ECE 462
Object-Oriented Programming using C++ and Java

Testing

Yung-Hsiang Lu
yunglu@purdue.edu

Unreachable Code

If a, b, and c are zeros or positive numbers

$(a + c) < b \Rightarrow a > b$ is impossible

$\Rightarrow$ problem in the logic?

```
if ((x <= 0) && (x >= width)) // hit left or right wall
{    // width > 0
     vx = -vx; // change direction
}
```

Testing Strategy

- Testing is one, not the only one, step to ensure quality.
- Before writing code, think about how to test it.
- Do not be surprised that you write more code for testing than for the project.
- Danger of using testing to ensure quality: you usually test what you suspect. The program usually breaks at places where you are confident.
- Sometimes, reading code line-by-line can find and fix problems faster than writing testing code, especially for multi-thread programs.

Design and Testing

code	unit test	⬅ familiar to most of you
design	integration test	
requirements	validation test	
system engineering	system testing	⬅ often the hardest

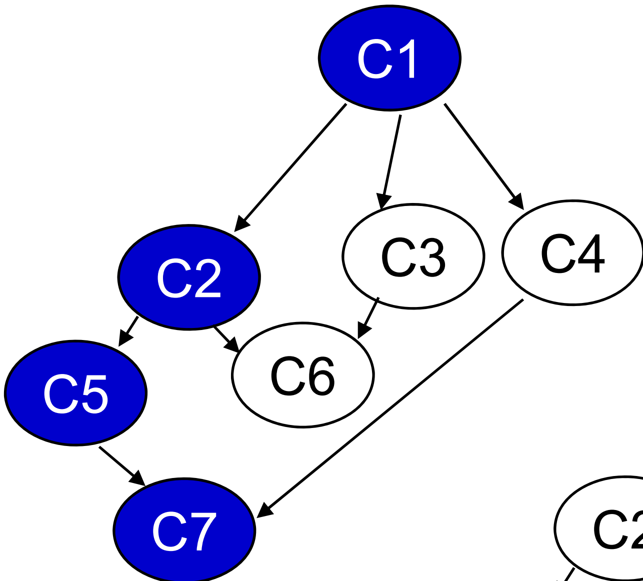
- Importance of unit testing: well-designed software should allow only **limited visibility** (encapsulation) for better consistency. Hence, testing from outside is difficult.
- Build software in **layers**. A lower layer should be fully tested before building a higher layer.

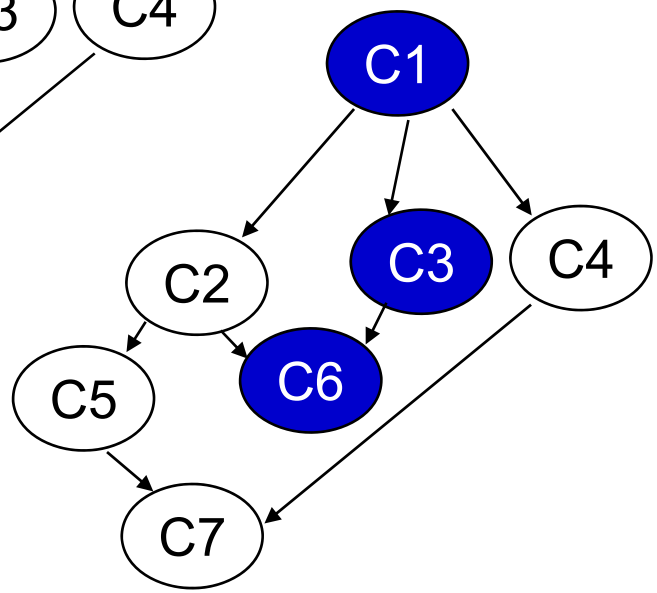
Test Coverage

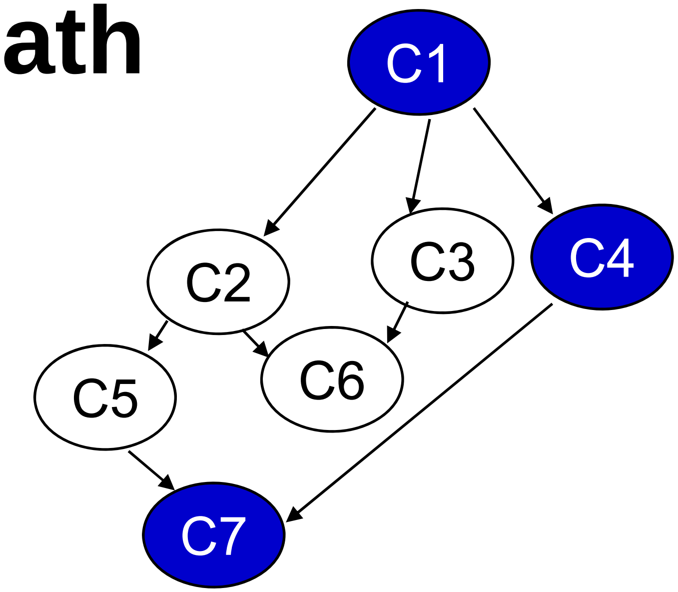
- How much code is exercised in a test? How many possible paths are traversed?
- Many tools exist for reporting code coverage.
- Low coverage: not fully tested ⇒ bad test
- High coverage: can **hardly** test each possible **path** ⇒ quality **unclear**
- Testing discover many problems? good or bad?
- "dead code": code that is impossible to reach, usually indicates design or coding errors

```
        return 0;
  →     x ++;
}
```

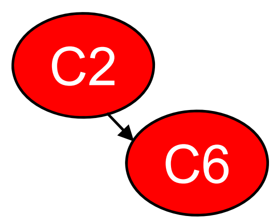
Execution Path







C: code segment



Every node has been visited (100% test coverage) but C2→C6 has not been tested

Quantify Testing Quality

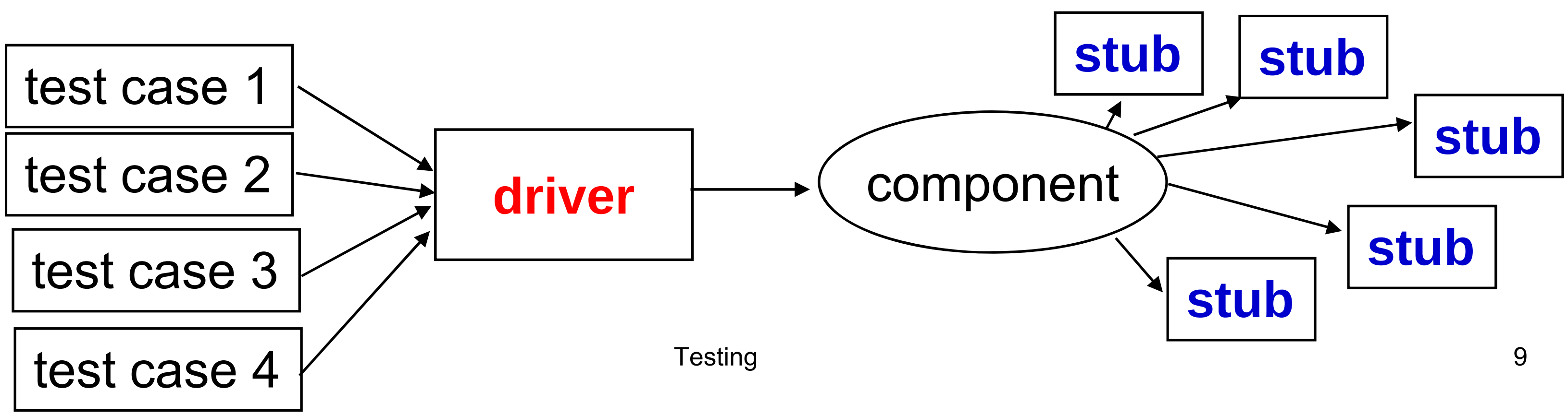
- coverage: (% code and % paths) of the test
- efficiency: evenly distribute? time to cover 99%?
- progression: % new code tested
- discovery rate: % bugs found for every line of test code
- configurability: selections of features to test
- ratio: how much testing code needed to test actual code
- expandability: amount of efforts needed to test new features
- degree of automation: can it be fully automated, semi-automated, or complete manual?

Testing Steps

- unit testing, integration testing, regression
- unit testing:
  - individual components
  - often conducted by the developer
  - often using dedicated testing code to create input data, exercise the components
  - often traced by single steps
  - check boundary conditions and error handling
  - check interface correctness and responses to incorrect inputs

Unit Testing

– examine the performance
– should be performed before "cvs commit"
– should be put into the repository
– should be configurable for related components
– require careful planning **in advance**
– driver: code to call the component, stub: code to be called by the component. both are overhead

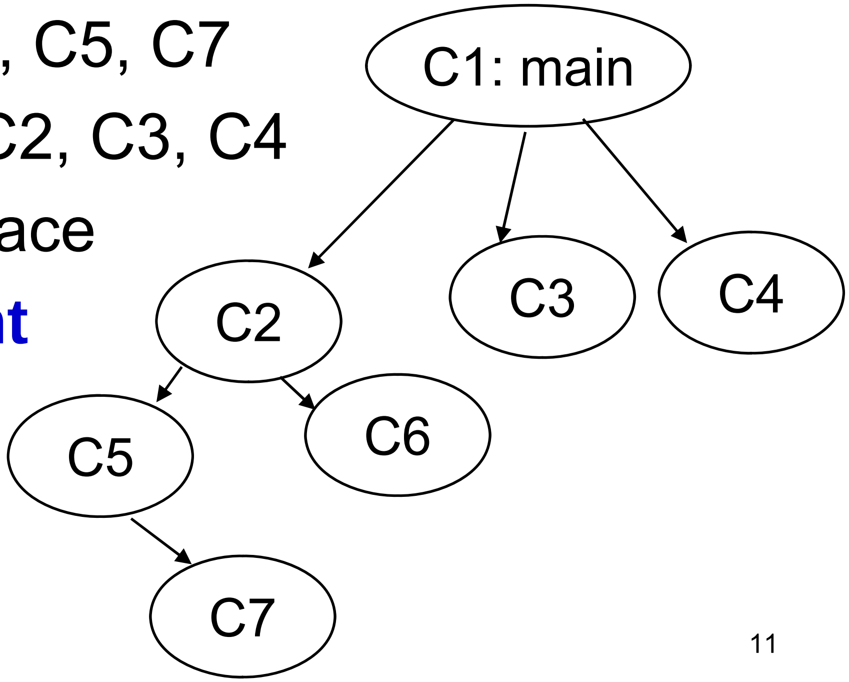


Integration Testing

- Interface incompatibility is often the reason software breaks. incompatibility ≠ compiler error
- types of interface errors, even passing compilation, e.g.
  - wrong types (object of derived class or base class)
  - wrong assumptions, for example
    - who is responsible for allocating or releasing memory
    - who may modify the data, especially global variables
    - sorted or nearly sorted? wrong result or wasting time
  - wrong timing assumption for real-time software
- **incremental** integration: add one component (e.g. class) each time
- may still use drivers and stubs (how do you know they are correct?)

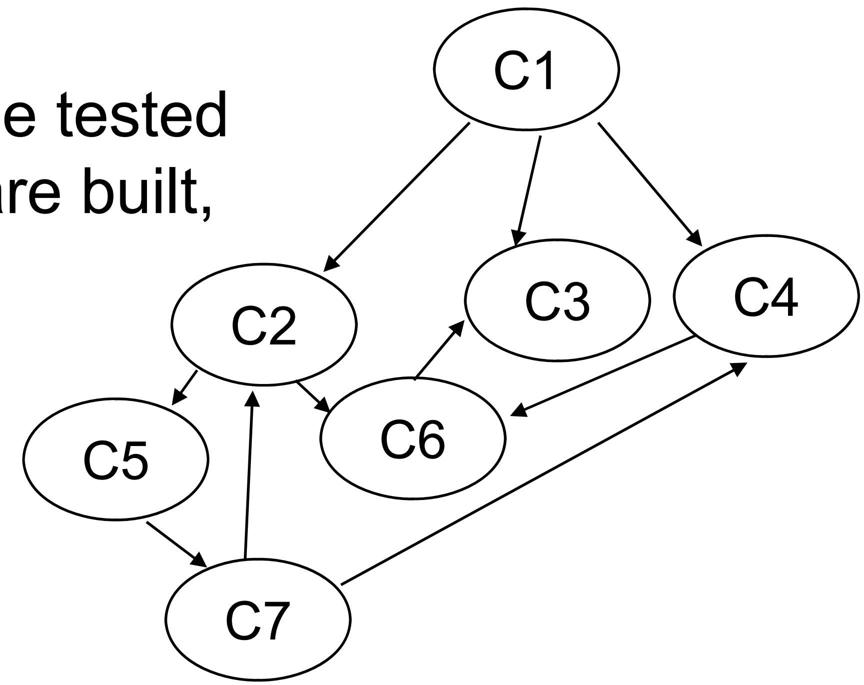
Top-Down Integration

- using control flow to determine the integration order
- starting from the main component ("main" in C/C++) as the driver
- integrate callees (replace stubs) of the main component
- depth-first integration: C1, C2, C5, C7
- breadth-first integration: C1, C2, C3, C4
- after one successful test, replace a **stub** by the real **component**
- regression test (later) to ensure tested components still work



Challenges in Top-Down Testing

- **control flow** and **call graph** are not downward only or acyclic
- many functionalities cannot be tested before the leaf components are built, e.g. C1 needs the data (or objects) generated in C7 to test C3
- depth-first or breath-first only may not represent normal execution paths



Bottom-Up Integration

1. start from individual components (such as classes)
2. put several components together, use a driver to test them
3. replace the driver by a real component
4. repeat step 2-3

- difficulties:
  - which components to integrate first? They must have a common driver.
  - control may not be upward only or acyclic
  - required data (or objects) may be generated from a component that has not been integrated

Regression Testing

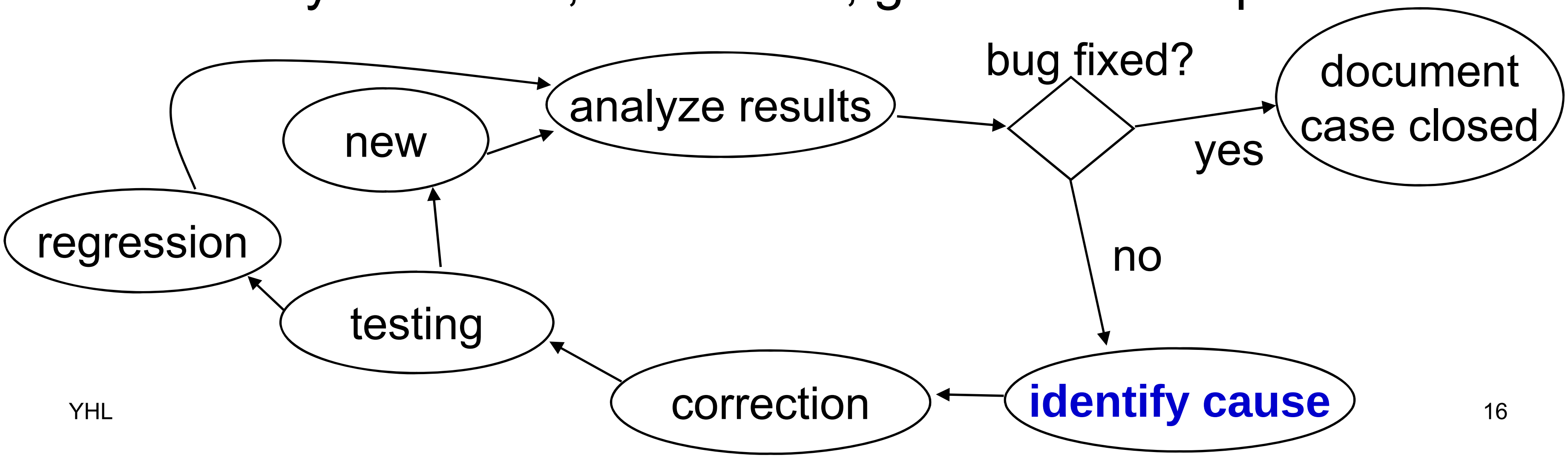
- re-test what has been tested after new components are integrated into the project
- (same) test after errors are corrected
- **expandable** as more components are added
- **configurable** so that new components can be exercised more
- should be automated as much as possible (consider using cron jobs)
- Most important / frequently used features should be test more thoroughly.

Test Documentation

- Testing should be planned and documented.
  - test plan: what to test, when to test, who runs the test, how to run the test, what data to use …
  - testing with integration: how components are integrated, regression testing procedure
  - procedure to test: manual, automated, or semi-automated? conditions, tools, special hardware …
  - test result analysis: what to expect, how to diagnose
  - test result management: providing a trace of integration and testing
  - re-test procedure after correction

Hypothesis-Test Debugging

- Most software developers take "hypothesis-testing" approach for debugging:
  - guess what is the cause ⟵ **usually the hardest part**
  - modify the code
  - run some tests
  - analyze results, if not fixed, guess another place



Time-Sensitive or Massive Data

- Single-step code is not always the best way to debug.
- Some programs cannot be single-stepped:
  - time-sensitive, interacting with the physical world. It does not wait for the program.
  - massive amount of data, too many steps. How do you single-step an image with 3 million pixels?
- Create increasingly complex and realistic testing data: smaller images, simpler images, single color, checkerboard …
- Detect error conditions before proceeding. **Always** check the return value of a system or library call, such as connect, read, write, **new**, fork …

Time-Sensitive or Massive Data

- Detect and handle errors before they propagate.
- Generate execution logs for post-execution analysis. Be careful about the impact on timing.
- controversy of "assert": assert (something must be true);

  assert (x > 0);

  Program stops immediately if the condition fails

  $\Rightarrow$ errors do not propagate.

  $\Rightarrow$ users cannot recover anything, especially lost data.

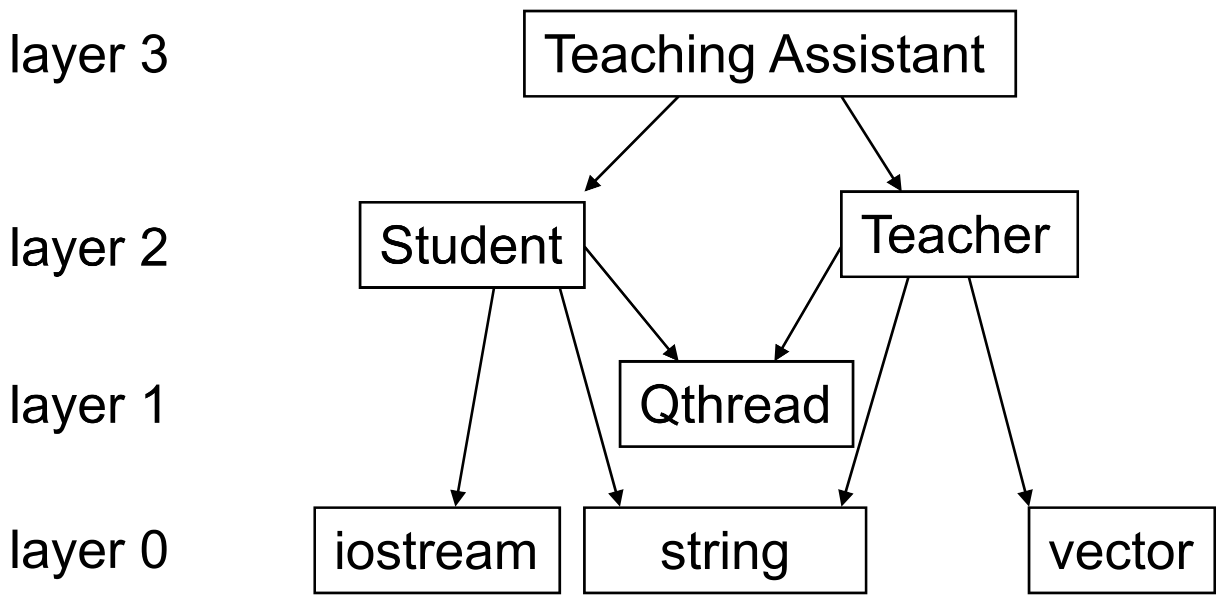
Layered Structure

- Structure the program so that each file can be assigned a unique layer number.
- Layer 0: files from language, such as iostream
- Layer 1: library files, such as Qt's classes
- Layer 2: common files used in multiple projects in your organization
- Layer 3: stable files used for months
- Layer 4: recently developed and test files
- Layer 5: unstable files
- Layer n: depends on files in layer 0, 1, 2, …, n-1

distinction not precise

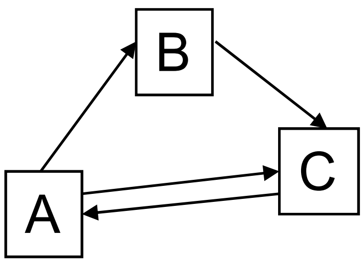
File Layers

A file is assigned layer n if it depends on only files in layer 0, 1, 2, …, n-1



Why to Layer Files / Classes

- A file with a lower layer number should be more stable and have a higher degree of correctness
- Strictly layered structure allow **unit testing** a recently developed module in the program
- Layering indicates the **precedence** of development. If a module is a foundation for some other modules, this module should be placed (physically) in a file that has a lower layer number.
- Cyclic dependence often suggests flaws in **logical** design.



Test Exceptional Cases

- Error / exception handling code, by definition, doesn't execute often. In "normal" conditions, the code is not tested.
- Testing exception handling code requires a well-designed plan to create the conditions for triggering the code's execution.
- Be careful about how to create the conditions and danger of "simulated disasters."
-

ECE 462
Object-Oriented Programming using C++ and Java

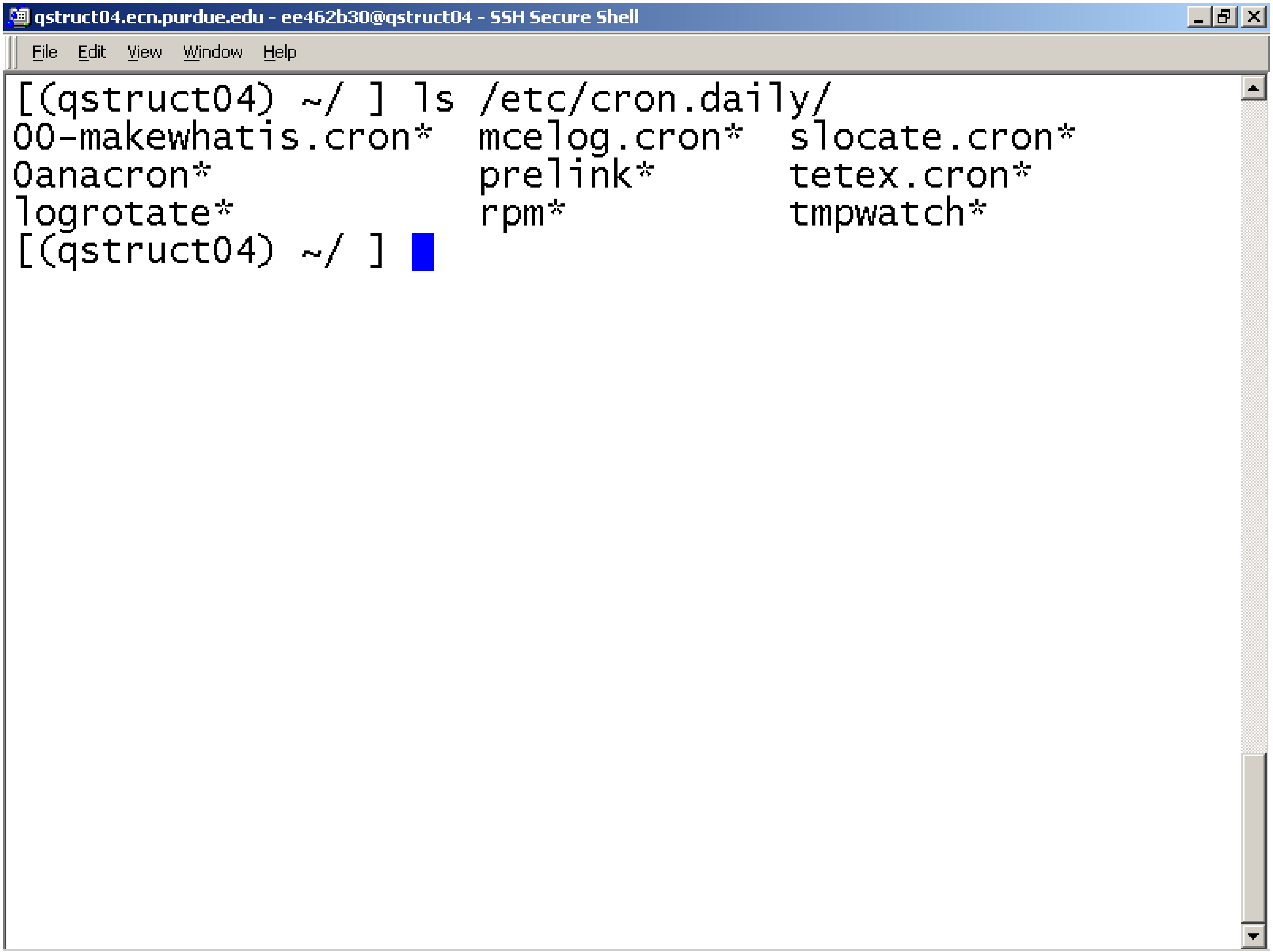
Automatic Testing

Yung-Hsiang Lu
yunglu@purdue.edu

Periodic Testing

- schedule periodic testing, for example, at 2AM everyday
- check out code from repository
- compile and link to create executable
- execute the program with known inputs
- direct the output to a (or several) file
- compare the output with expected output
- report test results
- inform project manager if serious errors are discovered

Periodic Tasks using cron


qstruct04.ecn.purdue.edu - ee462b30@qstruct04 - SSH Secure Shell
File Edit View Window Help
[(qstruct04) ~/] ls /etc/cron.daily/
00-makewhatis.cron* mcelog.cron* slocate.cron*
0anacron* prelink* tetex.cron*
logrotate* rpm* tmpwatch*
[(qstruct04) ~/]

qstruct04.ecn.purdue.edu - ee462b30@qstruct04 - SSH Secure Shell

File Edit View Window Help

```
[(qstruct04) ~/ ] more /etc/crontab
SHELL=/bin/bash
PATH=/sbin:/bin:/usr/sbin:/usr/bin
MAILTO=root
HOME=/

# run-parts
01 * * * * root run-parts /etc/cron.hourly
02 4 * * * root run-parts /etc/cron.daily
22 4 * * 0 root run-parts /etc/cron.weekly
42 4 1 * * root run-parts /etc/cron.monthly
[(qstruct04) ~/ ]
```

minute hour day-of-month month day-of-week command

Cron Tasks

17 8 * * * echo "daily at 8:17 am"

17 20 * * * echo "daily at 8:17 pm"

00 4 * * 0 echo "at 4 am every Sunday"

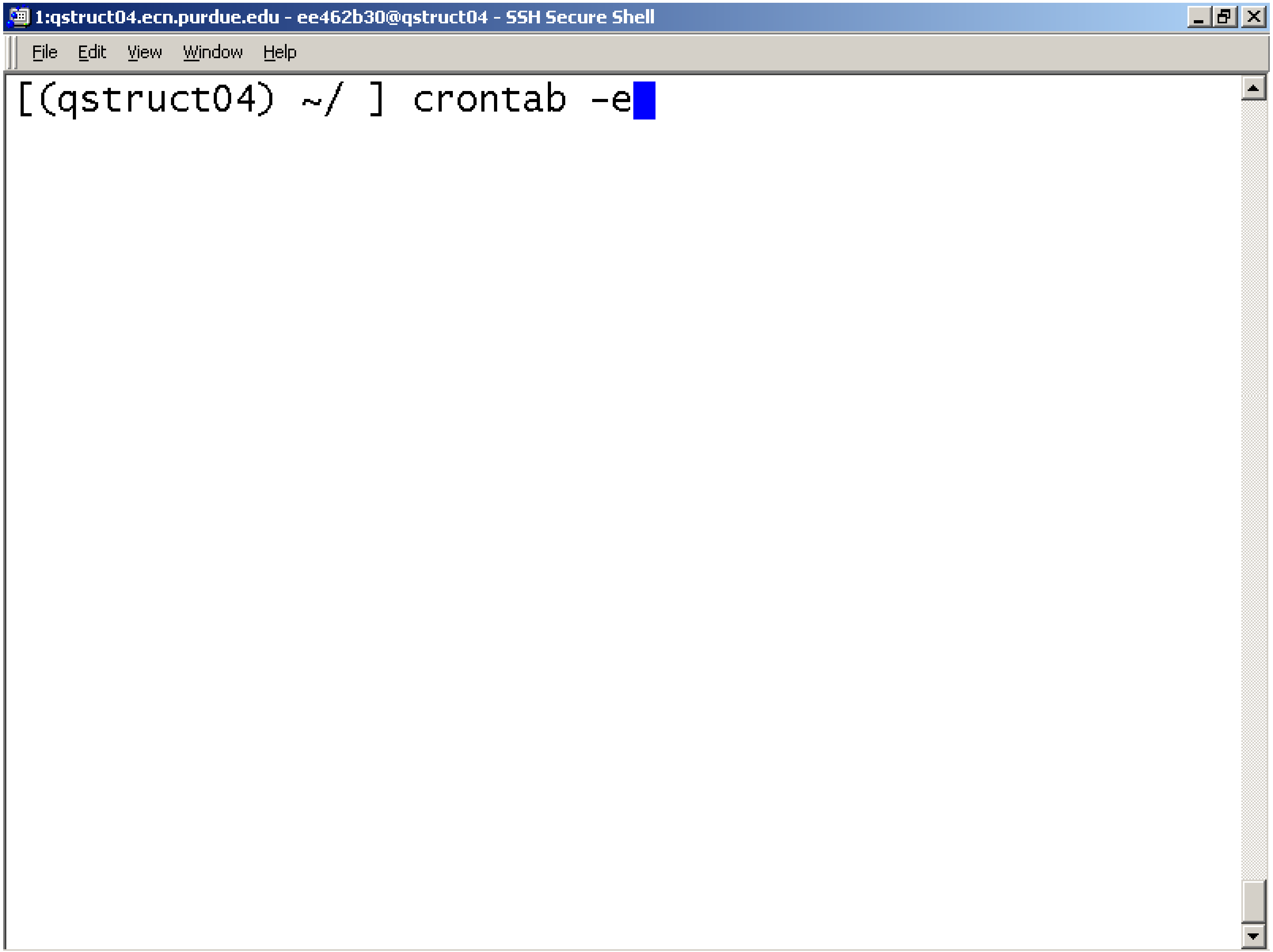
01 * 19 07 * echo "hourly on the 19th of July"

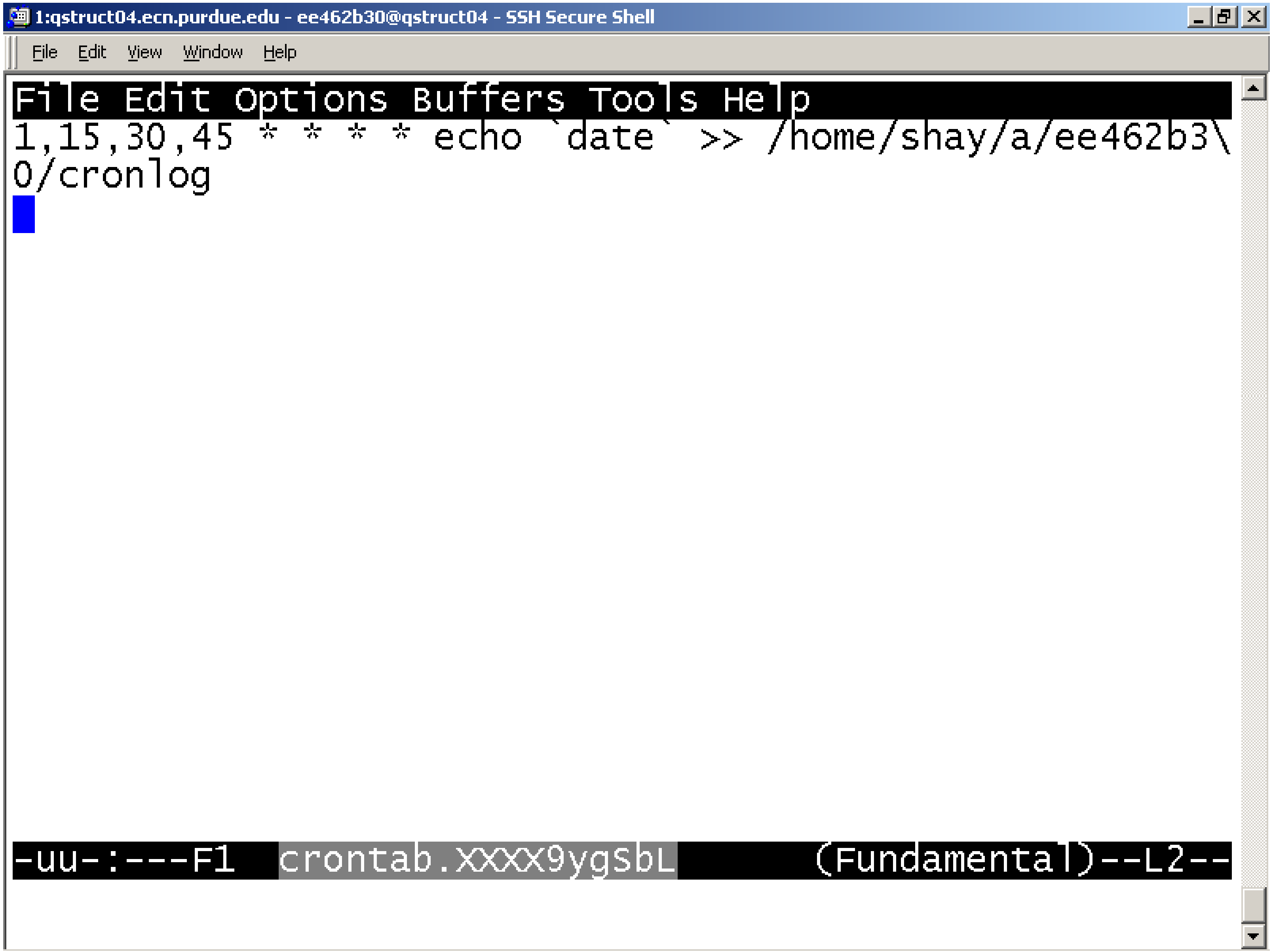
1,15,30,45 * * * * echo "every 15 minutes"

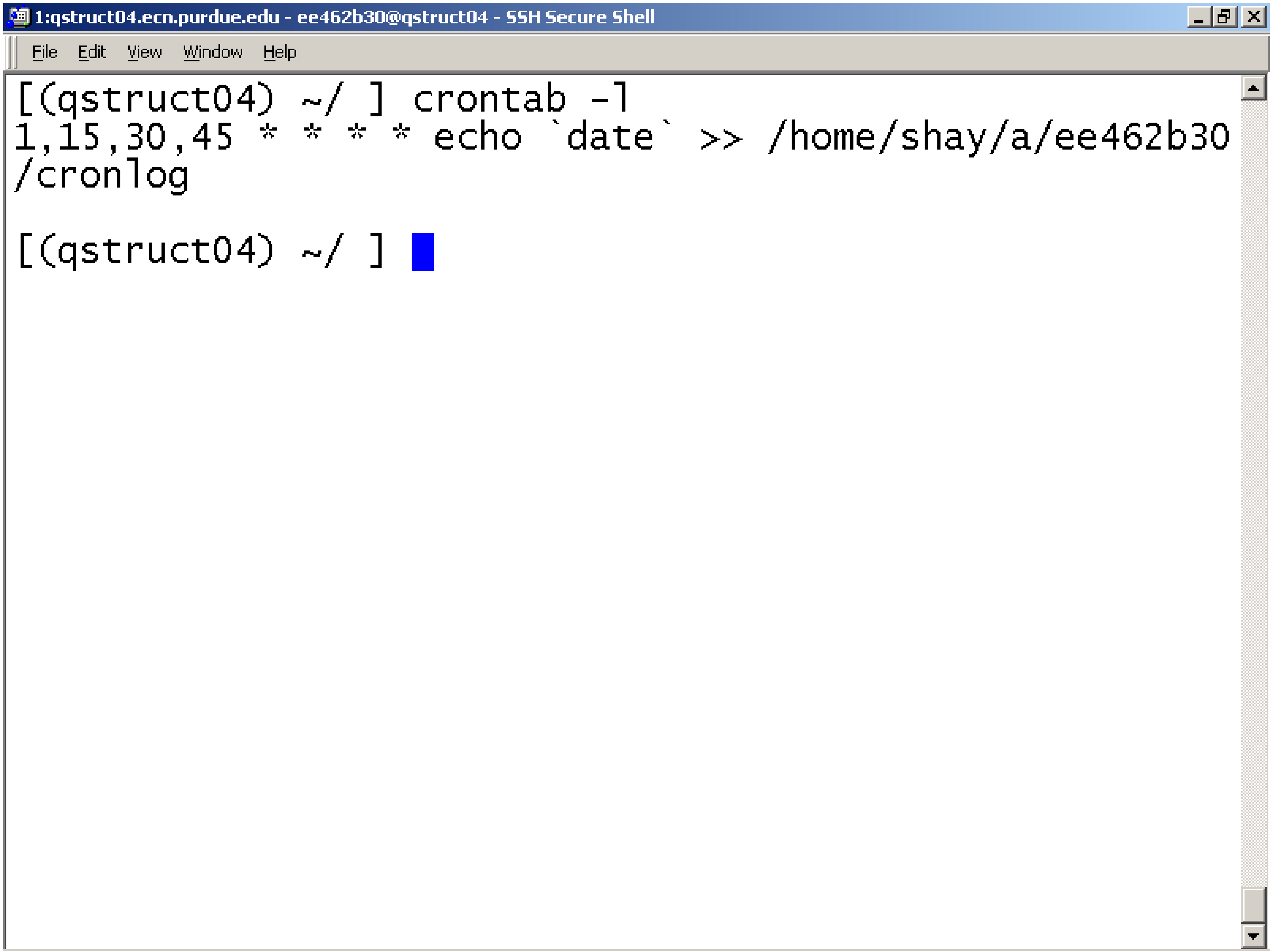
Crontab

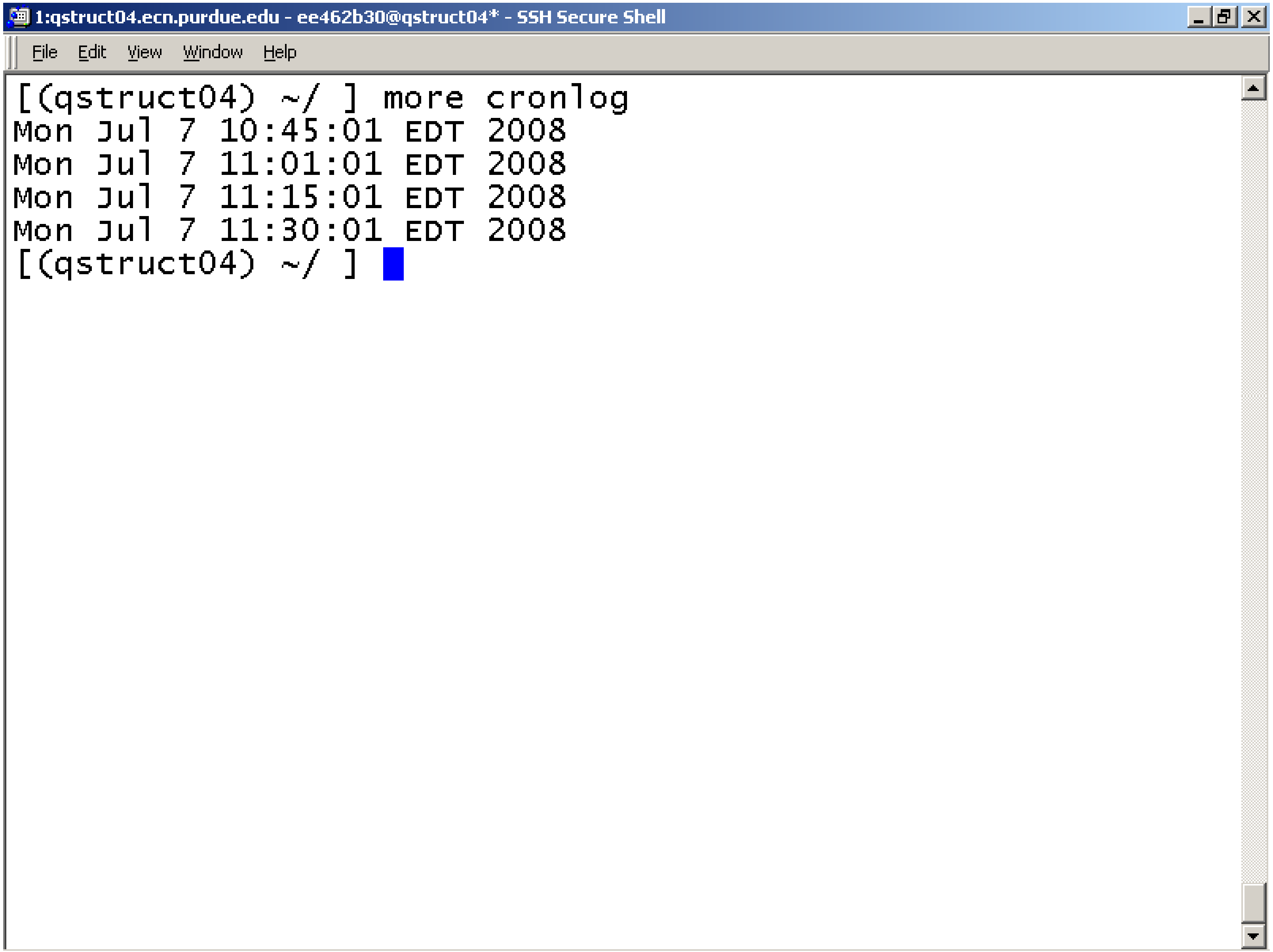
- crontab -l: list current cron tasks
- crontab -r: remove current cron tasks
- crontab -e: edit cron tasks using the editor specified by environment setting EDITOR

- 1,15,30,45 * * * * echo `date` >> LogFile


1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04 - SSH Secure Shell
File Edit View Window Help
[(qstruct04) ~/] crontab -e


1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04 - SSH Secure Shell
File Edit View Window Help
File Edit Options Buffers Tools Help
1,15,30,45 * * * * echo `date` >> /home/shay/a/ee462b3\
0/cronlog
-uu-:---F1 crontab.XXXX9ygSbL   (Fundamental)--L2--


1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04 - SSH Secure Shell
File Edit View Window Help
[(qstruct04) ~/] crontab -l
1,15,30,45 * * * * echo `date` >> /home/shay/a/ee462b30
/cronlog
[(qstruct04) ~/]


1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell
File Edit View Window Help
[(qstruct04) ~/] more cronlog
Mon Jul 7 10:45:01 EDT 2008
Mon Jul 7 11:01:01 EDT 2008
Mon Jul 7 11:15:01 EDT 2008
Mon Jul 7 11:30:01 EDT 2008
[(qstruct04) ~/]

```
0 2 * * * /path/to/your/crontask >> /path/to/your/logfile
```

```
#!/usr/bin/sh
CVSROOT=/your/CVS/root
CODEHOME=/here/to/store/the/checkout
cvs -d $CVSROOT co -d $CODEHOME program
echo `date`
```

```
#!/usr/bin/csh
set PROJPATH=/path/to/store/the/program
cd $PROJPATH
/bin/rm -f -r project
set CVSROOT=/path/to/CVSROOT
echo CVSROOT $CVSROOT
cvs -d $CVSROOT co project
cd project
set LOGFILE=testlog
make > $LOGFILE
./program arg1... >> $LOGFILE
./program arg2... >> $LOGFILE
analyze $LOGFILE
```

g++ -fprofile-arcs -ftest-coverage

1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell

File Edit View Window Help

```
int main(int argc, char * argv[])
{
  srand(time(NULL));
  for (int i = 0; i < 6; i++) {
    double a = 0.001 * (rand() % 1000);
    double b = 0.001 * (rand() % 1000);
    double c = 0.001 * (rand() % 1000);
    double d = 0.001 * (rand() % 1000);
    if (a > b) {
      cout << "a > b " << a << " " << b << endl;
    } else {
      cout << "a <= b " << a << " " << b << endl;
    }
    if (c > d) {
      cout << "c > d " << c << " " << d << endl;
    } else {
      cout << "c <= d " << c << " " << d << endl;
    }
    if ((a + c) < b) {
      if (a > b) {
        cout << "(a + c) < b and a > b " << endl;
      } else {
        cout << "(a + c) < b and a <= b " << endl;
      }
```

1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell

File Edit View Window Help

```
[(qstruct04) ~/lecturecode/1110/ ] ls
coverage.cpp
[(qstruct04) ~/lecturecode/1110/ ] g++ -fprofile-arcs -ftes
t-coverage coverage.cpp
[(qstruct04) ~/lecturecode/1110/ ] ./a.out
a <= b 0.273 0.405
c > d 0.325 0.222
a > b 0.39 0.073
c > d 0.368 0.248
a <= b 0.352 0.534
c <= d 0.631 0.819
a > b 0.439 0.12
c <= d 0.1 0.766
a <= b 0.67 0.834
c <= d 0.748 0.833
a <= b 0.256 0.514
c <= d 0.005 0.937
(a + c) < b and a <= b
[(qstruct04) ~/lecturecode/1110/ ] ls
a.out*  coverage.cpp  coverage.gcda  coverage.gcno
[(qstruct04) ~/lecturecode/1110/ ]
```

1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell

File Edit View Window Help

```
[(qstruct04) ~/lecturecode/1110/ ] gcov coverage.cpp
File `/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../in
clude/c++/3.4.6/bits/locale_facets.tcc'
Lines executed:0.00% of 11
/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../include/
c++/3.4.6/bits/locale_facets.tcc:creating `locale_facets.tc
c.gcov'

File `coverage.cpp'
Lines executed:94.74% of 19
coverage.cpp:creating `coverage.cpp.gcov'

File `/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../in
clude/c++/3.4.6/bits/stl_algobase.h'
Lines executed:0.00% of 4
/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../include/
c++/3.4.6/bits/stl_algobase.h:creating `stl_algobase.h.gcov
'

File `/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../in
clude/c++/3.4.6/iostream'
Lines executed:100.00% of 1
/usr/lib/gcc/x86_64-redhat-linux/3.4.6/../../../../include/
c++/3.4.6/iostream:creating `iostream.gcov'
```

1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell

File Edit View Window Help

```
[(qstruct04) ~/lecturecode/1110/ ] ls
a.out*             coverage.gcda  locale_facets.tcc.gcov
coverage.cpp       coverage.gcno  stl_algobase.h.gcov
coverage.cpp.gcov  iostream.gcov
[(qstruct04) ~/lecturecode/1110/ ]
```

1:qstruct04.ecn.purdue.edu - ee462b30@qstruct04* - SSH Secure Shell

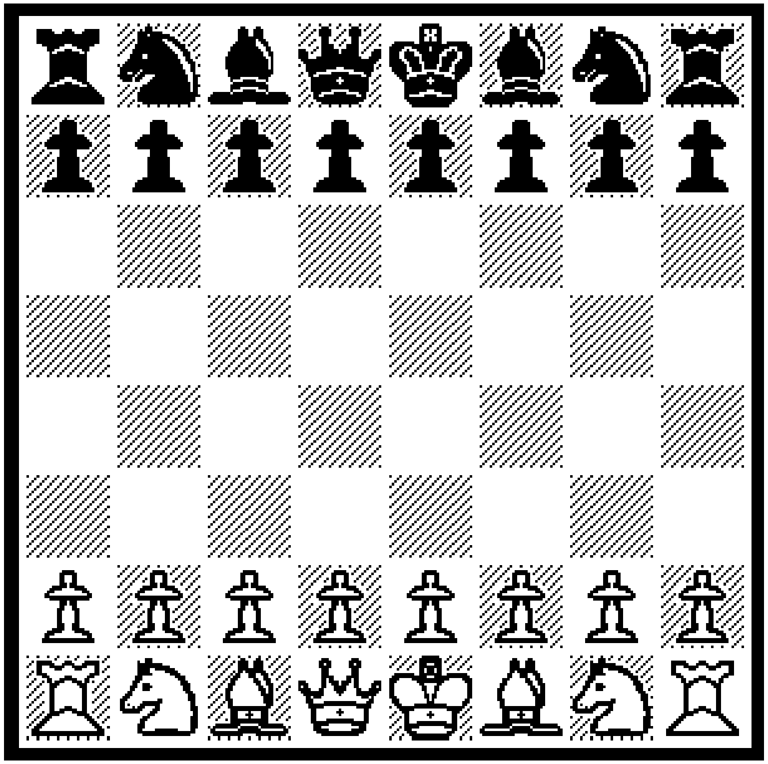
File Edit View Window Help

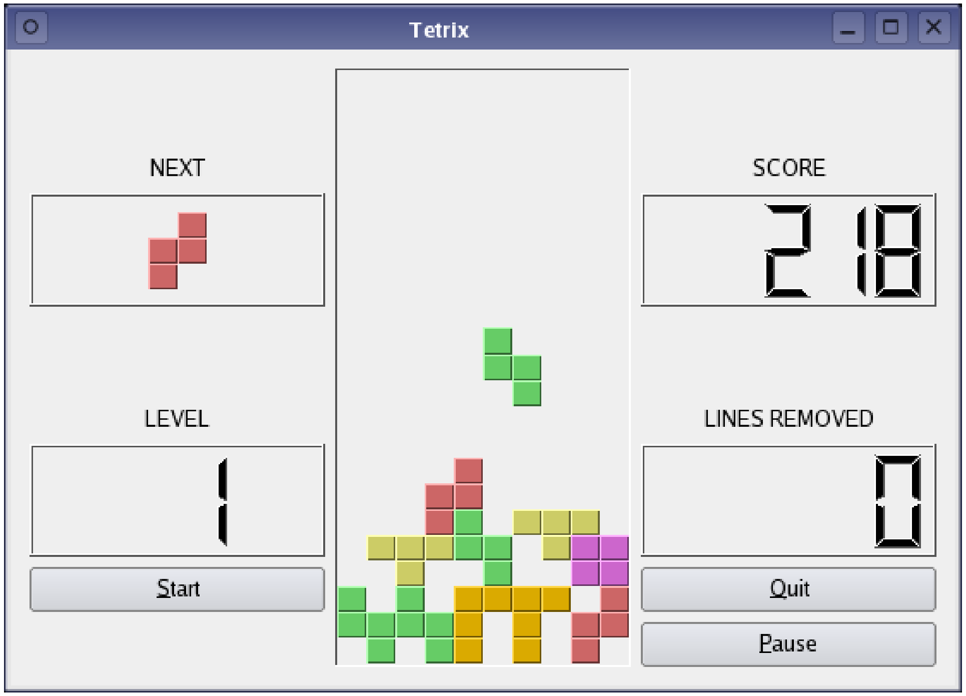
```
        6:    9:    double a = 0.001 * (rand() % 1000);
        6:   10:    double b = 0.001 * (rand() % 1000);
        6:   11:    double c = 0.001 * (rand() % 1000);
        6:   12:    double d = 0.001 * (rand() % 1000);
        6:   13:    if (a > b) {
        2:   14:      cout << "a > b " << a << " " << b <<
endl;
        -:   15:    } else {
        4:   16:      cout << "a <= b " << a << " " << b <<
 endl;
        -:   17:    }
        6:   18:    if (c > d) {
        2:   19:      cout << "c > d " << c << " " << d <<
endl;
        -:   20:    } else {
        4:   21:      cout << "c <= d " << c << " " << d <<
 endl;
        -:   22:    }
        6:   23:    if ((a + c) < b) {
        1:   24:      if (a > b) {
    #####:   25:        cout << "(a + c) < b and a > b " <<
 endl;
        -:   26:      } else {
        1:   27:        cout << "(a + c) < b and a <= b " <
:
```

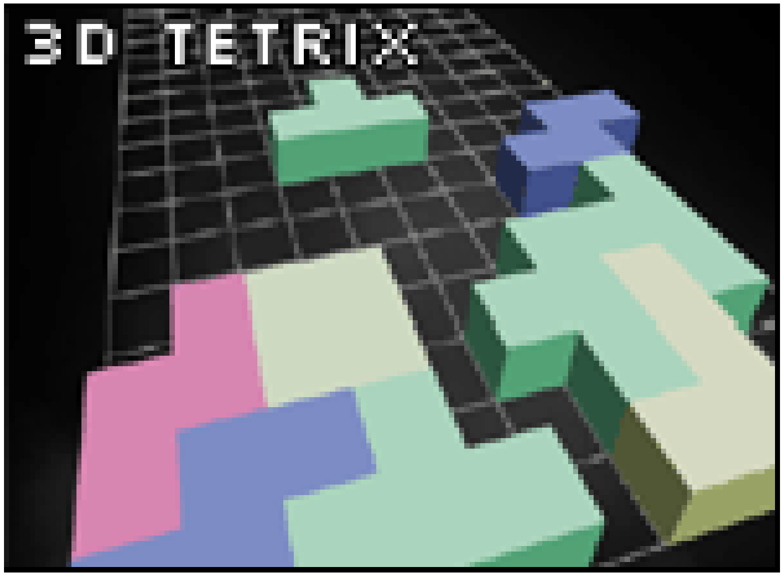
ECE 462
Object-Oriented Programming using C++ and Java

3-Dimensional Graphics

Yung-Hsiang Lu
yunglu@purdue.edu




Tetrix
NEXT
SCORE
218
LEVEL
1
LINES REMOVED
0
Start
Quit
Pause

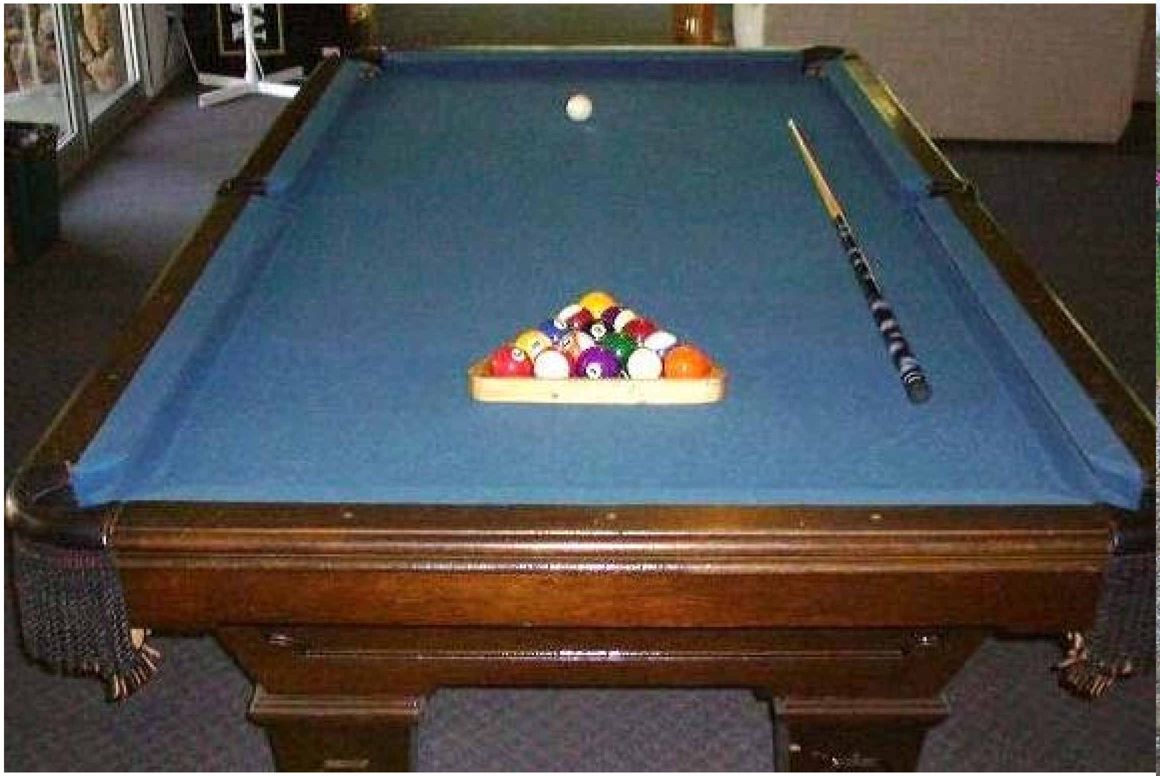

3D TETRIX


02:34
BUL 0 - 1 SKY
SPORTS
SKY news


HQ: Ki-84 reported in sector 16,15
*VF_2 :Entering the pattern.
*VF_2 :Change to trail formation.
G-METER
FUEL
WEP
THROTTLE
100%
GEAR RPM OIL STALL
ALT
AMMO
CHANNEL
001
AUTO


Pool 3D Training edition
Player 1
Player 2

Foreshortening

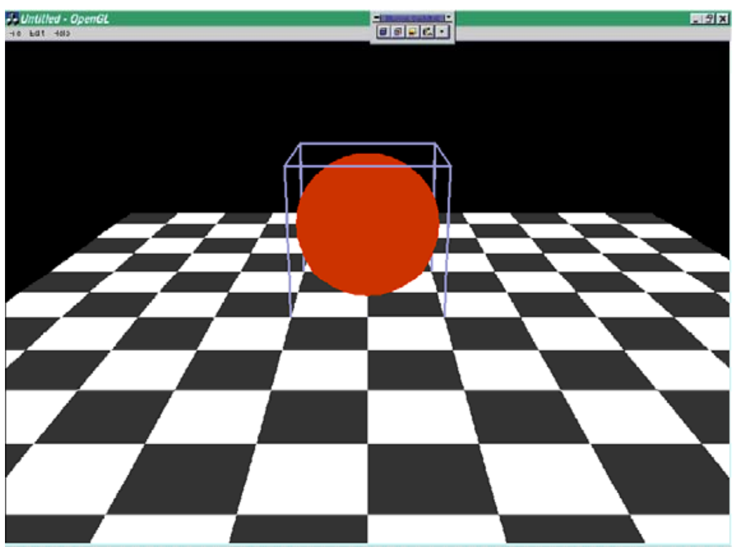


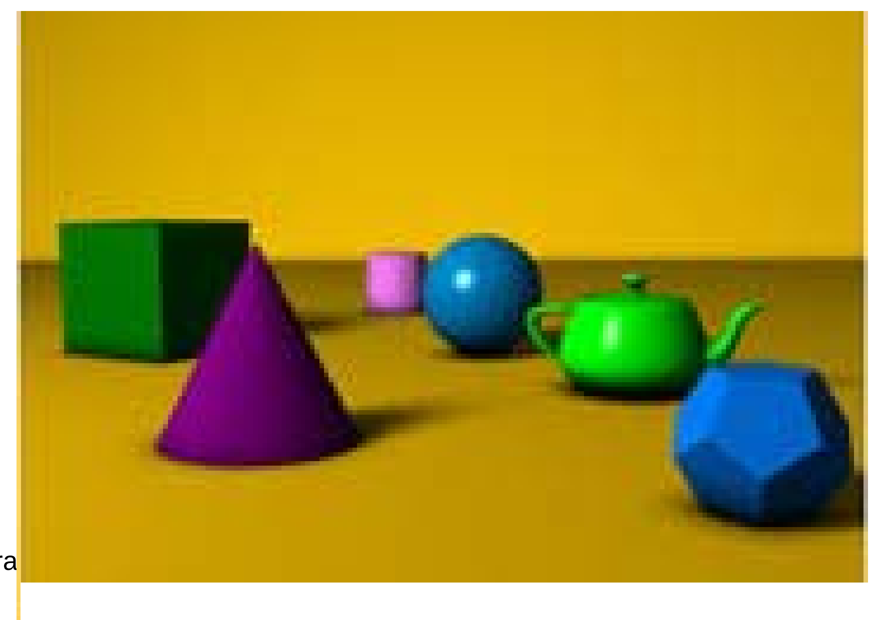
3D Graphics in C++ and Java

- libraries for 3D graphics:
  – C++
    G3D, http://g3d-cpp.sourceforge.net/index.html
    IrrLicht, http://irrlicht.sourceforge.net/index.html
  – Java 3D, http://java.sun.com/products/java-media/3D/

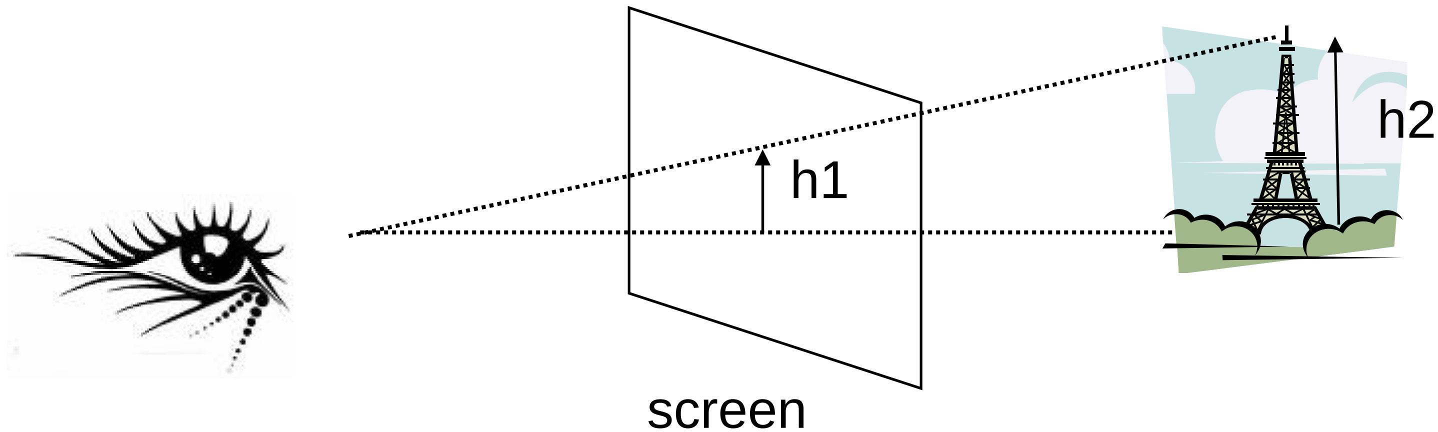
Show 3D on 2D Screen

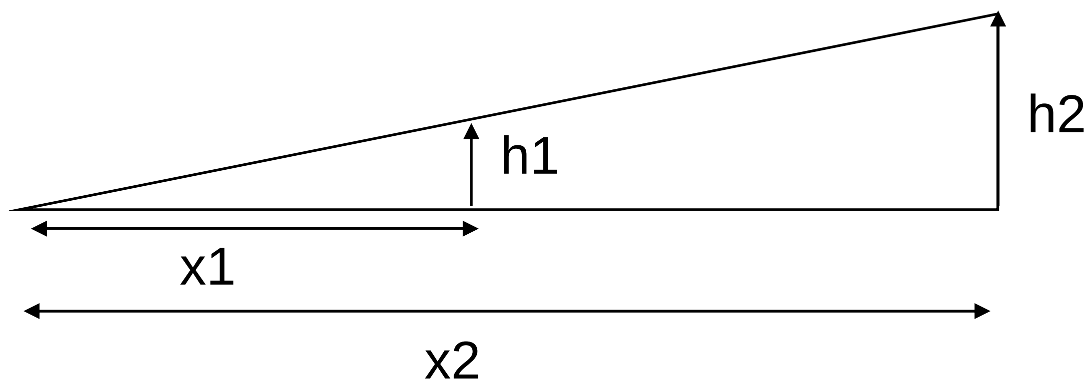
- project 3D on 2D: farther objects look smaller
- calculate depth: a near non-transparent object blocks the visibility of a farther object
- show lighting and shading





Calculate Projection on Screen



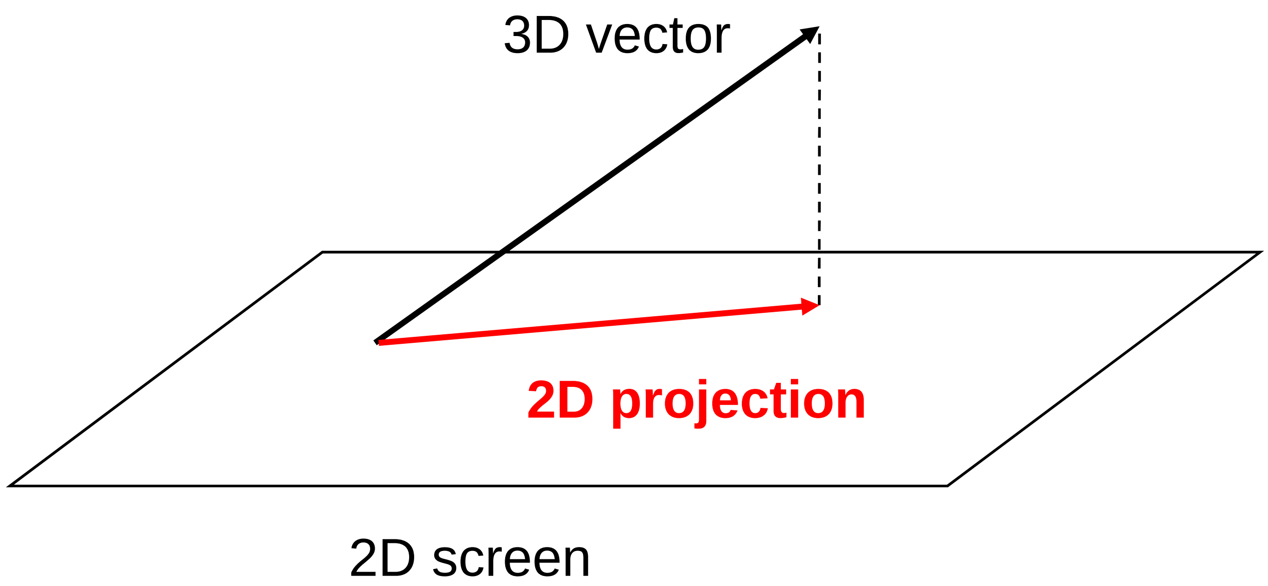


$$\frac{h1}{x1} = \frac{h2}{x2} \Rightarrow h1 = x1\frac{h2}{x2}$$

A farther object (larger x2) looks shorter (smaller h1).

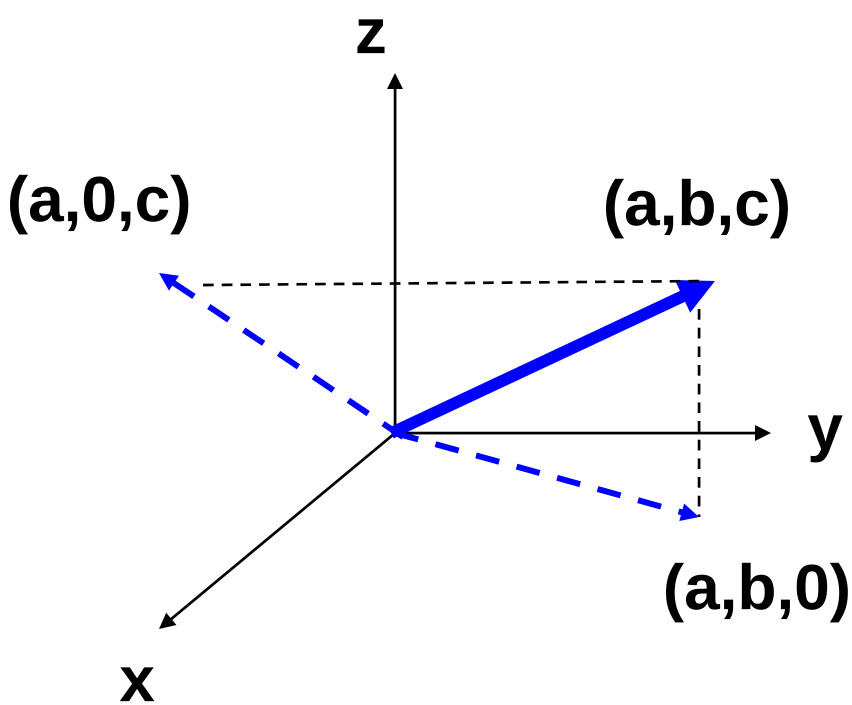
Projection

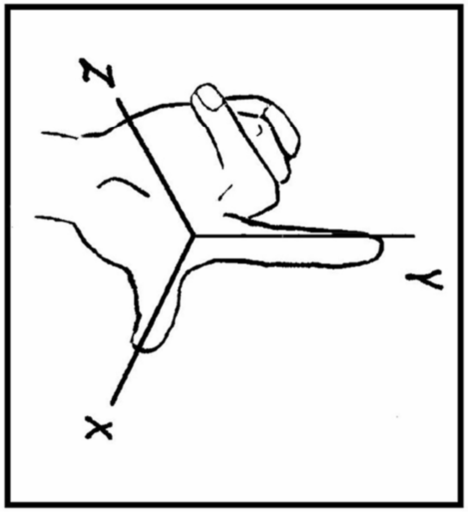
3D? It is a **projection** of 3D objects on a 2D screen.

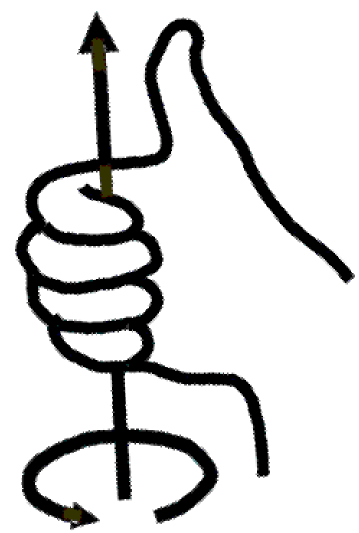


If a vector is (x, y, z), its 2D projection on the X-Y plane is (x,y)

Projections







Why is 3D More Complex

The image on the screen depends on many factors

- location of the viewer
- locations of the objects, including their relative depths to the viewer
- shape of the objects
- locations of the lights
- surface materials of the objects, reflective (such as polished metal) or absorptive (such as dark-color cloth)
- motion
- ...

Geometric Representations

- Each point is represented by a 3-D coordinate

$$(x, y, z)$$

- A vector is also represented by a 3-D coordinate

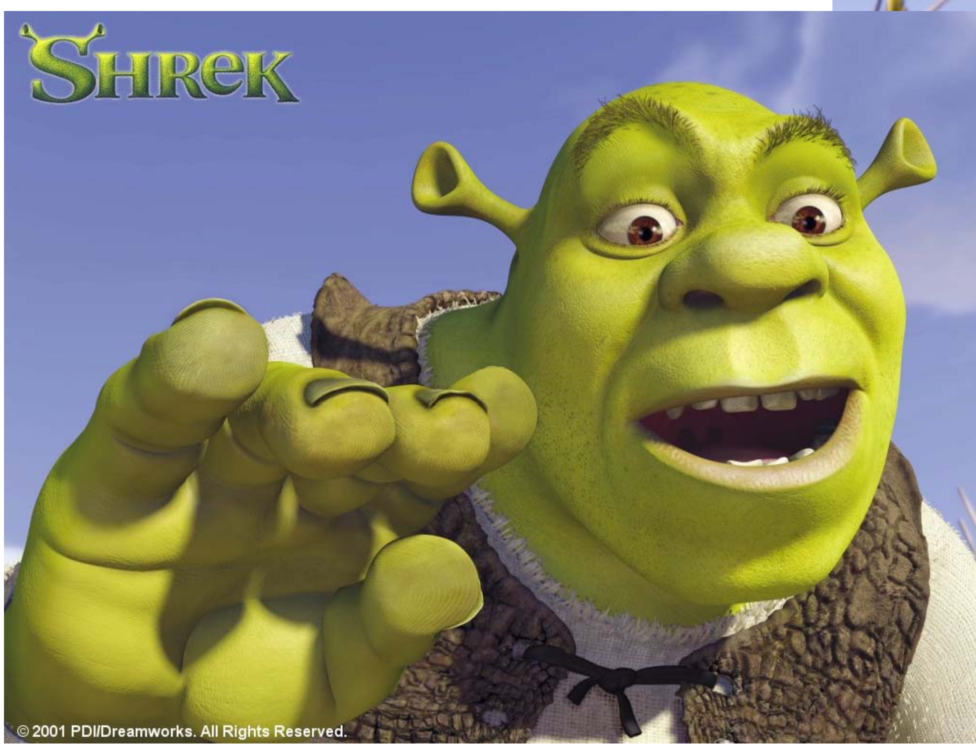
$$v = (x, y, z)$$

- A line is represented by one point of the line and the direction of the line

$$(x_0, y_0, z_0) + a\,(x_d, y_d, z_d),\ -\infty < a < \infty$$

- A plane is represented by one point of the plane and two vectors. The two vectors must not be parallel.

$$(x_0, y_0, z_0) + a\,(x_1, y_1, z_1) + b\,(x_2, y_2, z_2),\ -\infty < a, b < \infty$$


SHREK
© 2001 PDI/Dreamworks. All Rights Reserved.

3D Transformation

- Transformation: original location (x, y, z)
  – translation, i.e. move it to (x+dx, y+dy, z+dz)
  – scaling, move it to (ax, by, cz)
  – rotation θ along z axis ($x \cos\theta - y \sin\theta$, $x \sin\theta + y \cos\theta$, z)
- All transformations can be expressed by matrices.
- Let [x, y, z, 1] represent a 3-D location (x,y,z), called **homogeneous coordinates**.

- translation

$$\begin{bmatrix} 1 & 0 & 0 & dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x + dx \\ y + dy \\ z + dz \\ 1 \end{bmatrix}$$

- scaling

$$\begin{bmatrix} a & 0 & 0 & 0 \\ 0 & b & 0 & 0 \\ 0 & 0 & c & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} ax \\ by \\ cz \\ 1 \end{bmatrix}$$

- rotation along z

$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x\cos\theta - y\sin\theta \\ x\sin\theta + y\cos\theta \\ z \\ 1 \end{bmatrix}$$

Transformation not Commutative

- $T_1 \, T_2 \, v \neq T_2 \, T_1 \, v$ in general
- (3,0) translate (3,0) then rotate $45^o \Rightarrow$ (4.2, 4.2)
- (3,0) rotate 45^o then translate (3,0) $\Rightarrow$ (5.1, 2.1)