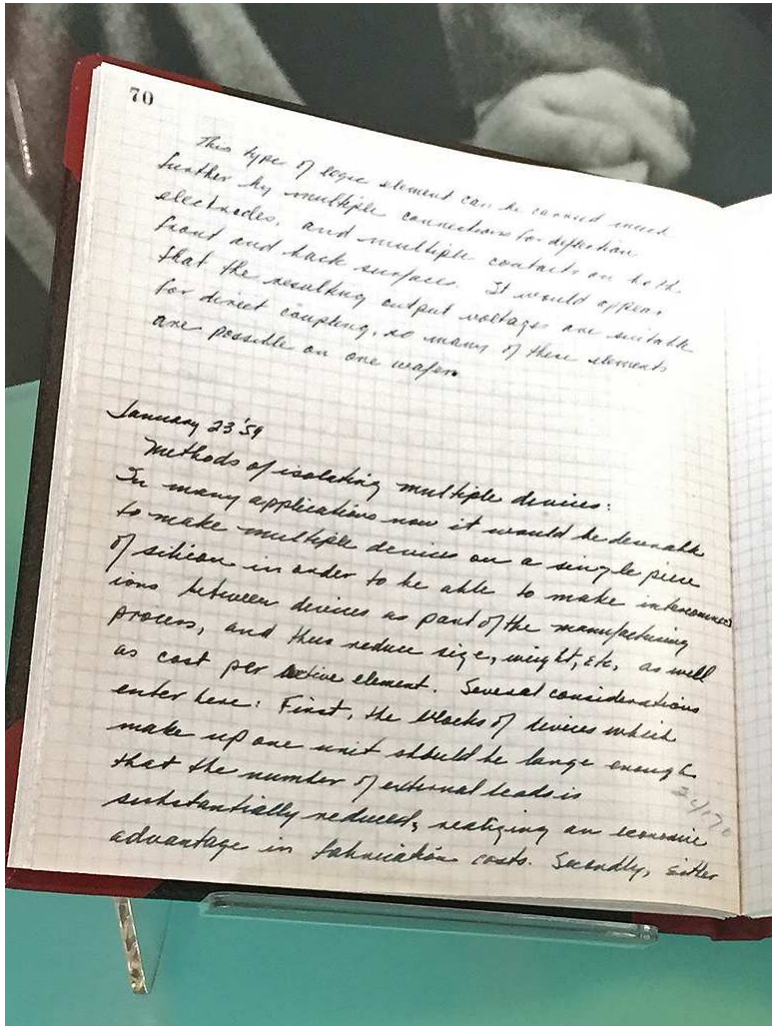
* As detailed as possible
* Include date, time, and location
* Include hostname, and version of OS, software, compilers
* Hand-written, not just an electronic version

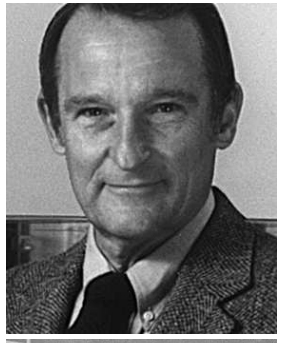


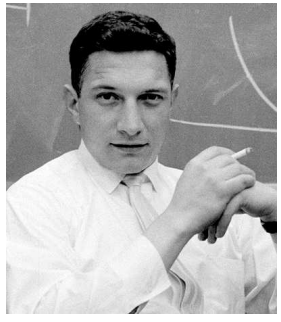
http://dilbert.com/strip/2007-05-23/

Notes





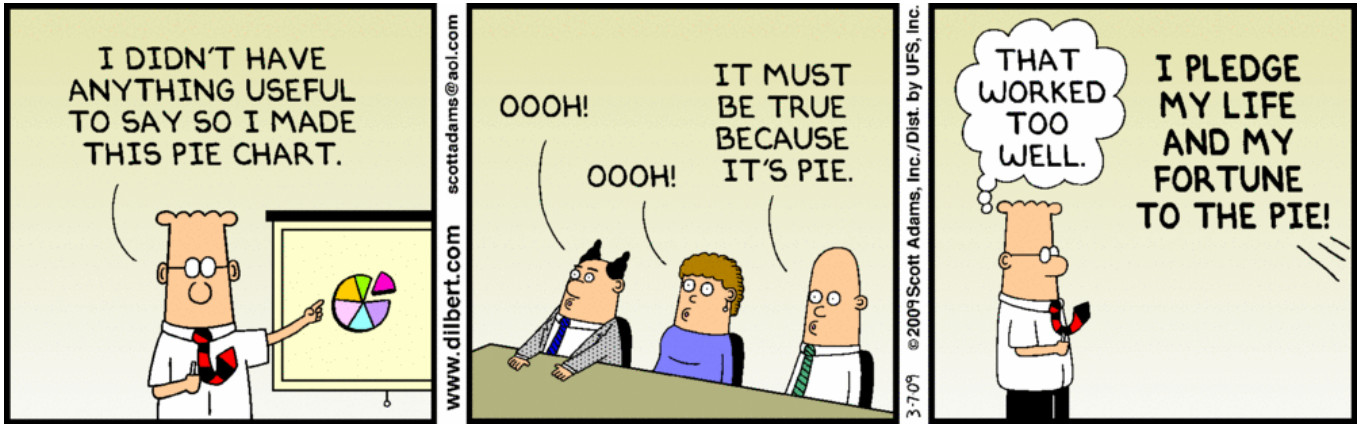




Seymour Roger Cray (1925 – 1996): American electrical engineer, entrepreneur; founder, Cray Research
Robert Norton Noyce (1927 – 1990): American physicist and entrepreneur; co-founder, Fairchild Semiconductor and Intel

Imagery

* Use schematics/plots - a picture is still worth a thousand words



http://dilbert.com/strip/2009-03-07/

Language of Choice

* Learn more than one if you can
* Know what best fits your research needs
* Realize that not every language does everything well

Examples: Scripting (BASH, PERL, Python), programming (C/C++, FORTRAN, Java, Julia, Mathematica, MATLAB), documentation (LaTeX), database (SQL, Oracle), web design (CSS, HTML, PHP)

Appearance Write for ~~computers~~ people

* A sense of *love at first sight*
* Should look pretty, have a good and logical flow, and be useful
* Statements and modules in top-down/alphabetical order

Appearance Write for ~~computers~~ people; useful but ~~not pretty~~ ugly

```
#include <stdio.h>
main(t,_,a)
char *a;
{return!0<t?t<3?main(-79,-13,a+main(-87,1-_,
main(-86, 0, a+1 )+a)):1,t<_?main(t+1, _, a ):3,main ( -94, -27+t, a
)&&t == 2 ?_<13 ?main ( 2, _+1, "%s %d %d\n" ):9:16:t<0?t<-72?main(_,
t,"@n'+,#'/*{}w+/w#cdnr/+,{}r/*de}+,/*{*+,/w{%+,/w#q#n+,/#{l,+,/n{n+\
,/+#n+,/#;#q#n+,/+k#;*+,/'r :'d*'3,}{w+K w'K:'+}e#';dq#'l q#'+d'K#!/\
+k#;q#'r}eKK#}w'r}eKK{nl]'/#;#q#n'){)#}w'){){nl]'/+#n';d}rw' i;# ){n\
l]!/n{n#'; r{#w'r nc{nl]'/#{l,+'K {rw' iK{;[{nl]'/w#q#\
n'wk nw' iwk{KK{nl]!/w{%'l##w#' i; :{nl]'/*{q#'ld;r'}{nlwb!/*de}'c \
;;{nl'-{}rw]'/+,}##'*}#nc,',#nw]'/+kd'+e}+;\
#'rdq#w! nr'/ ') }+}{rl#'{n' ')# }'+}##(!!/")
:t<-50?_==*a ?putchar(a[31]):main(-65,_,a+1):main((*a == '/')+t,_,a\
+1 ):0<t?main ( 2, 2 , "%s"):*a=='/'||main(0,main(-61,*a, "!ek;dc \
i@bK'(q)-[w]*%n+r3#l,{}:\nuwloca-O;m .vpbks,fxntdCeghiry"),a+1);}
```

Appearance Write for ~~computers~~ people; pretty but ~~not useful~~ dangerous

```c
// ForkBomb.c
// C program to demonstrate the fork bomb with memory leak. Compilation takes
// less than one second on most modern hardware running Linux OS with GCC.
//
// Compilation and execution:
// gcc ForkBomb.c -o ForkBomb.x
// ./ForkBomb.x

// Headers
#include <stdlib.h>

// main()
int main() {

  while (1) {
    // Replicate and allocate 8 GB memory
    fork(); // Not a bad call by itself; infinite while loop makes it dangerous
    double *ptr = (double *) malloc(1024 * 1024 * 1024 * sizeof(double));
  }

  // Indicate termination
  return 0;
}
```

Appearance Write for ~~computers~~ people; mostly pretty and somewhat useful

```c
// Factorial.c
//
// Computes factorial(n) where n is an
// integer (>=0) supplied by the user.
// Compilation/Execution takes about
// one second on most modern hardware
// running Linux OS with GCC.
//
// Compilation and execution:
// gcc Factorial.c -lm -o Factorial.x
// ./Factorial.x

// Headers
#include <stdio.h>

// Function declaration
int factorial(int n);

// main()
int main() {

  // Variable declaration/initialization
  int n = 0; // User-supplied number
  int N = 1; // factorial(n)

  // PRINT PROBLEM/PROGRAM STATEMENT

  // Accept user input
  printf("  A non-negative integer: ");
  scanf("%d", &n);

  // VALIDATE USER INPUT

  // Compute factorial and print result
  N = factorial(n);
  printf("  factorial(%d) = %d\n", n, N);

  // Indicate termination
  return 0;
}

// factorial()
int factorial(int n) {

  // Variable declaration/initialization
  int M = 1; // factorial(n)

  // Compute the factorial
  // factorial(0) or factorial(1) is 1
  if (n == 0 || n == 1) {
    M = 1;
  }

  // Recursive approach for n > 1
  if (n > 1) {
   M = n * factorial(n - 1);
  }

  // Return factorial to parent module
  return M;
}
```

Communication

* Meaningful nomenclature and comments

  Variables, arrays, structures and functions

* Documentation with metrics

  OS, architecture, hardware, compiler, versions, compilation and execution instructions, time required to compile/run, input and output requirements

* Revision control system

  Keep a detailed track of development

Modularization Divide n' conquer

- Module/Sub-routine
  - Accomplishes recurring tasks efficiently
  - Reduces program size and makes debugging easier
  - Requires description and comments just like the main program

Augusta Ada King, Countess of Lovelace (1815 – 1852): English mathematician and writer

Modularization Divide n' conquer

```
// sum_loop()
int sum_loop(int N) {

  // A sub-routine to compute the sum of first N integers for a given value of N
  // using a for loop.
  //
  // Usage:
  // sum = sum_loop(N);

  // Variable declaration and initialization
  int i   = 0; // Loop index
  int sum = 0; // Sum of integers from 1 through N

  // Loop method
  for(i = 1; i <= N; i++) {
    sum = sum + i;
  }

  // Return the value of sum to the parent function/module
  return sum;
}
```

Augusta Ada King, Countess of Lovelace (1815 – 1852): English mathematician and writer

Modularization Divide n' conquer

```
// sum_gauss()
int sum_gauss(int N) {

  // A sub-routine to compute the sum of first N integers for a given value of N
  // using Gauss' method.
  //
  // Usage:
  // sum = sum_gauss(N);

  // Variable declaration and initialization
  int sum = 0;

  // Gauss method
  sum = N * (N + 1)/2;

  // Return the value of sum to the parent function/module
  return sum;
}
```

Johann Carl Friedrich Gauss (1777 – 1855): German mathematician
Augusta Ada King, Countess of Lovelace (1815 – 1852): English mathematician and writer

Testing

* Check every line/step, and input/output
* Be a devil's advocate and check for extreme cases
* Does the program do NOTHING when it is supposed to NOTHING?

Unit test

A method by which individual units of source code, sets of one or more program modules together with associated control data, usage procedures, and operating procedures are tested to determine whether they are fit for use. It helps find problems early, facilitates change, simplifies integration, improves documentation, and the code's design.

Testing

Regression test

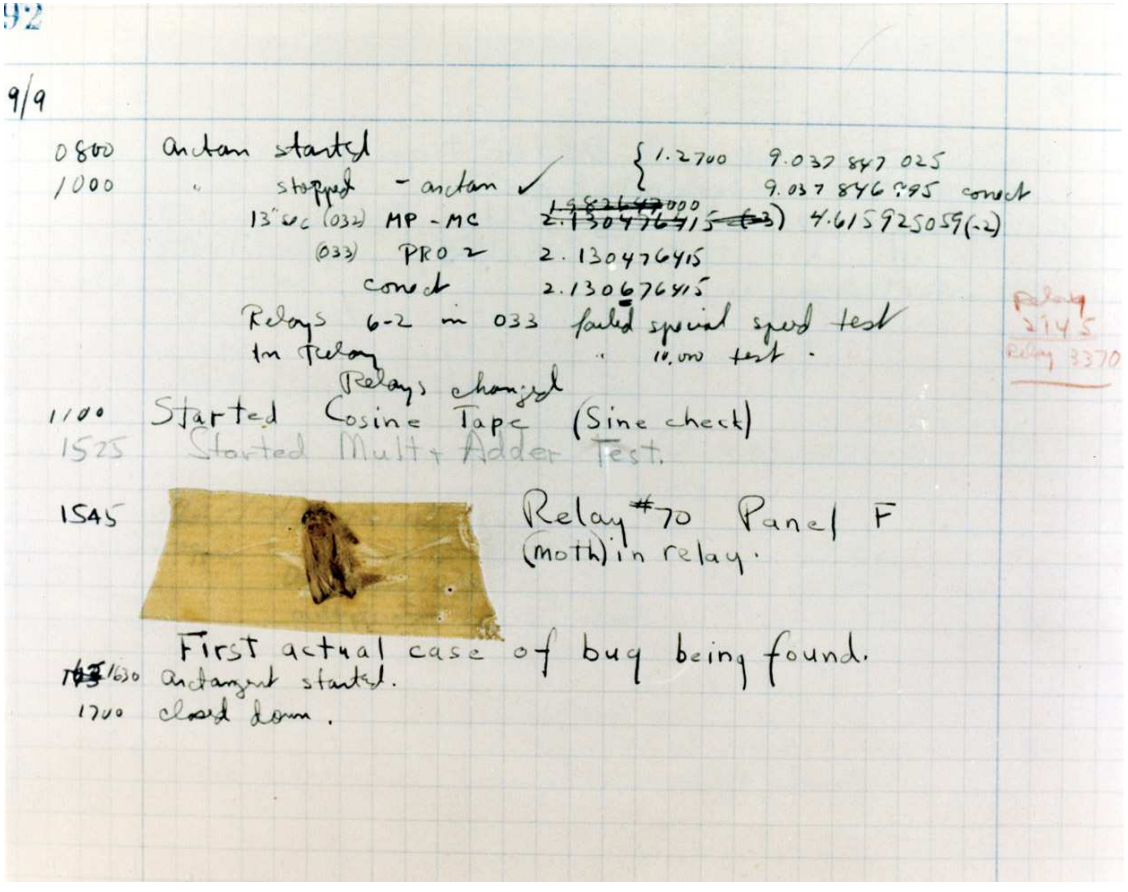
A type of software testing that seeks to

1. uncover new bugs (i.e., regressions) in existing functional and non-functional areas of a system after some changes have been made
2. ensure aforementioned changes have not inadvertently introduced new bugs (or re-introduced previously fixed old bugs), often in a different part of the code

The cause for re-appearance of bugs is often a poor revision control practice (or lack of a formal one, such as Git). The cause for new bugs is often a poor design and/or a fragile fix to a problem (i.e., solution tested for a particular case but not in general).

Debugging

* Identify the bug and understand its solution



Grace Brewster Murray Hopper (1906 – 1992): American computer scientist and US Navy Rear Admiral
She was one of the first programmers of Harvard Mark I (1944), invented the first compiler for programming languages, and popularized the idea of machine-independent programming languages. US Navy guided-missile destroyer, *USS Hopper*, and Cray XE supercomputer at NERSC, *Hopper*, are named in her honor of her achievements.

Debugging

- Angry Spouse Bug
- Bloombug
- Bugfoot
- Common Law Feature
- Defensive Coding
- Heisenbug
- Higgs Bugson
- Hindenbug
- Hydra Code
- Jenga Code
- Loch Ness Monster Bug
- Lorem Ipsum Bug
- Ninja Comments
- Reality 101
- Unicorn
- Yoda Conditions

http://blog.codinghorror.com/new-programming-jargon/

Ian Cummings (itcummin@mtu.edu), a PhD candidate in ECE, has written a script/program that reads through a MATLAB `.m` file, and uses the comments to prepare LaTeX documentation.

Optimization/Profiling

* Modifying the code to run more efficiently

Premature optimization

Act of letting performance considerations affect the code's design.

Design → Code → Debug → Optimize

It is better to design, then code from the design, and then profile or benchmark the resulting code to identify which parts should/can be optimized.

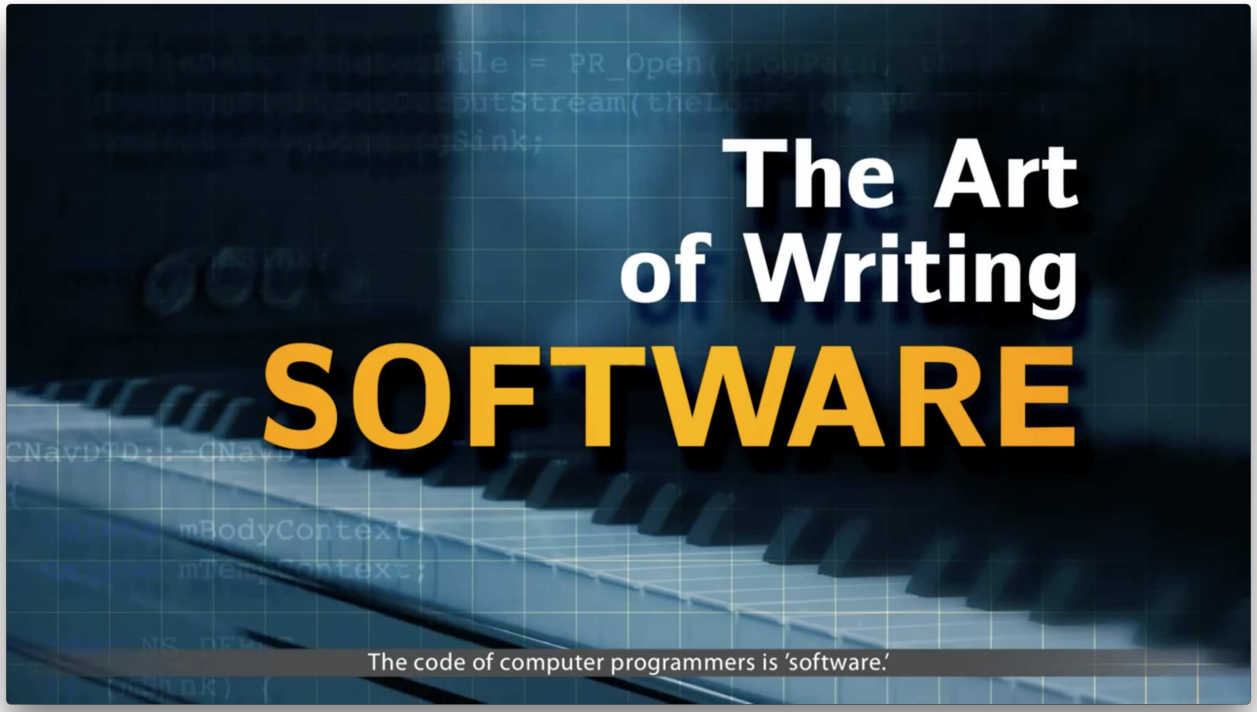
A simple and elegant design is often easier to optimize, and profiling may reveal unexpected performance problems that would be hidden behind the curtain of premature optimization.

Integrated Development Environment (IDE)

* Source code editor
* Syntax highlighting
* Intelligent code completion
* Build automation tools
* Debugger and profiler
* Compiler and/or interpreter
* Support for revision control system
* Object-oriented programming features

A comparison of IDEs

Additional References



https://www.youtube.com/watch?v=QdVFvsCWXrA

Additional References

* The Art Of Computer Programming, vol. 1-4A
  D. E. Knuth; Addison-Wesley (1968, 1969, 1973, 2011)

* The Idea Factory: Bell Labs And The Great Age Of American Innovation
  J. Gertner; Penguin Press (2012)

* The Design Of Everyday Things
  D. Norman; Basic Press (2013)

* Doxygen Official website | GitHub

  Automatic generation of documentation from source code

* Michigan Tech Multiliteracies Center (Walker Arts Building #107)

Additional References

* IDEs

  CLion (C/C++) | MATLAB | PyCharm | RStudio

  Vi(m): #1, #2, #3, #4, #5, #6, #7, #8, #9

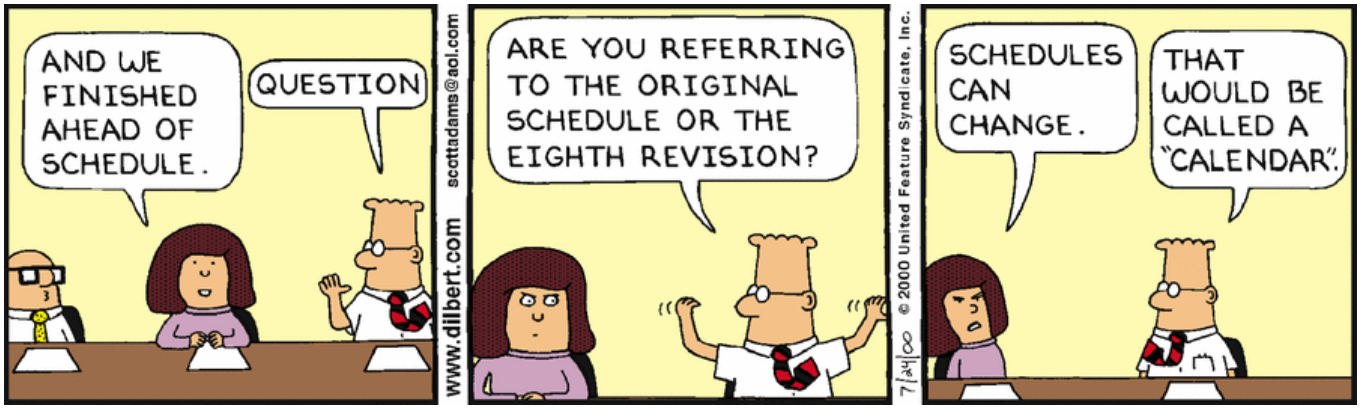
* Twitter

  @AdviceToWriters | @Doxygen | @Grammarly | @PurdueWLab
  @WritersDigest | @WritersRelief | @WritingCom | @Writing_Tips

  @inside_R | @MATLAB | @RBloggers | @RLangTip | @ROpenSci
  @RProgLangRR | @RStudio | @RStudioTips | @R_Programming

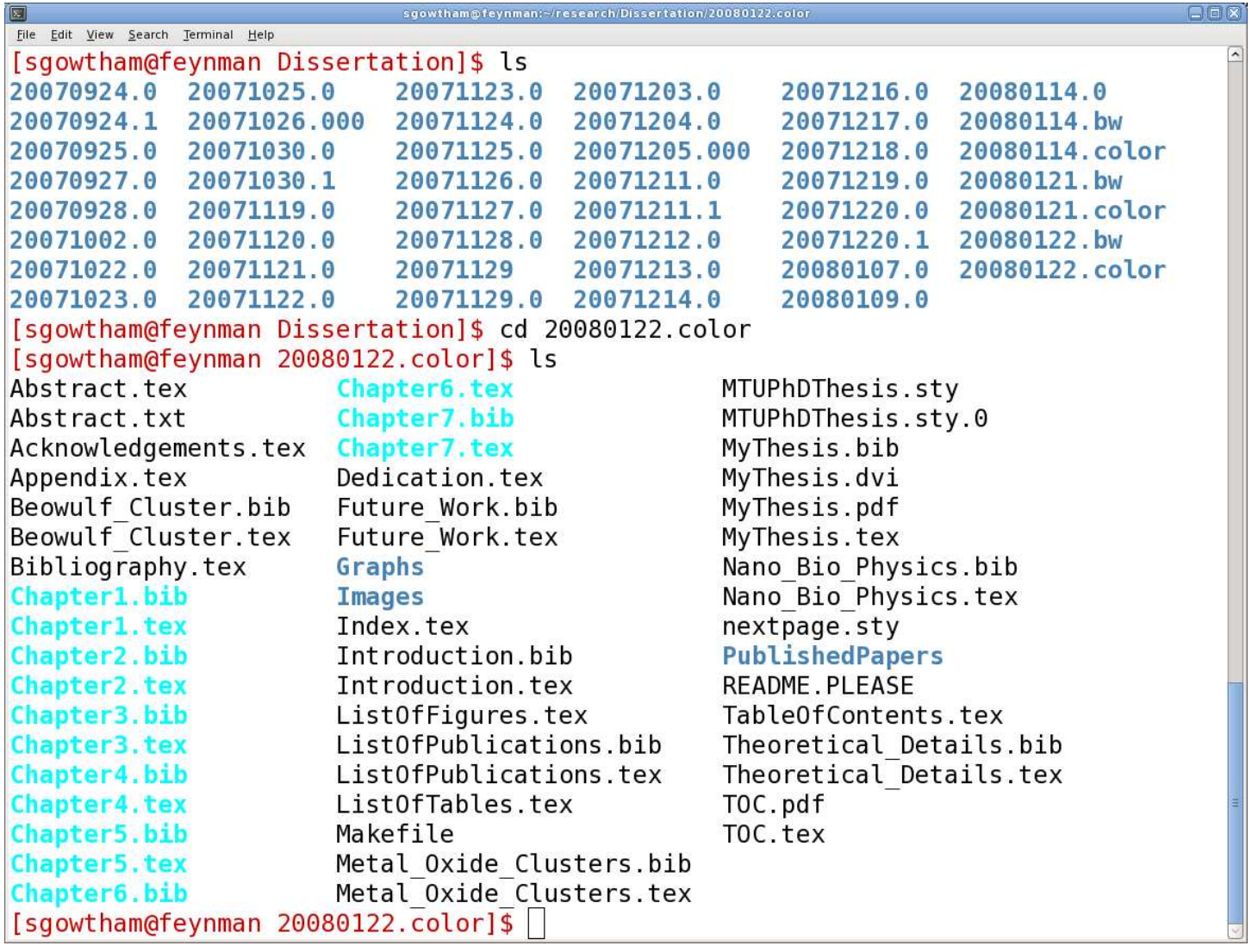
Revision Control System

Travel back and forth between revisions



http://dilbert.com/strip/2000-07-24/

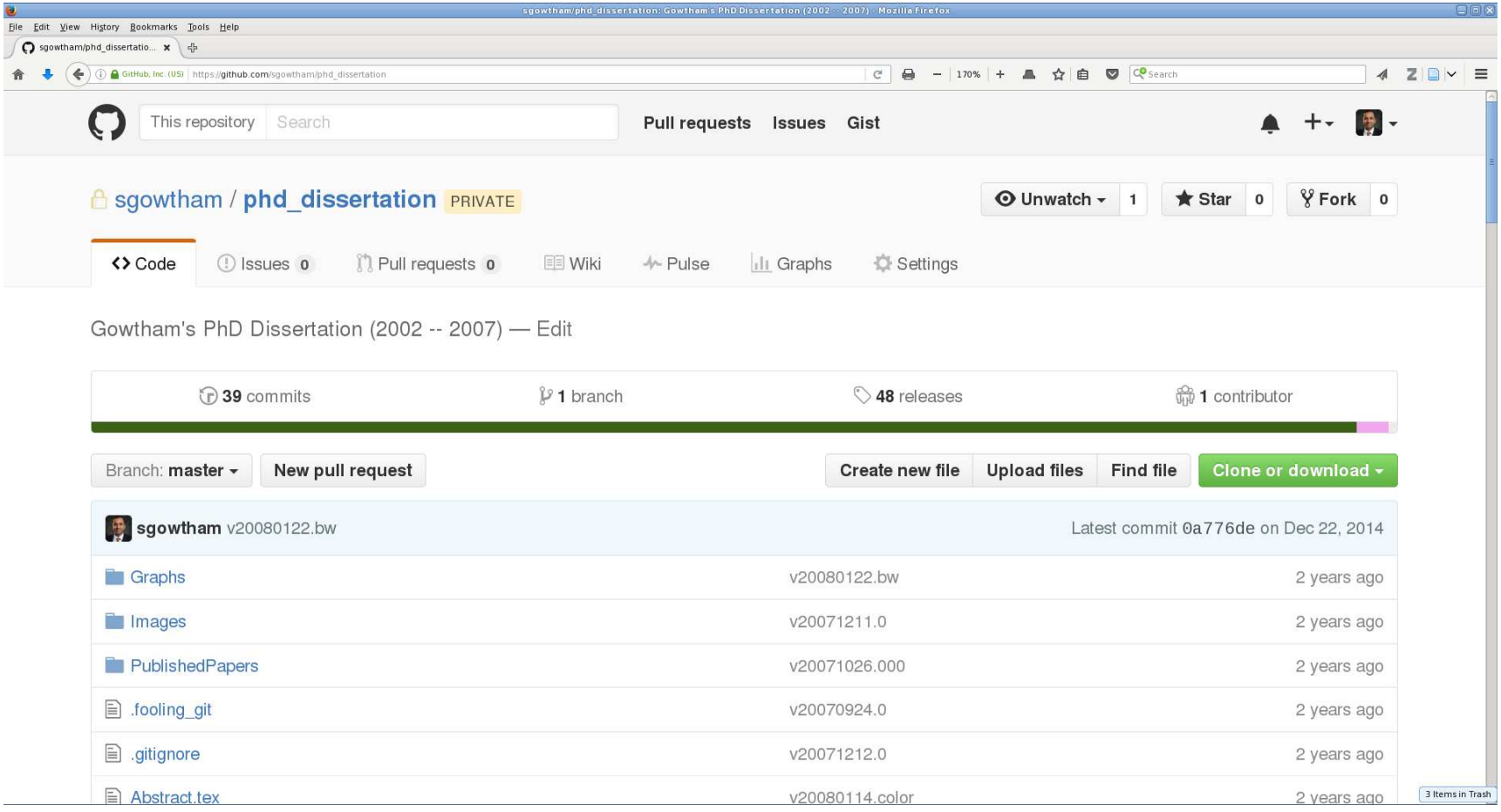
Instructor's Dissertation How it looked without a formal revision control system



Instructor's Dissertation Impact of not using a formal revision control system

* Did not have to spend time learning something new near graduation
* Spent a lot of time incorporating edits from advisor and advisory committee members, and between versions
* An incomplete sentence, and missed out on thanking six good friends (and their parents) in the final printed copy as a result of picking an incorrect version to continue editing
* Lifelong shame of being inept and ungrateful

Instructor's Dissertation How it would have looked with a formal revision control system



Git

Git

A distributed RCS with an emphasis on speed, data integrity, and support for distributed, non-linear workflows, and single/multiple users working on single/multiple projects.

Every working copy is a full-fledged repository with complete history and full version-tracking capabilities, independent of network access or a central server.

Potential applications

Systems administration, software development, manuscript preparation, event planning, etc.

http://git-scm.com

Linus Benedict Torvalds (1965 – present): Finnish American software engineer

Git and GitHub

GitHub, world's largest code host

A safe, secure and social web-based hosting service for software development projects that use Git revision control system. GitHub's copy is usually treated as the most trustworthy repository.

* The learning curve can be steep
* A form of data backup that keeps track of the workflow
* Easily move back and forth between revisions
* A readily available portfolio for potential employers
* Saves space, time, $, and creates opportunities

http://github.com

.gitignore

- Every Git repository should have one at its very top level
- List of files, folders and file types that should not be in the repository
  - OS- and language-specific temporary files
  - System files and symbolic links
  - Program executables and other binary files
  - Files with large data sets and/or sensitive information
  - A class of entities can be specified with wild card characters

Git Commit History

Textual output

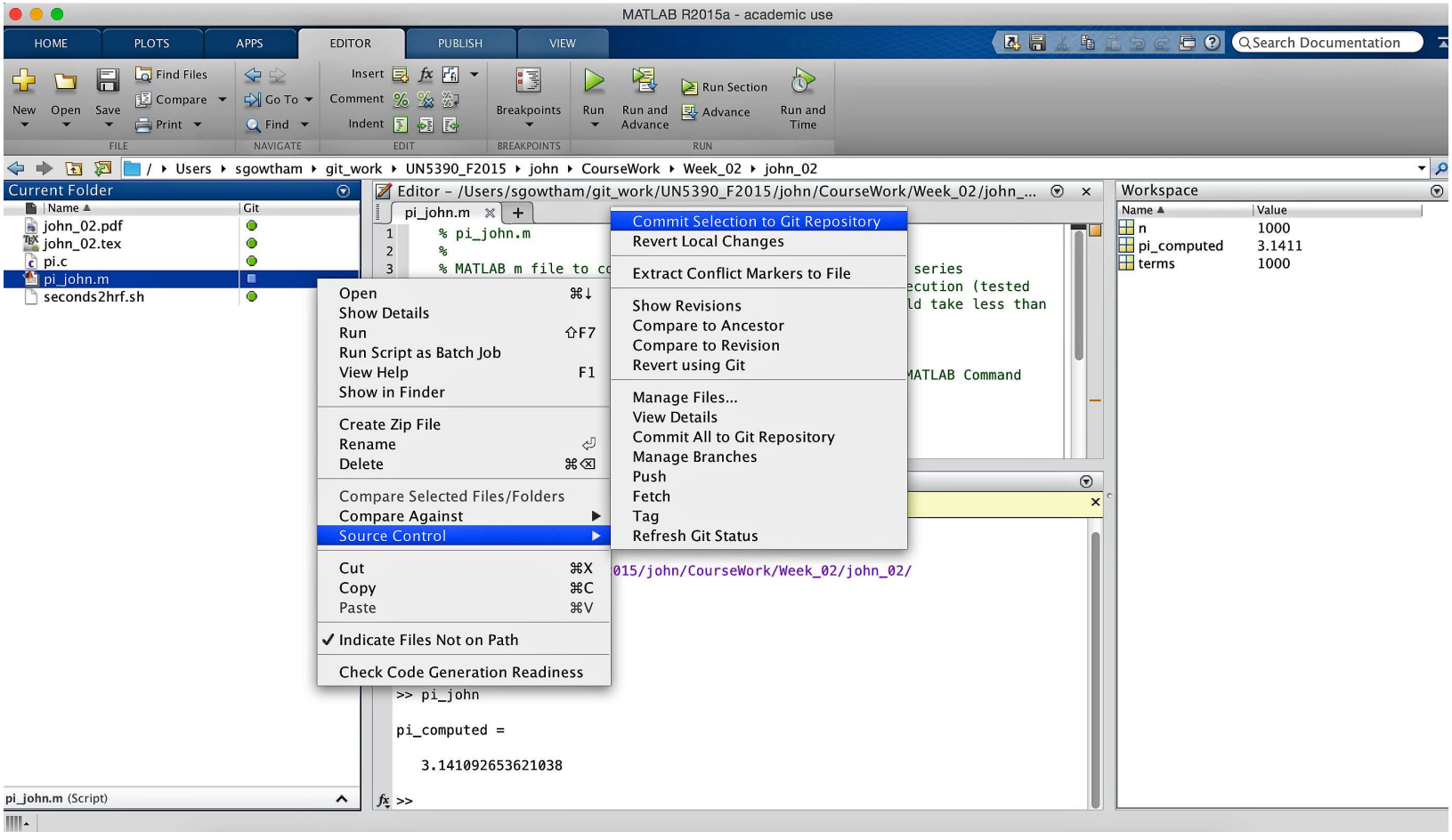
```
git log --pretty=format:"%h - %an, %ad :  %s"
```

Graphical output

```
gource --hide dirnames,filenames --seconds-per-day 0.1 \
    --auto-skip-seconds 1 -1280x720 -o - | \
    ffmpeg -y -r 60 -f image2pipe -vcodec ppm -i - \
    -vcodec libx264 -preset ultrafast -pix_fmt \
    yuv420p -crf 1 -threads 0 -bf 0 PROJECT_NAME.mp4
```

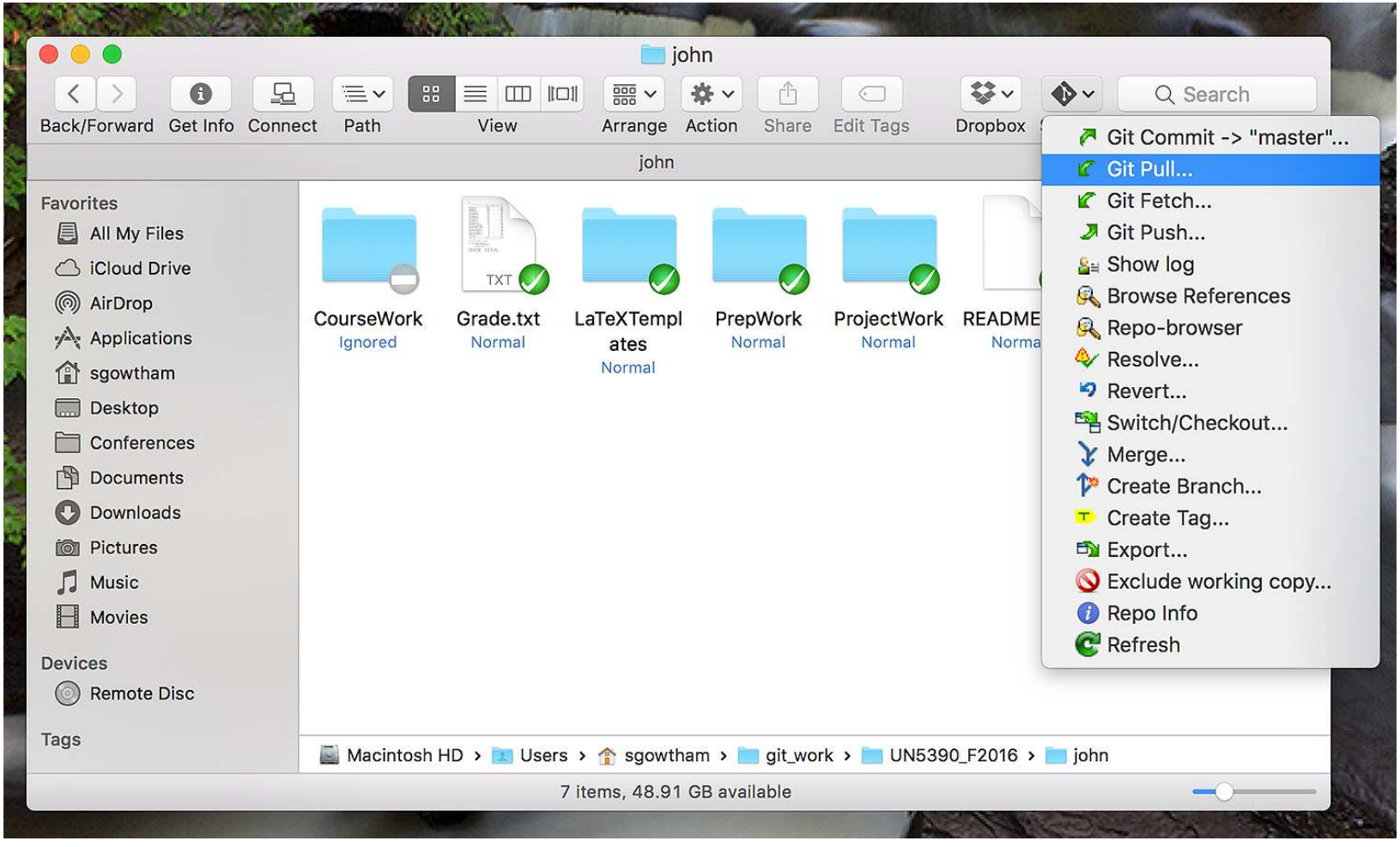
http://git-scm.com/book/en/Git-Basics-Viewing-the-Commit-History
Gource: Google project page | Linux kernel development 1991-2012.

Git and MATLAB R2014b and beyond



https://www.mathworks.com/help/matlab/source-control.html
https://www.mathworks.com/help/matlab/matlab_prog/set-up-git-source-control.html

Git and Mac



SnailGit on iTunes App Store (the free version supports one while the paid version supports many repositories).

Additional References

* Git

  Reference | Book | Videos | External links
  Tagging | Forking | Branching and merging

* Git – structuring commit messages: #1, #2, #3

* GitHub

  Interactive tutorial | Cheat sheet | Online training | Desktop version

* Twitter

  @GitHub | @GitHubEducation | @GitHubStatus

* Open a GitHub.com account (optional)

  Try to keep GitHub username same as Michigan Tech ISO username
  If you already have an account, there's no need to open a new one

Debugging With MATLAB

The art of finding and fixing mistakes

http://dilbert.com/strip/1995-11-14/

Commonly Used Techniques In Debugging Programs

- Taking detailed notes
- Using `printf()` (or equivalent) statements
- Logging with Standard Logging Frameworks using the debug flag
- Smarter text editors: emacs | gedit | Sublime Text | vim
- Free and open source tools: ddd | eclipse | gdb | valgrind
- Commercial tools: IBM Rational Purify | IDB | MATLAB | pgdbg

Debuggers are usually the last line of defense

There is no substitute for good programming etiquette OR taking detailed notes. Messages from debuggers often look cryptic to an untrained eye, and might require some effort to understand them.

Graphical Techniques Approximate value of π

$$\pi_{\text{computed}} = \left[\frac{2\sqrt{2}}{9801} \sum_{n=0}^{\infty} \frac{(4n)!\ (1103 + 26390n)}{(n!)^4\ 396^{4n}} \right]^{-1}$$

$$\epsilon = \left| \pi_{\text{known}} - \pi_{\text{computed}} \right|$$

$$\pi_{\text{known}} = 3.141592653589793$$

$$\delta = 10^{-15}$$

δ is the accepted value of zero (also known as the tolerance).

Graphical Techniques Approximate value of π

- Possible workflow
  - Use double-precision (i.e., `format long`)
  - Identify the constants (i.e., scaling factor, $2\sqrt{2}/9801$)
  - Simplify the core within the loop
  - Estimate the error associated with computed value of π
  - Loop should end when error is less than a given tolerance, δ
  - Display the results

Advanced Techniques MATLAB Command Window

`dbstop`	Set breakpoints for debugging
`dbstatus`	List all breakpoints
`dbstep`	Execute next executable line from the current breakpoint
`dbcont`	Resume execution
`dbclear`	Remove breakpoints
`dbtype`	Display file with line numbers
`dbstack`	Function call stack
`keyboard`	Input from keyboard
`dbquit`	Quit debugging mode

More information: http://www.mathworks.com/help/matlab/debugging-code.html

Potential Pitfalls

Highlight reel of some of my biggest blunders since 2002

http://dilbert.com/strips/comic/1999-09-14/

This won't happen to me Syndrome

- Getting enough sleep/rest
- Budgeting time and resources
- Taking detailed notes
- Using `printf()` (or equivalent) statements
- Describing the workflow to someone else
- Having someone else look at the code
- Understanding what the language can and cannot do
- Integrating more than one language into the workflow

Code samples in `AdditionalMaterial/CRTErrors/` are good candidates for this failed experiment.

Blind Copy, Compilation and Execution

* Read through the borrowed code
* Check if your hardware meets the criteria

This pitfall can often cause hardware damage beyond repair.

Variable Sizes and Limits

UN5390: Scientific Computing I

File Edit View Search Terminal Help

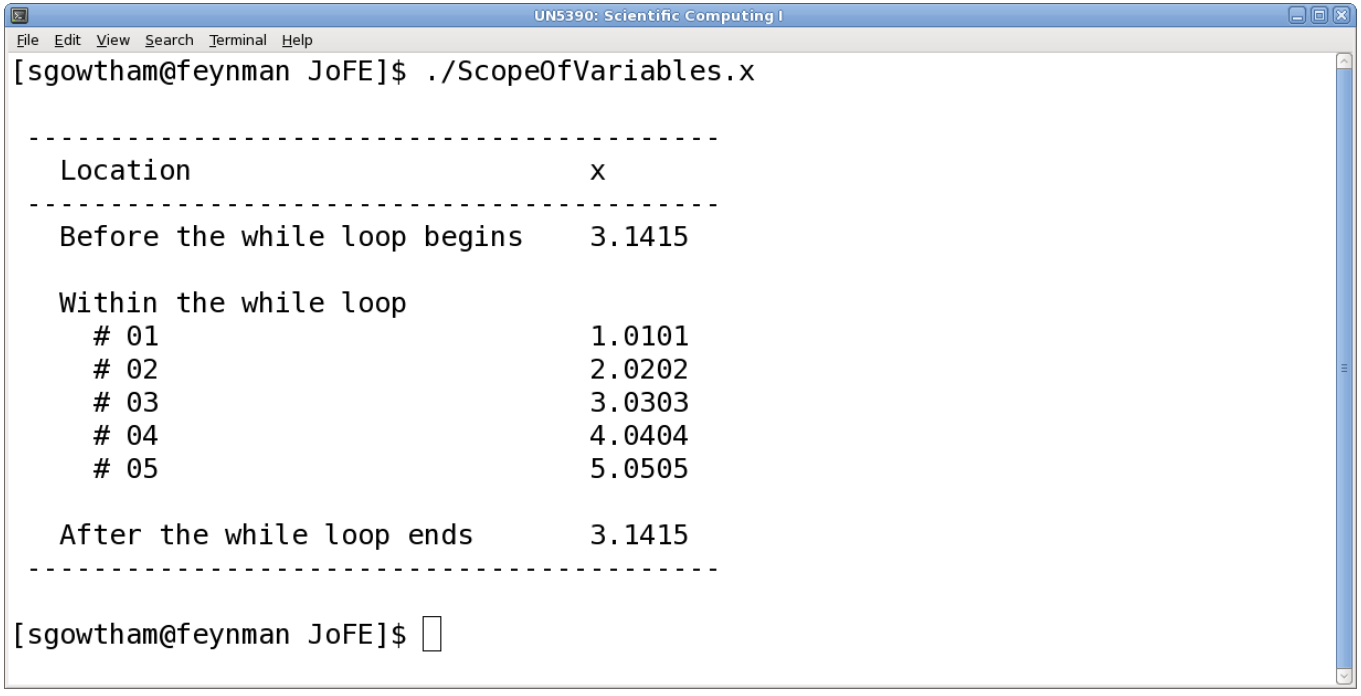
```
[sgowtham@feynman JoFE]$ ./VariableSizesLimits.x

 ------------------------------------------------------------------------------
   Data Type                            Minimum Value        Maximum Value  Bytes
 ------------------------------------------------------------------------------
   (signed) char                                 -128                  127      1
   unsigned char                                    0                  255      1
 ------------------------------------------------------------------------------
   (signed) int                           -2147483648           2147483647      4
   unsigned int                                     0           4294967295      4
   (unsigned) short int                        -32768                32767      2
   unsigned short int                               0                65535      2
   (signed) long int          -9223372036854775808   9223372036854775807      8
   unsigned long int                                0  18446744073709551615      8
   (signed) long long int     -9223372036854775808   9223372036854775807      8
   unsigned long long int                           0  18446744073709551615      8
 ------------------------------------------------------------------------------
   float       (6 digits)              1.17549e-38          3.40282e+38      4
   double      (15 digits)             2.22507e-308         1.79769e+308     8
   long double (18 digits)             3.3621e-4932         1.18973e+4932    16
 ------------------------------------------------------------------------------

[sgowtham@feynman JoFE]$
```

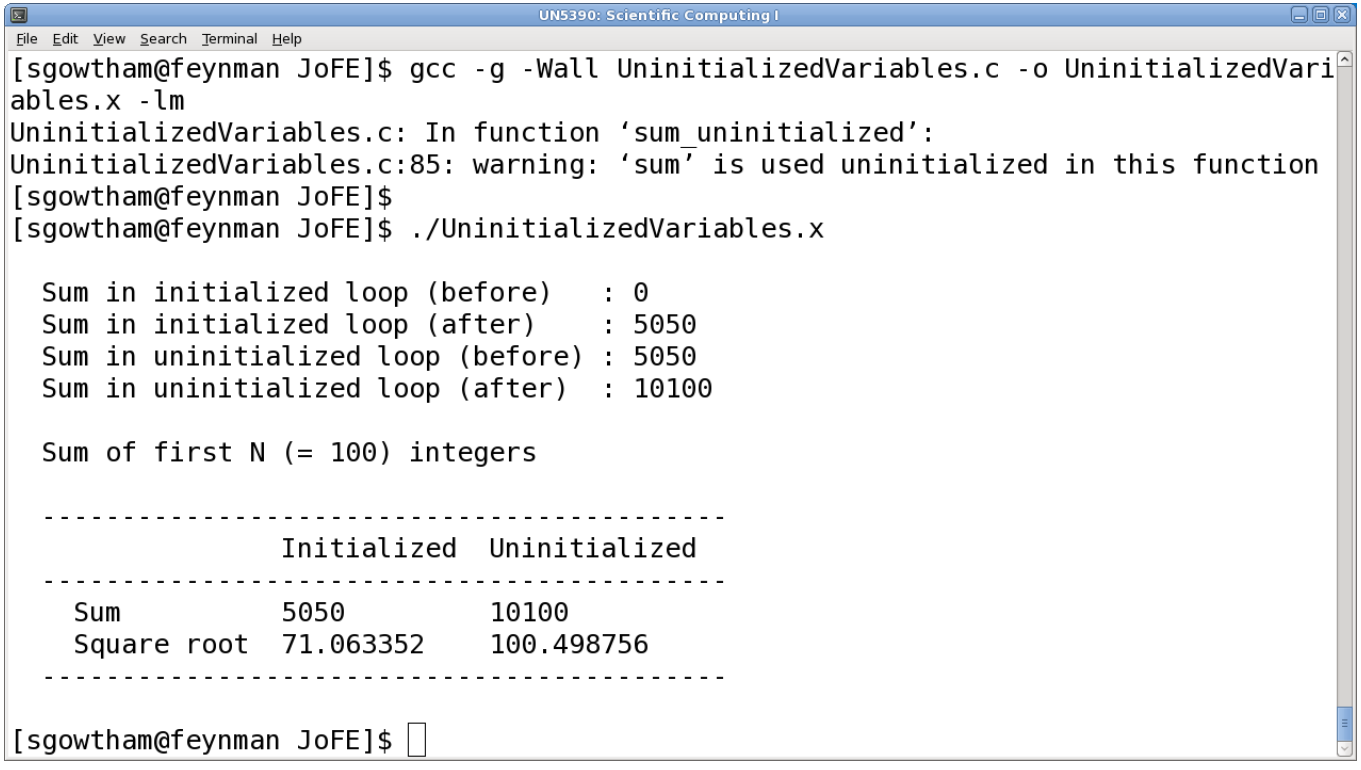
If a variable is assigned a value higher (or lower) than its defined upper (or lower) limit, then the value stored is the maximum (or minimum) value

Scope of Variables



Observe the value of x before, within and after the `while` loop

Uninitialized Variables



Observe the warning issued by the compiler

Without the `printf()` statements within `sum_uninitialized` function, it's quite tough to find this error.

Uninitialized Variables

UN5390: Scientific Computing I

File Edit View Search Terminal Help

```
[sgowtham@feynman JoFE]$ gcc -g -Wall UninitializedVariables.c -o UninitializedVari
ables.x -lm
[sgowtham@feynman JoFE]$
[sgowtham@feynman JoFE]$ ./UninitializedVariables.x

  Sum in initialized loop (before)   : 0
  Sum in initialized loop (after)    : 5050
  Sum in uninitialized loop (before) : 0
  Sum in uninitialized loop (after)  : 5050

  Sum of first N (= 100) integers

  ------------------------------------------
                Initialized  Uninitialized
  ------------------------------------------
    Sum         5050         5050
    Square root 71.063352    71.063352
  ------------------------------------------

[sgowtham@feynman JoFE]$
```

Once the program produces meaningful result, comment the `printf()` statements used for debugging purposes.

Assignment vs Equality, and Yoda Condition

Assignment vs Equality

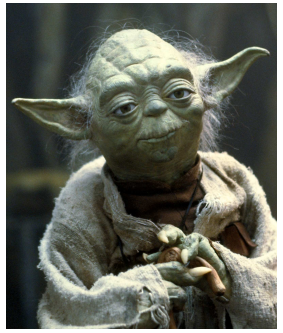
A single = represents the assignment operator. For e.g., `x = 42` means *assign the value 42 to variable* `x`.

A double = is used to check equality. For e.g., `if x == y` means *check if* `x` *has the same value as* `y`.

Yoda condition

Checking if a constant equals the variable instead of the other way.

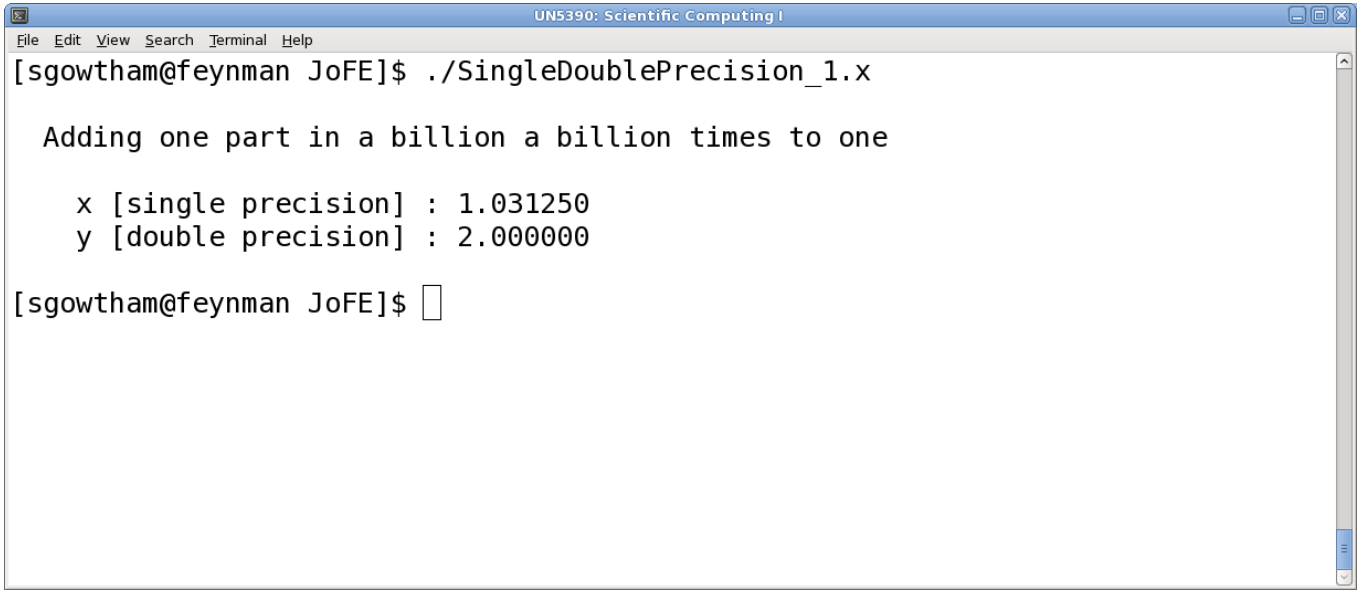
```
if (42 == x) {
  DO SOMETHING
}
```



Single- vs Double-Precision

Adding one to the sum of one part in a billion a billion times

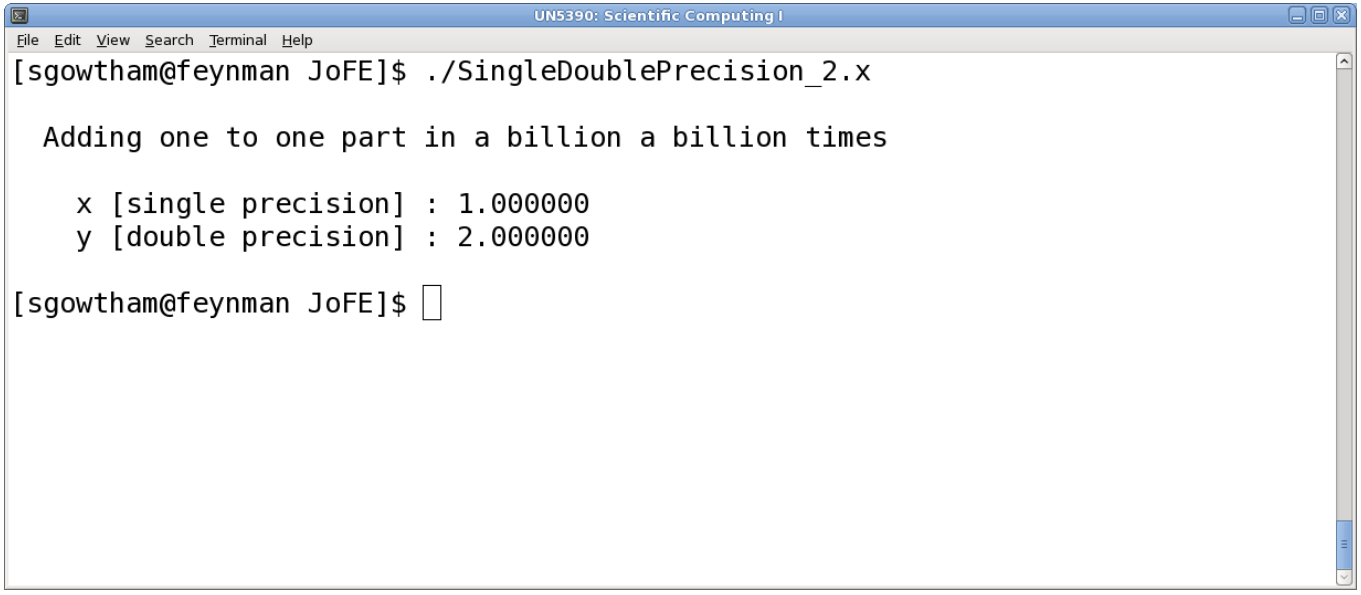
$$\left[\sum_{n=1}^{10^9} 10^{-9} \right] + 1 = ?$$



Single- vs Double-Precision

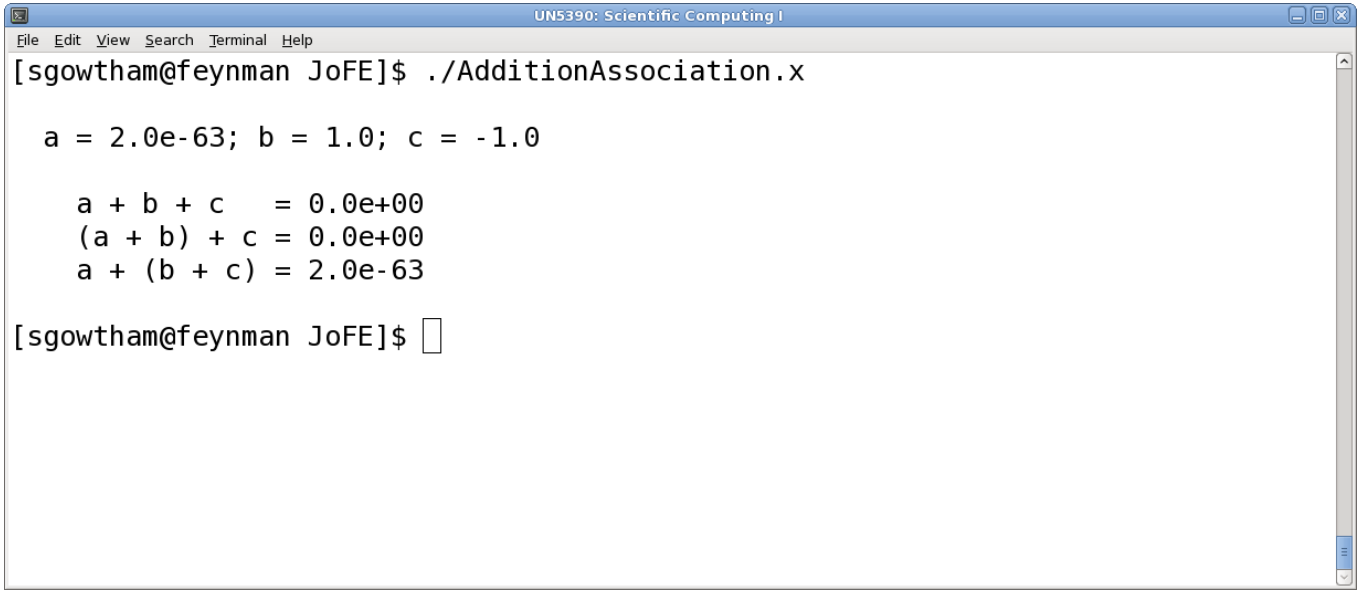
Adding the sum of one part in a billion a billion times to one

$$1 + \left[\sum_{n=1}^{10^9} 10^{-9} \right] = ?$$



Addition is Not Associative

$a + b + c$, $(a + b) + c$, and $a + (b + c)$ may not be same



Subtracting Nearly Equal Numbers

Functional derivative definition implies $f'(x)$ gets better as $h \to 0$

$$f'(x) = \lim_{h \to 0} \frac{f(x + h) - f(x)}{h}$$

With $f(x) = \sin(x)$,

$$f'_{\text{Functional}}(x) = \lim_{h \to 0} \frac{\sin(x + h) - \sin(x)}{h}$$

$$f'_{\text{Analytical}}(x) = \cos(x)$$

Subtracting Nearly Equal Numbers

UN5390: Scientific Computing I

File Edit View Search Terminal Help

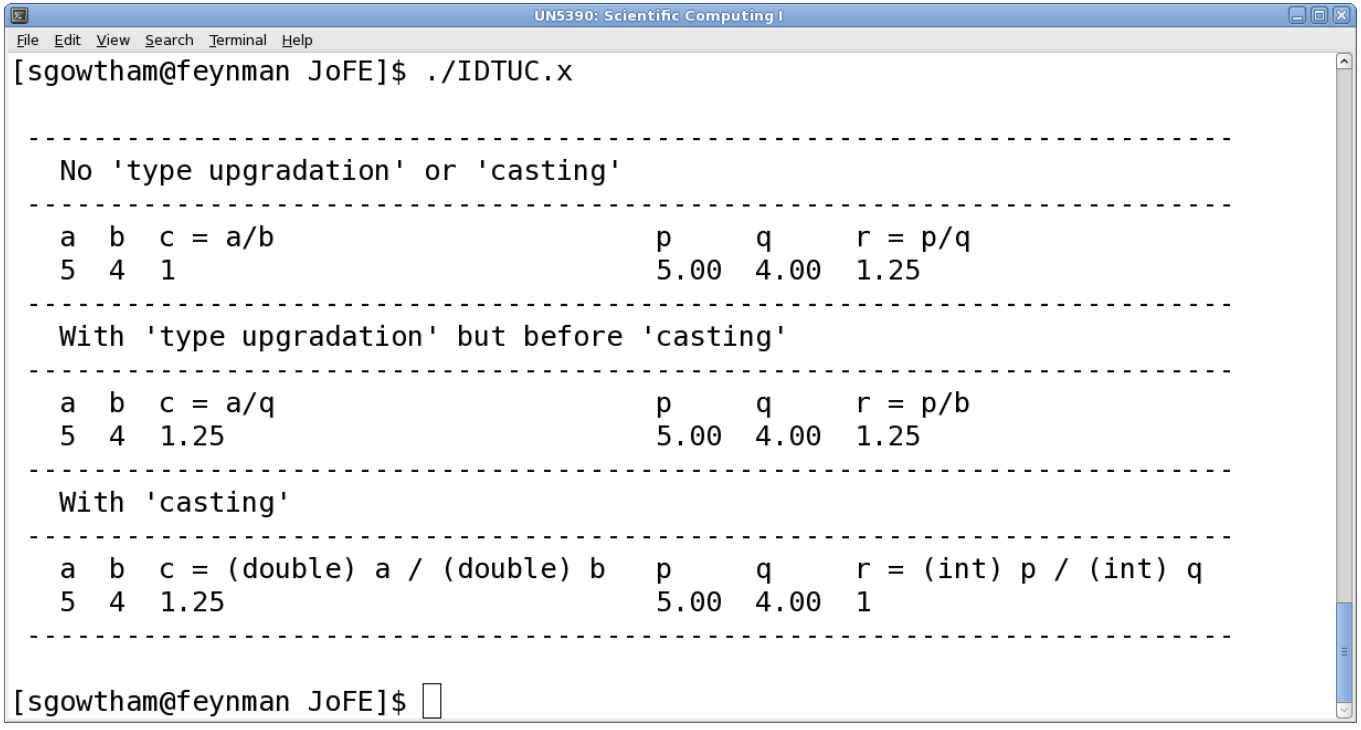
```
[sgowtham@feynman JoFE]$ ./SubtractionEqualNumbers.x

  ------------------------------------------------------------------
    h      Functional derivative  Analytical derivative  Error
  ------------------------------------------------------------------
    1e+00  0.0678264420177852     0.5403023058681398     5e-01
    1e-02  0.5360859810118690     0.5403023058681398     4e-03
    1e-04  0.5402602314186211     0.5403023058681398     4e-05
    1e-06  0.5403018851213304     0.5403023058681398     4e-07
    1e-08  0.5403023028982545     0.5403023058681398     3e-09
    1e-10  0.5403022473871033     0.5403023058681398     6e-08
    1e-12  0.5403455460850637     0.5403023058681398     4e-05
    1e-14  0.5440092820663267     0.5403023058681398     4e-03
    1e-16  0.0000000000000000     0.5403023058681398     5e-01
    1e-18  0.0000000000000000     0.5403023058681398     5e-01
    1e-20  0.0000000000000000     0.5403023058681398     5e-01
  ------------------------------------------------------------------
[sgowtham@feynman JoFE]$
```

What's the value of h that minimizes the error?

Integer Division, Type Upgrade and Casting

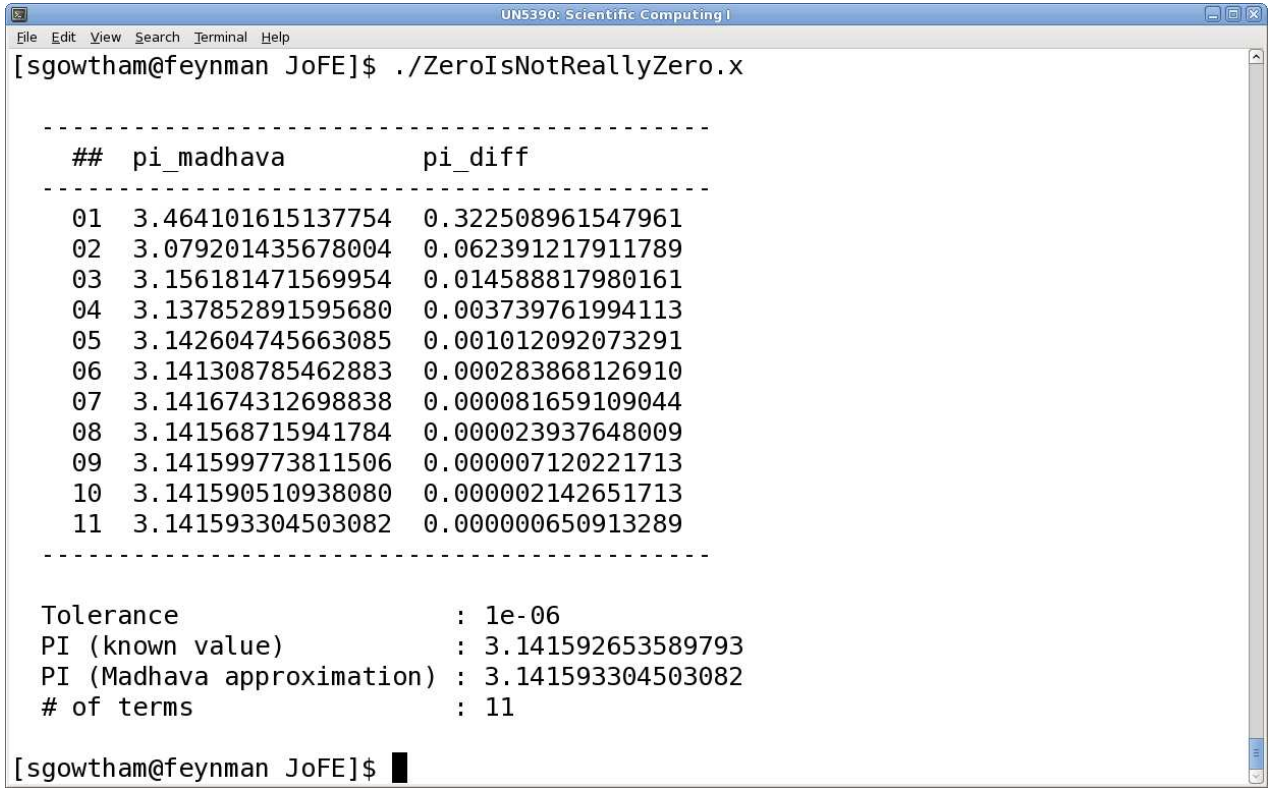
a and b are `integers`; p and q are `double-precision`.



Observe the value of c and r after each case

One can invoke double-precision in MATLAB using the command `format long`.
Different programming languages treat variable declaration differently.

Zero is Not Really Zero



Tolerance, δ, is the tolerable/accepted value of zero

It can be used to check if the value of two variables is identical

δ can change from one problem (or project) to another.

Zero Costs Space and Time

$$A = \begin{pmatrix} 0 & 0 & 0 & 0 & a_{14} & 0 & 0 & 0 & 0 & 0 \\ 0 & a_{21} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{39} \\ 0 & 0 & 0 & a_{43} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{55} & 0 & 0 & a_{58} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{66} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{74} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{87} & 0 & 0 \\ 0 & 0 & a_{92} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Storing every double-precision element requires 800 bytes

Storing only non-zero double-precision elements requires 80 bytes

Matrix in which most elements are zero is *sparse*, and one in which most elements are non-zero is *dense*.

Row-Major Language C, C++, Python

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

* A, laid out in linear fashion, would look like

  a_{11} a_{12} ... a_{1n} a_{21} a_{22} ... a_{2n} ..... a_{m1} a_{m2} ... a_{mn}

* To loop through the array in above order
  * First, loop over rows
  * Next, loop over columns

Column-Major Language FORTRAN, MATLAB, Octave, R

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

* A, laid out in linear fashion, would look like

  a_{11} a_{21} ... a_{m1} a_{12} a_{22} ... a_{m2} ..... a_{1n} a_{2n} ... a_{mn}

* To loop through the array in above order
  * First, loop over columns
  * Next, loop over rows

Memory Pre-Allocation and Memory Leak

Pre-allocation

The act of checking the availability of required amount of memory, and if available, reserving it to store entities at the beginning of a program.

Leak

The act of not releasing (i.e., freeing up) the memory that is no longer necessary. Leaks often occur when a memory allocations are incorrectly managed by a program and/or when an entity stored in memory cannot be accessed by the running code.

`MemoryPreAllocation.c` is in `AdditionalMaterial/JoFE/`.
`ForkBomb.c` discussed previously demonstrated both these aspects but in a very dangerous fashion.

Things To Try

- Division by zero
- Square root of a negative number
- Array population/manipulation starting with 0 as the array index
- Generate the Fibonacci sequence

$$F(n) = F(n-1) + F(n-2)$$

Use $F(0) = 0$ and $F(1) = 1$ for $n = 2, 3, 4, \ldots$

- A multi-file project where the master file calls one or more dependent files but not all dependent files are in the same (or designated) folder as the master file

- Installed by default on most Linux machines
- Supports C, C++, FORTRAN, Java and Python
- Historical recall (with arrow keys) and auto-completion (with tab)
- More information about a specific topic can be accessed via `help`

Compiling, running and debugging a C program

```
gcc -Wall -g -pg PROGRAM.c -lm -o PROGRAM.x
./PROGRAM.x
gdb -q ./PROGRAM.x
run
```

gdb The Gnu Debugger

`run`	Run `PROGRAM.x`
`kill`	Stop executing `PROGRAM.x`
`help`	Get help on debugger commands
`list`	List the source code in `PROGRAM.c`, 10 lines at a time
`list M,N`	List the source code between lines `M` and `N`
`break M`	Pause the execution at line `M` (i.e., set a breakpoint)
`continue`	Continue the execution
`delete M`	Delete the pause at line `M` (i.e., remove a breakpoint)
`step`	Execute the current line in source code but stop before the next line
`next`	Execute the next line in source code
`print EXPR`	Print the value of expression `EXPR`
`quit`	Exit `gdb`

Observe the similarity between these and MATLAB commands.

Additional References

* An Introduction To Fast Format
* Logging Frameworks

  Boost (C++), Pantheios (C/C++). SLF4J (Java), etc.
* The Science Of Debugging

  M. Telles, Y. Hsieh; Coriolis Technology Press (2001)
* Twitter

  @AnoushNajarian | @HadleyWickham

Before We Meet On Friday

- Locate an IT-managed lab with a Linux workstation

  http://www.mtu.edu/it/services/computer-labs/

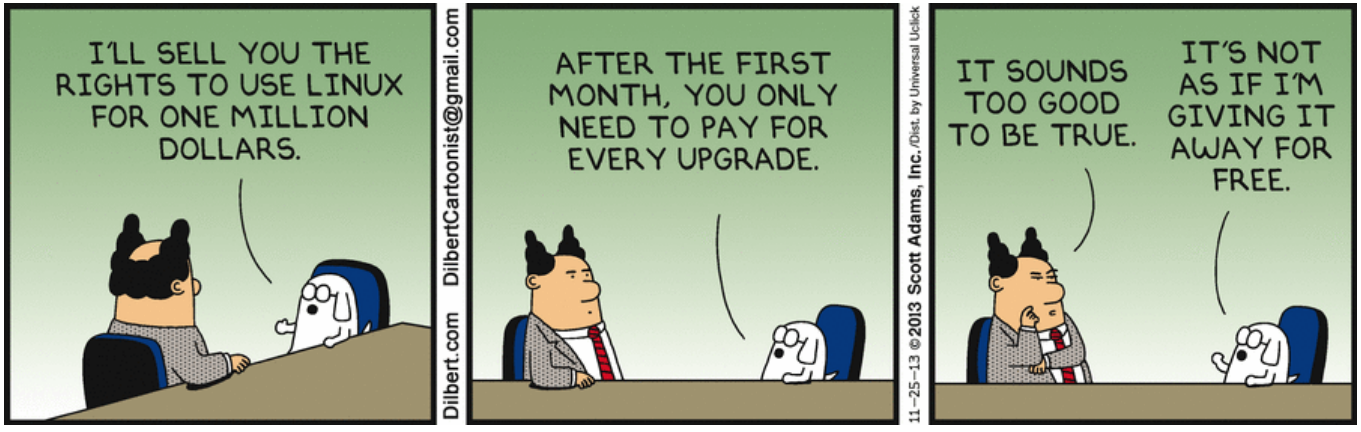
  Note down the location (building, floor, room, etc.)

- Verify that you can log into one such workstation using your Michigan Tech ISO credentials

- Change your default login shell to `/bin/bash`
  - Log into https://mylogin.mtu.edu/
  - Click on **My Profile** tab
  - Select `/bin/bash` from **NIS Shell** dropdown list
  - Click on **Submit**

Linux

The free and open source operating system



http://dilbert.com/strip/2013-11-25/

Linux

Linux is a Unix-like and mostly POSIX-compliant computer operating system assembled under the model of, and a prime example for concept and practice of, free and open source software development and distribution.

The underlying source code may be used, modified, and distributed – commercially or non-commercially – by anyone under licenses such as the GNU GPL.

Linux is user friendly but ...

It is picky as to who its friends are, and often very unforgiving of mistakes. It prefers friends to be committed to mindful practice, and be sensitive to case, space, and other weird characters.

Linus Benedict Torvalds (1965 – present): Finnish American software engineer

Linux gymnasium

- `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
- 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

Just so you know

All IT-managed workstations, unless explicitly indicated otherwise, run RHEL 7.x and will mount your campus home directory.

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 during software development.

Additional References

* FOSS 101: Essentials of Free and Open Source Software
  * Free and online course from Michigan Tech
  * 10 total modules with chain-like dependency
  * Each module has 10 untimed yes/no-like tasks and unlimited attempts (+ a *module completion badge* to show off in your Canvas profile)
  * Attempt to work through the first six modules
  * Contact Dr. Gowtham when in need of help with these tasks
  * Dr. Mork will observe of our progress

Additional References

- POSIX Compliance | GNU General Public License
- Linux | The Linux Command Line | The Command Line Crash Course
- Red Hat Enterprise Linux (RHEL) | CentOS Project | Fedora
- Vi(m) editor: Interactive Tutorial | Reference
- BASH Scripting/Programming: Introduction | Beginners | Advanced
- Twitter

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

Linux Server Setup

A bird's eye view of general HOW TOs, DOs and DON'Ts

http://dilbert.com/strip/2011-06-09/

Installation

- Type #1: Complete
  - Install all packages and services, and then disable unnecessary services
  - Time to install/update packages can be very long
  - Installation usually takes care of package dependency
  - Forgetting to disable/enable critical services can be a show-stopper
- Type #2: Selective
  - Install only necessary packages and services
  - Time to install/update packages can be short
  - Resolving new package dependency can be non-trivial/time consuming

Services Inexhaustive list

* Database (MySQL, PostgreSQL, Oracle)
* DHCP and DNS
* Email (IMAP and POP3; SMTP)
* LDAP (directory services; e.g., *stalker net* at Michigan Tech)
* Load Balancing (balance incoming traffic amongst different servers)
* Print
* Programming and Scripting
* SSH (remote access) and FTP (files and folders)
* Web (Apache, Tomcat)

Security Firewall

* Quickest way to protect a new installation
* Should be implemented before the server goes online
* Change the default username/password for the server/services
* Keeps the door (i.e., access) to a service open to necessary sources

From Dr. Gowtham's *Journal of Failed Experiments*

Office workstation, `feynman.it.mtu.edu`, had 193 failed login attempts as `root` within the first 10 minutes of its installation.

Brand new installation of Raspberry Pi 3 was being used by someone else as a hopping point and a playstation server within 24 hours of going online (forgot to change the default username and password).

Security Ownership and permission

* Ownership of files, folders and other entities
  * `user`: the user who created the entity (i.e., the owner)
  * `group`: the group of users associated with the entity
  * `others`: everybody else
* Permissions for files, folders and other entities
  * `read`: read the entity (numerical value: 4)
  * `write`: write to/modify the entity (numerical value: 2)
  * `execute`: run the entity (numerical value: 1)

Run `ls -l` in a Terminal and observe the first column of output

Identification

* Name
  * Needs a fully qualified domain name (FQDN) to be on the network

    `Jim's Foodmart`
    `feynman.it.mtu.edu` or `superior.research.mtu.edu`
  * Can have aliases/nicknames for easier (local) identification

    `Jim's` or `feynman` or `superior`
* Number (i.e., IP address)
  * Needs an IPv4/IPv6 address that corresponds to the FQDN

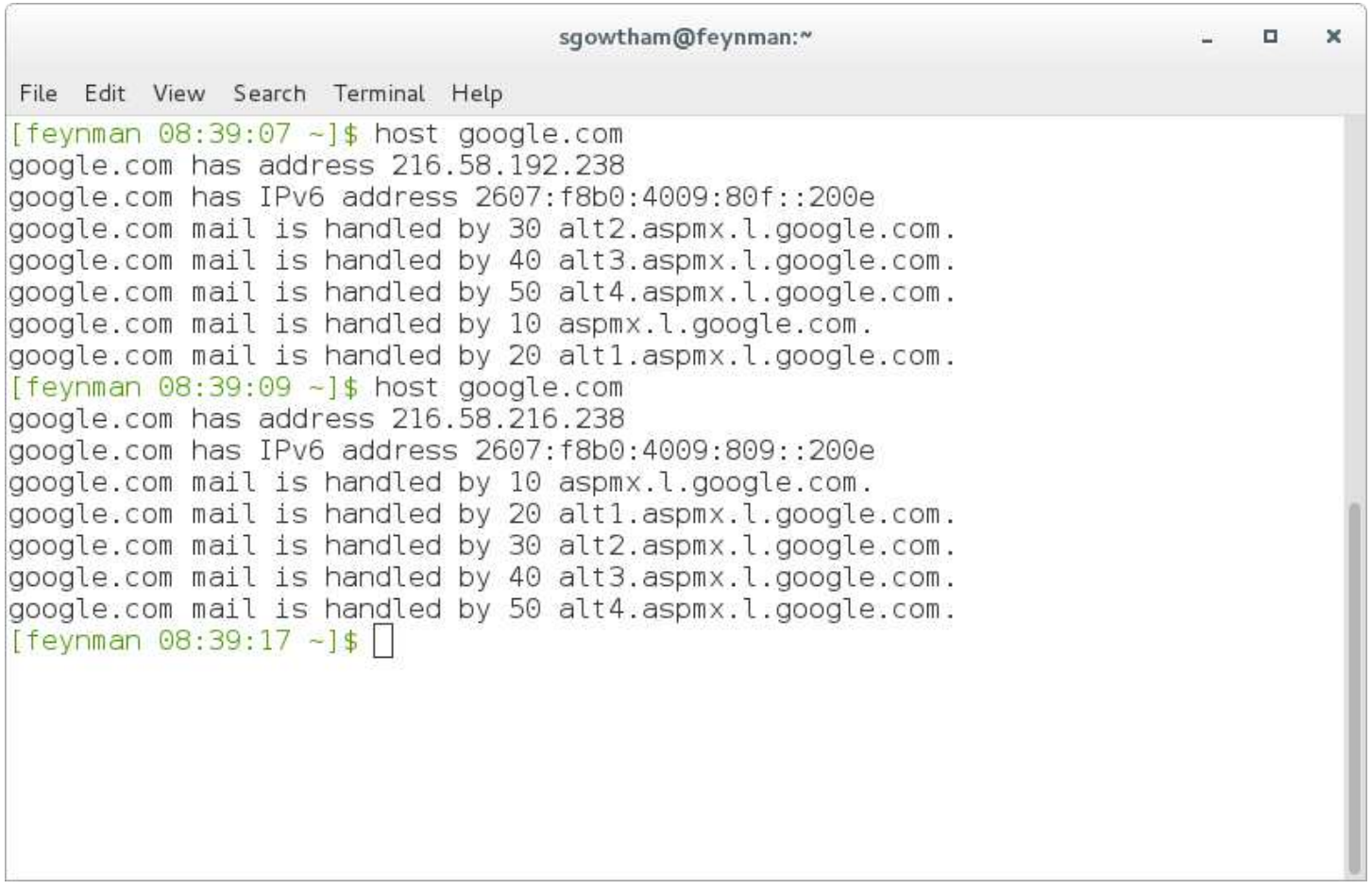
    `300 Pearl Street, Houghton, MI 49931`
    `141.219.41.21` or `141.219.92.69`

IP Address *Ain't no place like 127.0.0.1!*

- Special purposes
  - Loopback and diagnostic functions: 127.0.0.0 – 127.255.255.255
  - Multicast groups: 224.0.0.0 – 239.255.255.255
  - Future use and R&D: 240.0.0.0 – 254.255.255.254
- Private/Internal network (e.g., router at home, office, etc.)
  - Class A: 10.0.0.0 – 10.255.255.255
  - Class B: 172.16.0.0 – 172.31.255.255
  - Class C: 192.168.0.0 – 192.168.255.255
- Public/External network (everything else)

Things To Try

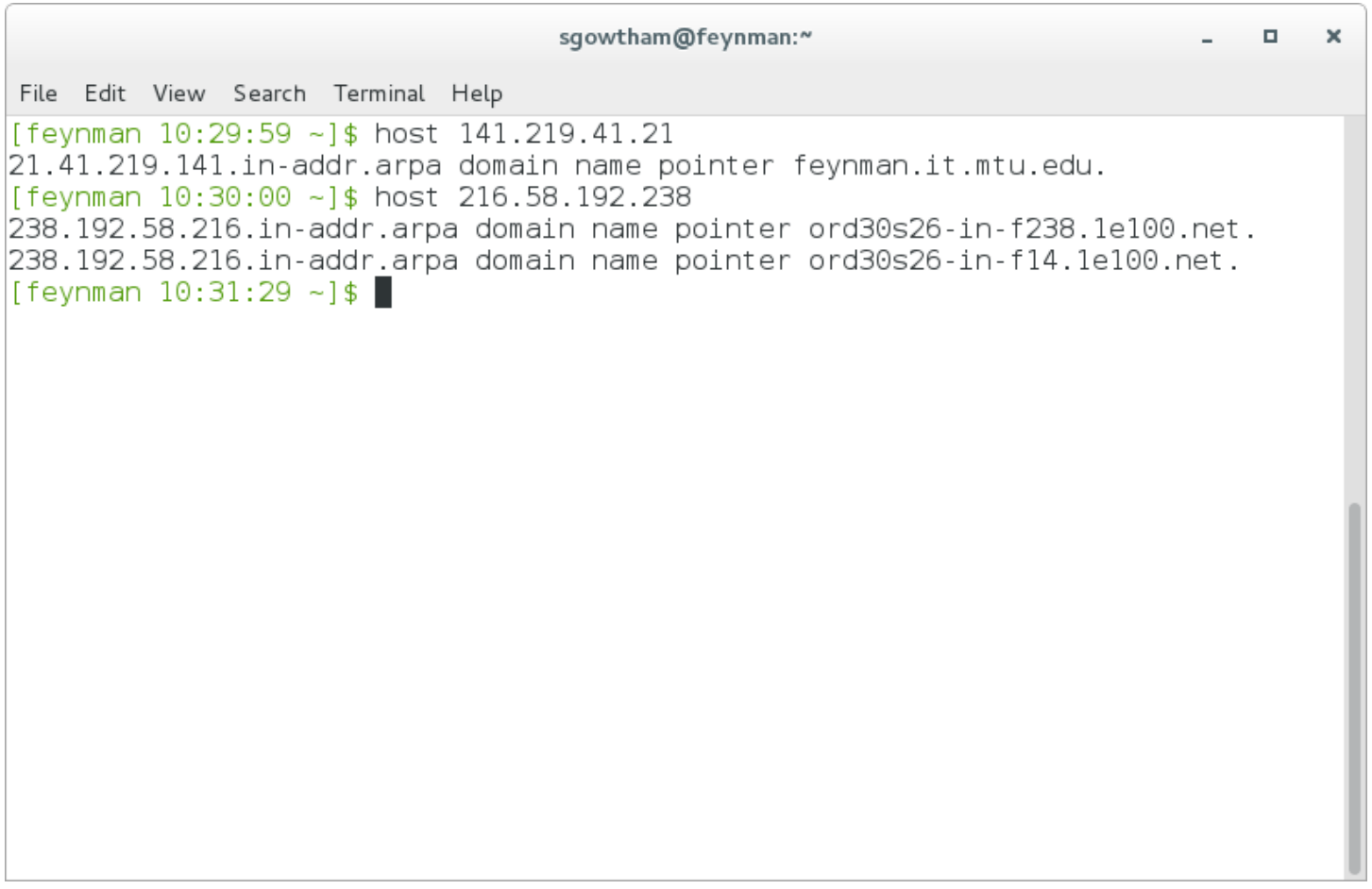
Finding IP address given the hostname (DNS lookup)



Observe that the host command returns two DIFFERENT IP addresses for the same hostname.

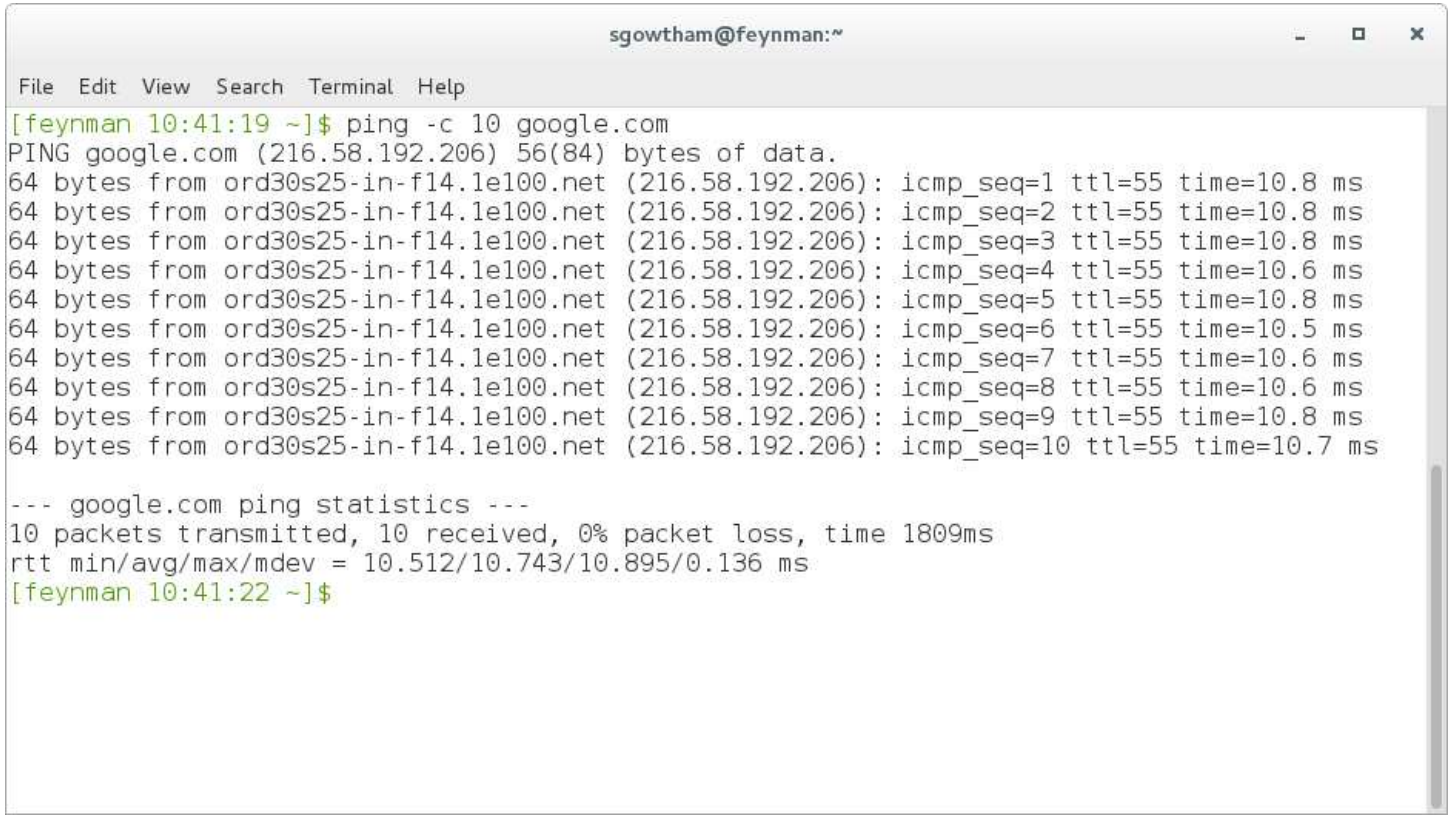
Things To Try

Finding hostname given the IP address (reverse DNS lookup)



Things To Try

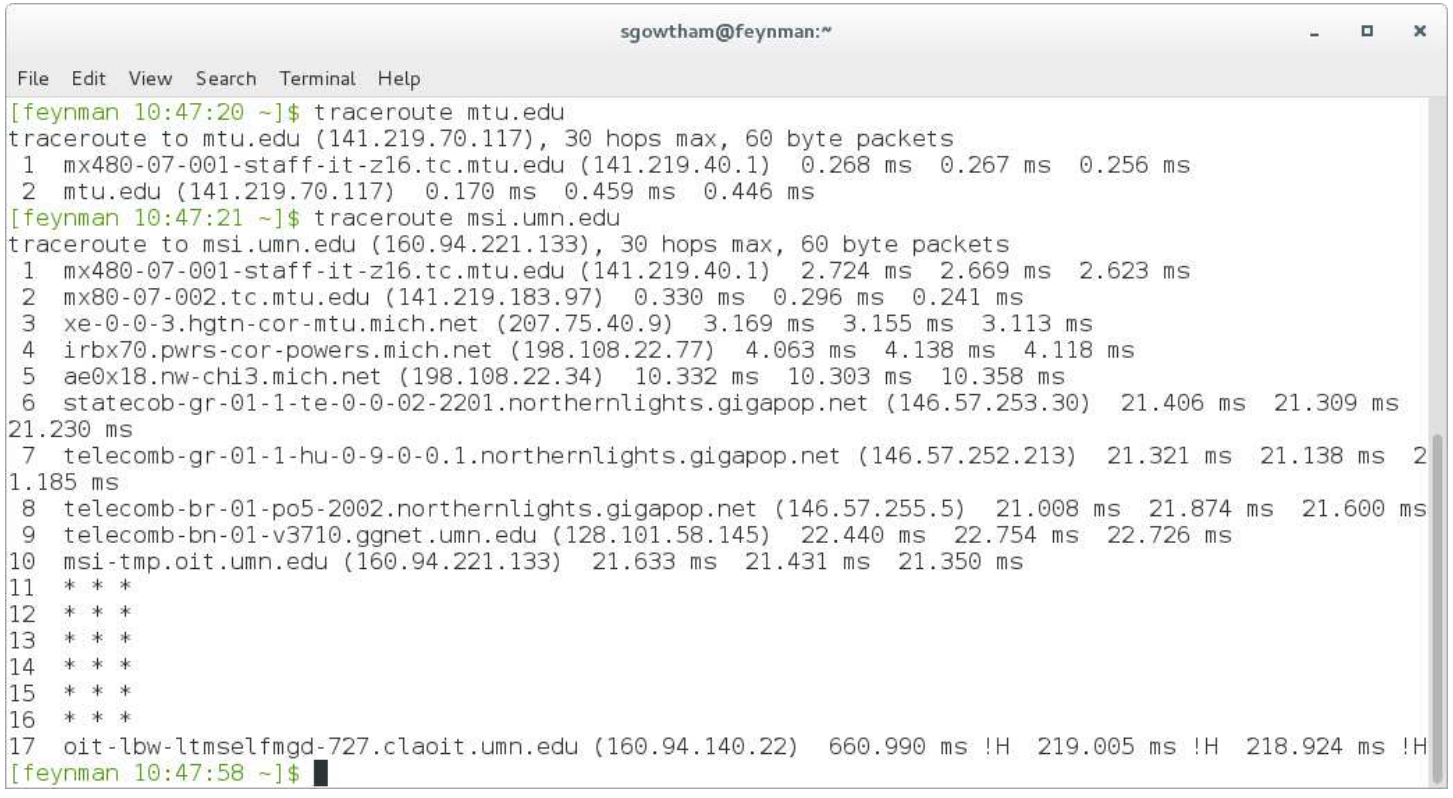
Checking if a server is online (pinging)



A really useful tool to include in (automated) workflows – such as transferring data to or from a remote server.

Things To Try

Checking the path of a packet of information



Things To Try

Uptime and summary of network connections

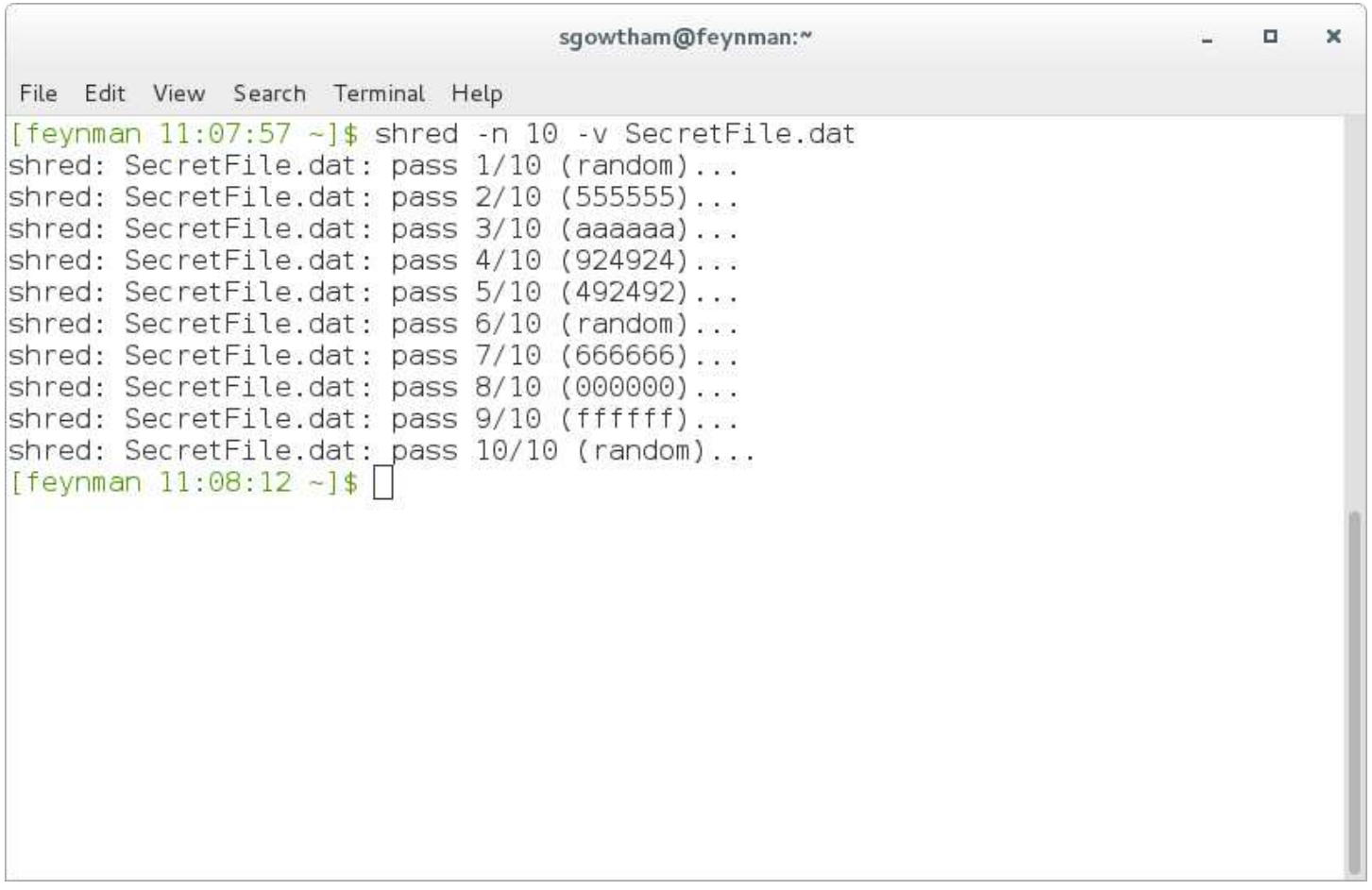
sgowtham@feynman:~

File Edit View Search Terminal Help

```
[feynman 10:58:10 ~]$ uptime
 10:58:12 up 16 days,  2:33,  6 users,  load average: 0.27, 0.20, 0.16
[feynman 10:58:12 ~]$ netstat
Active Internet connections (w/o servers)
Proto Recv-Q Send-Q Local Address           Foreign Address         State
tcp        0      0 feynman.it.mtu.ed:47676 linuxplesk7.openho:http TIME_WAIT
tcp        0      0 feynman.it.mtu.ed:47666 linuxplesk7.openho:http ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:47670 linuxplesk7.openho:http ESTABLISHED
tcp        0      0 feynman.it.mtu.edu:ssh  rover-227-237.rov:53295 ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:45918 superior-login1.res:ssh ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:33546 mail.tecmint.com:http   TIME_WAIT
tcp        0      0 feynman.it.mtu.ed:49200 ord30s25-in-f196.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:42530 ord30s25-in-f206.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:47668 linuxplesk7.openho:http ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:42574 ord30s25-in-f206.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:47674 linuxplesk7.openho:http ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:60840 ord30s25-in-f198.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:34104 ord30s21-in-f14.1:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:56040 ix-in-f189.1e100.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:47672 linuxplesk7.openho:http ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:33550 mail.tecmint.com:http   TIME_WAIT
tcp        0      0 feynman.it.mtu.ed:48182 ord30s25-in-f197.:https ESTABLISHED
tcp        0      0 feynman.it.mtu.ed:33548 mail.tecmint.com:http   TIME_WAIT
udp        0      0 feynman.it.mtu.ed:43338 up2.com:ntp             ESTABLISHED
```

Things To Try

Securely shred a file



Things To Try

List every process from every user

sgowtham@feynman:~

File Edit View Search Terminal Help

```
[feynman 11:31:07 ~]$ ps aux
USER        PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root          1  0.0  0.0 193820  6960 ?        Ss   Feb15   4:05 /usr/lib/system
root          2  0.0  0.0      0     0 ?        S    Feb15   0:00 [kthreadd]
root          3  0.0  0.0      0     0 ?        S    Feb15   0:01 [ksoftirqd/0]
root          5  0.0  0.0      0     0 ?        S<   Feb15   0:00 [kworker/0:0H]
root          7  0.0  0.0      0     0 ?        S    Feb15   0:01 [migration/0]
root          8  0.0  0.0      0     0 ?        S    Feb15   0:00 [rcu_bh]
root          9  0.0  0.0      0     0 ?        S    Feb15  11:46 [rcu_sched]
root         10  0.0  0.0      0     0 ?        S    Feb15   0:06 [watchdog/0]
root         11  0.0  0.0      0     0 ?        S    Feb15   0:05 [watchdog/1]
root         12  0.0  0.0      0     0 ?        S    Feb15   0:00 [migration/1]
root         13  0.0  0.0      0     0 ?        S    Feb15   0:09 [ksoftirqd/1]
root         16  0.0  0.0      0     0 ?        S    Feb15   0:06 [watchdog/2]
root         17  0.0  0.0      0     0 ?        S    Feb15   0:02 [migration/2]
root         18  0.0  0.0      0     0 ?        S    Feb15   0:00 [ksoftirqd/2]
root         21  0.0  0.0      0     0 ?        S    Feb15   0:06 [watchdog/3]
root         22  0.0  0.0      0     0 ?        S    Feb15   0:02 [migration/3]
root         23  0.0  0.0      0     0 ?        S    Feb15   0:03 [ksoftirqd/3]
root         27  0.0  0.0      0     0 ?        S<   Feb15   0:00 [khelper]
root         28  0.0  0.0      0     0 ?        S    Feb15   0:00 [kdevtmpfs]
root         29  0.0  0.0      0     0 ?        S<   Feb15   0:00 [netns]
root         30  0.0  0.0      0     0 ?        S    Feb15   0:00 [khungtaskd]
root         31  0.0  0.0      0     0 ?        S<   Feb15   0:00 [writeback]
```

Things To Try

List every process from a given user

sgowtham@feynman:~

File Edit View Search Terminal Help

```
[feynman 11:33:16 ~]$ top -b -n 1 -u sgowtham
top - 11:33:19 up 16 days,  3:08,  7 users,  load average: 0.08, 0.28, 0.29
Tasks: 265 total,   1 running, 256 sleeping,   8 stopped,   0 zombie
%Cpu(s):  1.1 us,  0.3 sy,  0.0 ni, 98.5 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem : 65777552 total, 50674580 free,  4180720 used, 10922252 buff/cache
KiB Swap: 33030140 total, 33030140 free,        0 used. 60542956 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
 9921 sgowtham  20   0  562748  16328   5544 S   6.2  0.0   3:13.80 caribou
 1977 sgowtham  20   0  144988   2332   1068 S   0.0  0.0   0:00.13 sshd
 1993 sgowtham  20   0  120784   7492   1744 S   0.0  0.0   0:00.07 bash
 2057 sgowtham  20   0   79032   4232   3276 S   0.0  0.0   0:00.12 ssh
 3013 sgowtham  20   0  386136   5984   3156 S   0.0  0.0   0:00.03 gvfsd-http
 4034 sgowtham  20   0   53756   1008    420 S   0.0  0.0   0:00.13 ssh-agent
 4352 sgowtham  20   0  120864   7676   1840 S   0.0  0.0   0:00.40 bash
 6248 sgowtham  20   0  149664   5568   2612 S   0.0  0.0   0:00.06 vim
 9543 sgowtham  20   0  387940   4272   3336 S   0.0  0.0   0:12.08 gnome-keyr+
 9550 sgowtham  20   0  663732   8472   6316 S   0.0  0.0   0:09.95 gnome-sess+
 9557 sgowtham  20   0   13944    596    452 S   0.0  0.0   0:00.00 dbus-launch
 9558 sgowtham  20   0  102100   3032   1192 S   0.0  0.0   0:29.14 dbus-daemon
 9626 sgowtham  20   0  380488   3532   2820 S   0.0  0.0   0:00.19 gvfsd
 9631 sgowtham  20   0  434936   5632   2900 S   0.0  0.0   0:00.03 gvfsd-fuse
 9718 sgowtham  20   0   52864    568      0 S   0.0  0.0   0:05.18 ssh-agent
 9752 sgowtham  20   0  337912   5516   2876 S   0.0  0.0   0:00.00 at-spi-bus+
```

Automation

* Manual feed (run one command at a time)

```
last > file_01.tmp
sed "/^\s*$/d" file_01.tmp > file_02.tmp
awk '{ print $1 }' file_02.tmp > file_03.tmp
sort file_03.tmp > file_04.tmp
uniq -c file_04.tmp > file_05.tmp
sort -nr file_05.tmp
```

* Piping

  The act of using output of one command as the input for the next command

```
last | sed "/^\s*$/d" | awk '{ print $1 }' | sort | \
 uniq -c | sort -nr
```

Automation

* Function and script

  A (portable) entity with a list of commands to accomplish a task

* Cron job

  A service that's useful to run a command (or a script or any other program) at a designated time (say, at 3 am on every Saturday) without needing user initiation/intervention.

Why is it a generally not a good idea to schedule something to run at 1 am or 2 am?

Additional References

* A Guide From Newbies To System Administrator
* Explore the built-in manual page for a given command (press q to exit out of it)

```
man man
man host
man ping
man traceroute
man mkdir
man netstat
```

* Explore the built-in manual page for a random command (useful for discovering new commands)

```
man $(ls /bin | shuf | head -1)
```

Got questions?

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