

## Implementation principles

### Goals:

- ❑ Identify, study principles that can guide implementation of network protocols
  - Common principles among many protocols
- ❑ *Synthesis*: Big picture

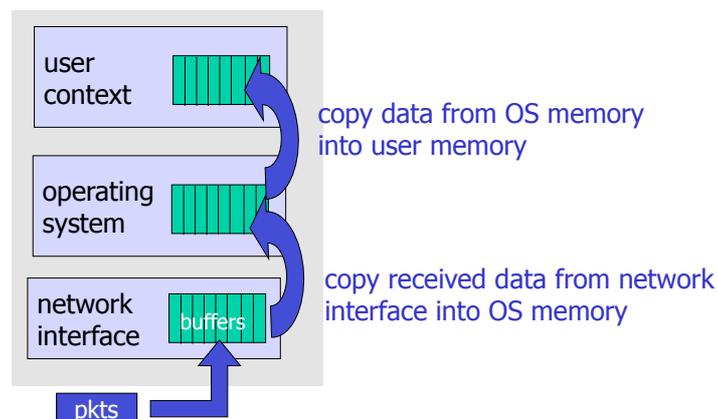
### 3 classes of principles:

- ❑ System principles
- ❑ Improving efficiency while retaining modularity
- ❑ Making it go fast
- ❑ Cautionary tales: *Think twice!*

1

### **P1: Avoid *obvious* waste in common situations**

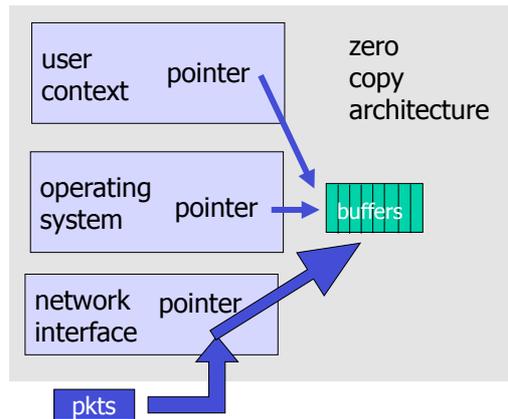
- ❑ Obvious waste occurs when one does something twice, but (with thought) could do it only once (or never)



2

## P1: Avoid *obvious* waste in common situations

- Obvious waste occurs when one does something twice, but (with thought) can do it only once (or never)



Real-world example?

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3

## P2a: Use precomputation to shift computation in time

- Precompute quantities to save time at the point of use
  - Precompute/initialize packet headers for packets in a connection
  - Stored video data to be streamed to client: Store video data on disk prepackaged into IP packets. Finish filling out packet header when sending

Real-world examples?

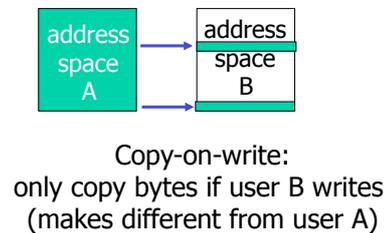
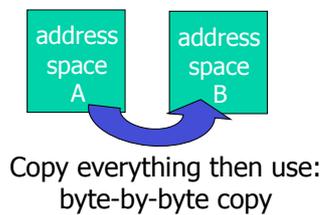
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4

**P2b:** Lazy evaluation: Only do work when it is needed

□ Postpone work in hope not needed later, or more time later to do the work. Examples:

- Data arrives in wrong byte ordering (e.g., big-endian, on little endian machine): Only swap bytes when data actually read (savings if some bytes not read)
- Copy-on write:



5

**P2b:** Lazy evaluation: Only do work when it is needed

**Real world examples**

- Students reading assigned readings:  
“Lazy evaluation” says do the reading only if it is on a homework!

6

### P2c: Batching to share overhead

- ❑ Process work (e.g., packet processing) in batches to amortize setup overhead
- ❑ Example:
  - When processing data “up” (or “down”) protocol stack, do multiple packets from connection at same time

#### Real-world example:

- Sending a bunch of printouts to print room at once (only one trip over)
- Laundry – you don’t do it every day!
- Factory: Make a lot of one item at a time to only incur machine setup costs once

7

### P3a: Trading certainty for time

- ❑ If a deterministic approach is too slow, try a randomized approach
  - Random access protocols (Ethernet)
  - Statistical sampling of packet flows

#### Real-world examples?

- Sampling customers (surveying)
- Shopping schedule: Too much of a hassle to go shopping every sat morning so buy takeout for dinner

8

### P3b: Trading accuracy for time

- If computing the exact result is too slow, maybe an approximate solution will do
  - Optimal solutions may be hard: Heuristics will do (e.g., optimal multicast routing is a Steiner tree problem)
  - Faster compression using “lossy” compression
    - Lossy compression: Decompression at receiver will not exactly recreate original signal
  - Hot potato routing

#### Real-world examples?

- Managing budget
- Quality/time tradeoff: Decreasing marginal returns: A 90% solution is good enough. Go one and do the next thing once you’re 90% there

9

### P4: Leverage other system components

- Network protocols run in computing context:
  - Lay out data structures and implement algorithms to enhance caching effects
  - Realize memory is pages, lay out data structures to not cross page boundaries
- Trade memory for speed: Use precomputed lookup tables to get a value, rather than computing on fly each time

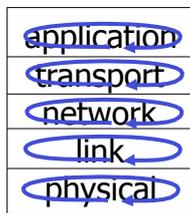
#### Real-world examples?

- Precompute answers to questions at a press conference or talk ahead of time

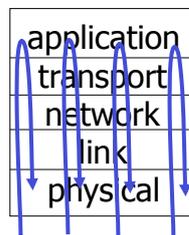
10

### P5: Throw hardware at the problem

- ❑ Special-function hardware: CRC calculation, encryption
- ❑ Export processing functions “off-board”
  - Network-interfaces
- ❑ Parallelize protocol functions
  - Parallelized protocols (by layer, by connection, by packet)



thread per layer



thread per connection

11

### P6: Replace inefficient general-purpose routines

### P7: Avoid unnecessary generality

- ❑ One-size fits all can lead to inefficiencies
- ❑ By specializing, can gain performance (at cost of code bloat)
  - TCP bundles congestion control and error control. What if you want congestion control but don't care about error control (e.g., real-time delivery of multimedia data)
  - Other example: ATM cell size (optimized for voice but used for lots of other types of traffic)
  - But then why do we have only a small number of protocols/ approaches at each layer?

#### Real-world examples

- Help lines: treat you like a dummy, takes time to get specialized assistance.
- Standardized pants

12

### P8: Don't confuse specification with implementation

- ❑ Specifications indicate external effects/interaction of protocol.
- ❑ How protocol is implemented is up to designer
- ❑ Programming language specifications: In addition to specifying *what*, tend to suggest *how*.

#### Real-world example:

- ❑ Recipe:
  1. Cut onions
  2. Cut potatoes
  3. Put onion and potatoes into pot and boil

Steps 1 and 2 can obviously be interchanged ...

13

### P9: Pass information, such as hints, across interfaces

### P10: Pass information in protocol headers

- ❑ Hints: Additional information that, if correct, can improve protocol performance/processing
- ❑ P10 example:
  - Each arriving TCP segment contains the receiver-side memory location for the TCP connection record for that segment
  - Receiver initially passes this information to sender, sender includes in all subsequent segments
  - Receiver can find TCP connection records in future without lookup

#### Real-world examples:

- Letters of recommendation
- Passing information to sales people (order #, phone #) before actual conversations allows them to prefetch all data

14

### P11: Optimize for the expected case

- ❑ Future system behavior often (but not always) follows expected pattern. Protocol processing sped up by assuming common case happens
- ❑ **Example 1:** Assume next arriving packet at receiver is from same connection as previous one
  - Keep pointer to last accessed TCP connection record, check that one first before searching connection record list
- ❑ **Example 2:** Assume TCP segments arrive in order
  - Can answer question: "Is this packet in order?" faster than "Is this packet in my receiver window?"
  - Keep pointer to last byte copied into user's socket buffer, next in-order byte will follow that

15

### P11: Optimize for the expected case

#### Real-world examples:

- ❑ Service lines (e.g., help desks): Expect that user is novice (common case). If you know what you're doing, it takes longer to get help.
- ❑ Remote controls and user interfaces: common functions are fast and easy

16

### P12: Add or exploit state to gain speed

- ❑ Maintain state so that you don't have to compute something every time
- ❑ Example: Resource allocation
  - Keep track of resources allocated so know what is free (alternative: go around to all resource users, compute what is being used. What not used is free)

#### Real-world example:

- Checking account balance

17

### P13: Optimize degrees of freedom

### P14: Use special techniques with small sets of values

### P15: Use algorithmic techniques

18

## Some cautionary tales

Q1: Is it worth improving performance?

- Does performance increase have high complexity cost?
- KISS: keep it simple silly
- E.g., router has so many protocols. Would routers be more "robust" if there were fewer protocols?

Q2: Is this really a bottleneck?

- 80% of gains achievable by focusing on 20% of system
- Use profiling tools to see where time is spent

19

## Some cautionary tales

Q3: Effect of change on rest of system?

- Does change increase performance in one place but slow down in other places?

Q4: Does an initial analysis indicate potential significant improvement is possible?

- Is there room for improvement?
- How close to best possible performance ? Think about *bounds*, solutions (e.g., oracle) with unachievable performance

20

## Some cautionary tales

Q5: Is it worth adding custom hardware?

- ❑ Ride Moore's curve (doubling of processing speed every 18 months) or use specialized hardware?

Q6: Can protocol changes be avoided?

- ❑ Rather than scrap existing protocol, tweak/rethink it to solve problem?
- ❑ Example: TCP's imminent demise predicted many times (e.g., TCP too slow for high-speed implementation)

21

## Some cautionary tales

Q7: Does prototype confirm initial promise?

- ❑ Initial high-level analysis will miss details that could be important
- ❑ Some people will never be convinced without an implementation

Q8: Will performance gains be lost if environment changes?

- ❑ Think about if improvements limited to small number of environments
- ❑ **Example:** Same-connection, in-order packet assumptions won't hold in busy server.

22

## Any missing cautionary tales?

- ❑ Make sure no one else has done it
  - Corollary: If you have thought it up, it's likely that someone else has (or will soon) too
- ❑ Stress: complexity versus performance tradeoff: what really matters?
- ❑ Evaluate benefits under meaningful conditions

23

## Radia Perlman's folklore of protocol design

- ❑ Collect various tricks and "gotchas" in protocol design.
- ❑ "Here are several ways to solve problem X", with technical explanation of pros/cons
- ❑ Some "real world" examples

We'll cover most, not all,  
"tricks and gotchas"

24

## Simplicity vs. flexibility vs. optimality

- ❑ Is a more complex protocol reasonable?
  - ❑ Is "optimal" important?
  - ❑ **KISS**: "The simpler the protocol, the more likely it is to be successfully implemented and deployed."
- Why are protocols overly complex?
- ❑ Design by committee
  - ❑ Backward compatibility
  - ❑ Flexibility: Heavyweight swiss army knife
  - ❑ Unreasonable striving for optimality
  - ❑ Underspecification
  - ❑ Exotic/unneeded features

— Charles Mingus

"Making the simple complicated is commonplace; making the complicated simple, awesomely simple, that's creativity!"

25

## More folklore/advice:

**Know the problem you are trying to solve:**

- ❑ Have at least one well-defined problem in mind
- ❑ Solve other problems without complicating solution?

**Think about scaling**

- ❑ Think about what happens if you're successful: protocol is used by millions
- ❑ Does the protocol make sense in small situations as well?

26

## More folklore/advice:

### Operation above capacity

- ❑ Protocol should degrade gracefully in overload, at least detect overload and complain
- ❑ How does protocol break and die?
- ❑ Can't just die under overload

### Identifiers: Two approaches

- ❑ Highly encoded universal IDs: E.g., upper layer protocol # assigned by IANA
- ❑ General purpose object identifiers, as in ASN.1

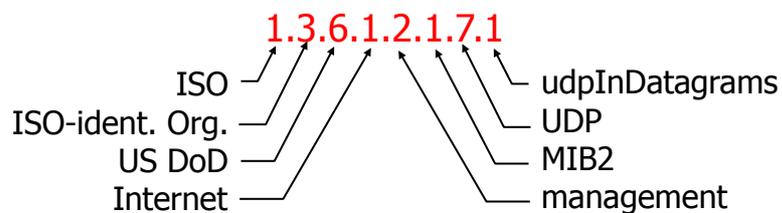
27

## SNMP naming

**Question:** How to name every possible standard object (protocol, data, more ...) in every possible network standard??

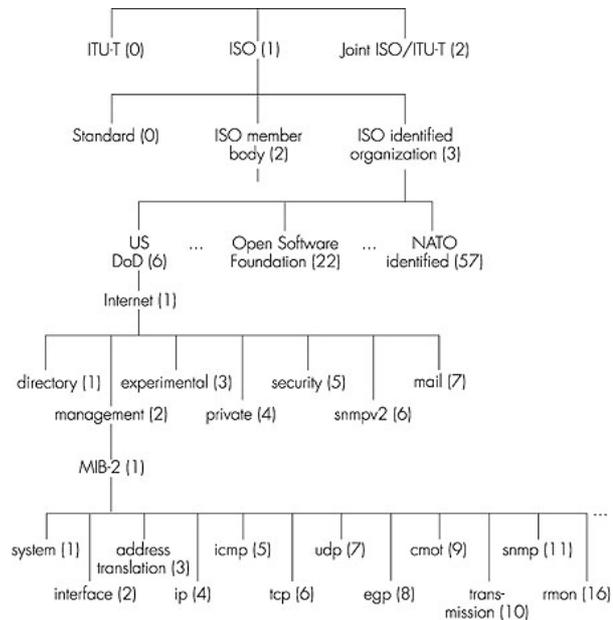
**Answer:** *ISO Object Identifier tree:*

- Hierarchical naming of all objects
- Each branch point has name, number



28

## OSI Object Identifier Tree



Check out [www.alvestrand.no/harald/objectid/top.html](http://www.alvestrand.no/harald/objectid/top.html)

29

## Assigned Internet Protocol numbers

From RFC 1700:

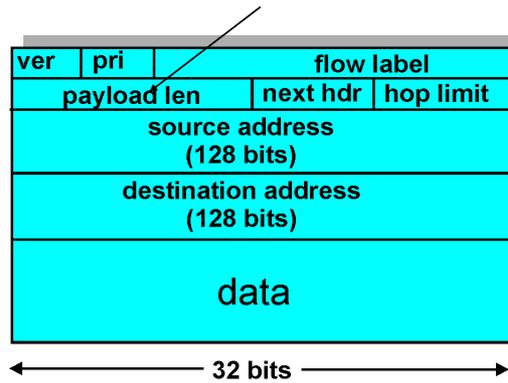
Decimal	Keyword	Protocol	References
0		Reserved	[JBP]
1	ICMP	Internet Control Message	[RFC792, JBP]
2	IGMP	Internet Group Management	[RFC1112, JBP]
3	GGP	Gateway-to-Gateway	[RFC823, MB]
4	IP	IP in IP (encapsulation)	[JBP]
5	ST	Stream	[RFC1190, IEN119, JWF]
6	TCP	Transmission Control	[RFC793, JBP]
7	UCL	UCL	[PK]
8	EGP	Exterior Gateway Protocol	[RFC888, DLM1]
9	IGP	any private interior gateway	[JBP]
10	BBN-RCC-MON	BBN RCC Monitoring	[SGC]
11	NVP-II	Network Voice Protocol	[RFC741, SC3]
12	PUP	PUP	[PUP, XEROX]
13	ARGUS	ARGUS	[RWS4]
14	EMCON	EMCON	[BN7]
15	XNET	Cross Net Debugger	[IEN158, JFH2]

30

## More folklore/advice:

### Optimize for common case

- ❑ Seen this before ...
- ❑ Nice example: IPV6 payload (packet) length field
- ❑ Payload length:
  - 2 bytes
- ❑ If packet longer:
  - payload length = 0
  - 4 byte length field found in IP options
- ❑ Designers chose against 4-byte header to optimize common case:
  - 2 bytes are enough



31

## More folklore/advice:

### Forward compatibility

- ❑ Think about future changes, evolution
- ❑ Make fields large enough
- ❑ Reserve some spare bits
- ❑ Specify an options field that can be used/augmented later

### Parameters

- ❑ Protocol parameters can be useful
  - Designers can't determine reasonable values
  - Tradeoffs exist: Leave parameter choice to users
- ❑ Parameters can be bad
  - Users (often not well informed) will need to choose values
  - Try to make values plug-and-play

32

## More folklore/advice:

### Making systems "robust": Many forms of robustness

- Immediately adapt to failure/change
- Self-stabilization: Eventually adapt to failure/change
- Byzantine robustness: Will work in spite of malicious users
  
- Maybe better to crash than degrade when problems occur: Signal problem exists
- Techniques for limited spread of figures

33

## Missing folklore/advice:

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34

## The end: Implementation principles

### Goals:

- ❑ Identify, study principles that can guide implementation of network protocols
  - Common principles among many protocols
  - “Folklore” of protocol design
- ❑ *Synthesis*: Big picture
- ❑ *Architecture and implementation*:  
Both more art than science