Modularity
and
Separation of Concerns

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Goals

- Explore the benefits of modularity and separation of concerns
- Explore some of the *limits and drawbacks* of modular systems
Abstracting the Hard Disk
What’s a hard disk?

- Now: [http://www.youtube.com/watch?v=3owqvmMf6No](http://www.youtube.com/watch?v=3owqvmMf6No)

- Then: [http://www.youtube.com/watch?v=CUExy80zMBg&t=19s](http://www.youtube.com/watch?v=CUExy80zMBg&t=19s)
What’s a hard disk?

Typical Characteristics

- Fixed sized data blocks (512 bytes -> 4K bytes)
- Seek time: 3ms – 15ms (depends on drive and distance)
- Rotational delay: ~5ms for commodity drives
- Transfer rate from platter: 100MBytes/sec
How does our software show us the disk?

- **Filesystem**
  - Names: /home/noah/myfile.txt
  - Files can grow and shrink dynamically
  - Geometry and timing hidden
  - Free space managed transparently
  - Sharing and security
  - Buffering and optimization
  - May span multiple drives

- **Relational database**
  - Collections of tables: rows + columns
  - Access via query language
How is the disk used in Unix / Linux?

Application

Filesystem

Unix Kernel

Block Device Driver

In-memory Block Cache

Direct read/write of filesystem “blocks” (hides sector size and device geometry)

Buffers block r/w: hides timing

Raw Device Driver

Sector

Access by cylinder/track/sector

Files/Dirs security, etc

Buffered block r/w: hides timing
How is the disk used in Unix / Linux (over-simplified)

Application -> Filesystem

Unix Kernel

Files/Dirs security, etc

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Access by cylinder/track/sector

Direct read/write of filesystem “blocks” (hides sector size and device geometry)
How is the disk used in Unix / Linux?

- **Application**
- **Unix Kernel**
- **Filesystem**
- **Block Device Driver**
- **Raw Device Driver**
- **Sector**

### Access by
- cylinder/track/sector

### Buffering
- Direct read/write of filesystem “blocks” (hides sector size and device geometry)
- Buffered block r/w: hides timing
Things to note

- Each layer provides clean abstraction for next
- Code replaceable by layer
  - New filesystem on same block driver
  - New raw driver supports new device (different manufacturer, SSD, USB key, digital camera, etc.)
  - Cached block space supports (nearly) same interface as uncached
- Reuse!
  - All devices supported by common buffer management and filesystem
  - Common APIs at all levels above device
Network Layering Revisited
## Architecture of the Internet Protocols

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<th>Example</th>
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We can replace link layer and still use upper layers!
Compare the following RFC’s

- http://www.ietf.org/rfc/rfc1149.txt

Please note that RFC 1149 support has been demonstrated: http://www.blug.linux.no/rfc1149/
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Implementations are often layered to match the architecture!
Overview of Layering/Modularity Issues
Some terms

- Separation of concerns
- Modularity
- Layering
- Encapsulation
- Information hiding
- Abstraction
- Reuse
Separation of concerns – HTTP

HTTP Status Codes Evolve Orthogonally from Rest of Protocol

HTTP/1.1 200 OK
Date: Tue, 28 Aug 2007 01:49:33 GMT
Server: Apache
Transfer-Encoding: chunked
Content-Type: text/html

<html>
<head>
<title>Demo #1</title>
</head>
<body>
<h1>A very simple Web page</h1>
</body>
</html>
Separation of concerns – HTTP

Media type registrations shared with E-mail (MIME) infrastructure

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Separation of concerns – HTTP

Unicode, HTML and other specifications modular and shareable with other systems

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The HTML for the page.
Why modularity and encapsulation?

- Sharing and re-use
- Layers can evolve separately
- Synergies:
  - Photoshop and GIMP help everyone who uses JPEG
  - Including Web use of image/jpeg media type
- Reasoning about systems: correctness proofs, etc.
- Hiding complexity
- Progressive disclosure of complexity
- Making complex functions economical
Noah’s Theory of Simplification Choke Points

Very complex telephone switching system

Nationwide cable & fiber network & ESS Switches
Noah’s Theory of Simplification Choke Points

Wonderfully simple choke point interface

Nationwide cable & fiber network & ESS Switches

RJ-11 Jack & Touch Tones = Talk to anyone in the world using simple touch tone pad.. hook up devices
Noah’s Theory of Simplification Choke Points

Group 3 Fax Protocols

Very complex modulation and signalling standard

Nationwide cable & fiber network & ESS Switches

RJ-11 Jack & Touch Tones = Talk to anyone in the world using simple touch tone pad.
hook up devices
Noah’s theory….

Group 3 Fax Protocols

Nationwide cable & fiber network & ESS Switches

Drop in paper, dial #, paper delivered

RJ-11 Jack & Touch Tones = Talk to anyone in the world using simple touch tone pad.. hook up devices
Example: the Web Stack

- **Deliver stream to Named Destination**
- **TCP w/flow control, etc.**
  - a) name->ip addr
  - b) UDP Packet to named addr
- **Distributed DNS resolution**
  - Drop in packet, probably gets there
- **Internet dynamic routing, ARP, etc.**
- **URIs, Hyperlinks, HTTP Get, Media typed streams, HTML**

Each layer hides significant complexity behind simple interface
Layering and Performance
Layering can help performance

- Wrap highly tuned implementations in easy-to-use interfaces!
- Make those implementations easy to reuse
- This is a big, big deal!
- But...
Layering can *hurt* performance

- Layering can keep you from getting at details that need to be tuned

**Examples:**
- Disk errors
- TCP/IP performance
- Compiler optimizations
Layering and disk performance

- Many disks and device drivers automatically forward data to a spare cylinder when a sector goes bad … spares are usually at inside or outside of disk
- *But…the filesystem may put critical directory there, unaware access will be amazingly slow*
- Thanks to Forest Baskett, who gave me this example in about 1980
Layering and TCP/IP Performance

- Hard to share buffers and get alignment right across TCP/IP software layers in the OS

- *Layered implementations can lead to data copying*

- *Studies show that TCP/IP implementations need to share buffers and optimizations across the device, IP, and TCP layers*

- The highest performing remote file systems share buffers between network and filesystem code

- Watson & Mamrak: “a common mistake is to take a layered design as a requirement for a correspondingly layered implementation.” *ACM Transactions on Computer Systems (TOCS), Volume 5 Issue 2, May 1987*
Layering and compiler optimizations

- Compiler front ends tend to respect language layering
- **Compiler code generators need to optimize across layers**

This code doesn’t compute anything useful, but it’s interesting to see how it would be optimized:

```c
int myArray[20];
For (i=0; i<19 && (myArray[i]/2 < 50); i++)
  myArray[i] += myArray[i+1]/2;
```

A good compiler will remember pointer to myArray[i] or even value myArray[i]/2 from previous loop iteration

I checked: gcc –O3 does indeed do these optimizations
Code from previous example

int i;

unsigned int myArray[SIZE] =
{0, 2, 5, 7, 13};

for (i=0; i< (SIZE - 1) &&
    (myArray[i]/2 < 50);
    i++)
    myArray[i] += myArray[i+1]/2;

leal 44(%esp), %esi
xorl %edx, %edx
movl $0, 28(%esp)
leal 32(%esp), %eax
movl $2, 32(%esp)
movl $5, 36(%esp)
movl $7, 40(%esp)
movl $13, 44(%esp)

movl (%eax), %ecx
movl %ecx, %ebx
shrl %ebx
addl %ebx, %edx
cmpl %esi, %eax
movl %edx, -4(%eax)
je L5
addl $4, %eax
cmpl $99, %ecx
movl %ecx, %edx
jbe L4
.p2align 4,,7

Array only read once in loop!
Abstractions Leak!
Leaky abstractions

- When you abstract something...you lose something
- Sometimes the details you lose show through
- These leaky details can cause big trouble!

See “The Law of Leaky Abstractions”
A posting by Joel Spolsky
http://www.joelonsoftware.com/articles/LeakyAbstractions.html

By the way, Joel is the person behind StackOverflow and other “Stack” sites
Leaky example: CPU memory

- CPU memory reads faster when locality is good
- Cache-aligned loads/stores faster
- Multi-core: memory access in one core can slow the other.
- Subtlety: even adjacent accesses may be slow if referencing separate cache blocks
- Etc.

Factors like these can make it very difficult to predict or tune performance
Leaky example: Filesystem performance

- Sequential access faster than random
  - Random causes seeks
  - Sequential predictable: allows streaming and pre-fetching
- Device geometry “shows through”
- SSDs perform differently from hard disks

Factors like these can make it very difficult to predict or tune performance
Summary
Summary

- Separation of concerns is one of the key principles of CS
- Proper layering and modularization of your designs and code will bring tremendous benefits
- But…beware of “leaky” abstractions, performance concerns, etc.