# Software Architecture

## Lecture 2
## Data Flow Systems

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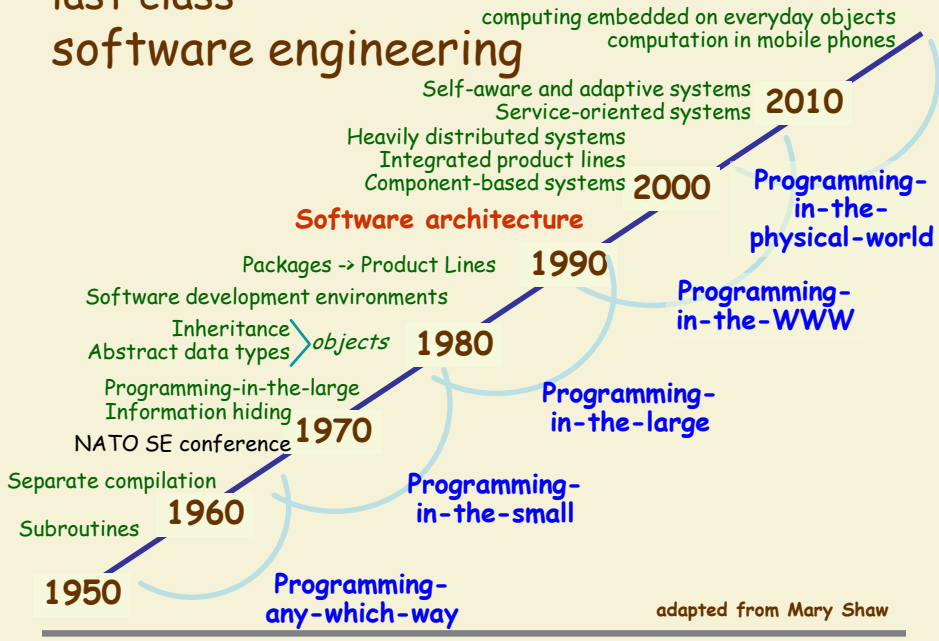
## last class
## software engineering




adapted from Mary Shaw

## last class
## Software Architecture

- representing the **structure** of a system from different angles: views
- views help manage the complexity of describing the architecture
- viewtypes
  determine the kinds of things a view talks about
  - three primary viewtypes: module, C&C, allocation
- some styles occur frequently within each viewtype
  - module: decomposition, generalization, layered, …
  - C&C: pipe & filter, client-server, pub-sub…
  - allocation: deployment, work assignment…



## many styles
## in the C&C viewtype

**data flow**
- batch sequential
- dataflow network (pipe & filter)
  - acyclic, fan-out, pipeline, Unix
- closed loop control

**call-and-return**
- main program/subroutines
- information hiding – objects
- stateless client-server
- SOA

**interacting processes**
- communicating processes
- event systems
  - implicit invocation
  - publish-subscribe

**data-oriented repository**
- transactional databases
  - stateful client-server
- blackboard
- modern compiler

**data-sharing**
- compound documents
- hypertext
- Fortran COMMON
- LW processes

**hierarchical**
- tiers
  - interpreter
  - N-tiered client-server

# today's outline

- data flow styles
  - process control
  - batch-sequential
  - pipe & filter
    - case study: Tektronix
- lab 1
- pipe & filter sub-styles & implementation

Acknowledgment
some of the material presented in this course is adapted from 17655, taught to the MSE at CMU by David Garlan and Tony Lattanze

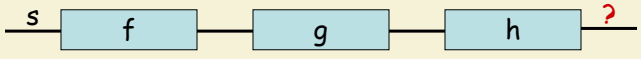


# data flow styles assume:

- connectors are data streams
  - interfaces are reader and writer roles
  - transport data from writer roles to reader roles
  - unidirectional (usually asynchronous, buffered)
- components do not know the identity of upstream/downstream producers/consumers
  - read data from input ports
  - compute
  - write data to output ports

## in data flow styles
## availability of data controls the computation

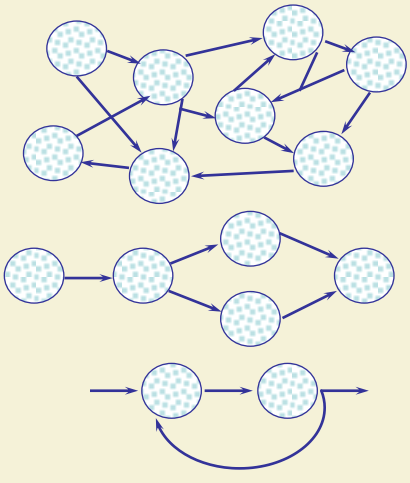
- any component that has input may process it
- overall data transformation is the "functional composition" of individual transformations




h(g(f(s)))



## data flow styles
## structure is an arbitrary graph

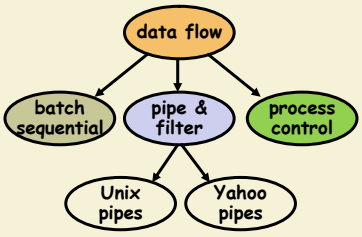


in general, data can flow in arbitrary patterns

however, frequently data flows in "stages"

or in simple, highly constrained cyclic structures

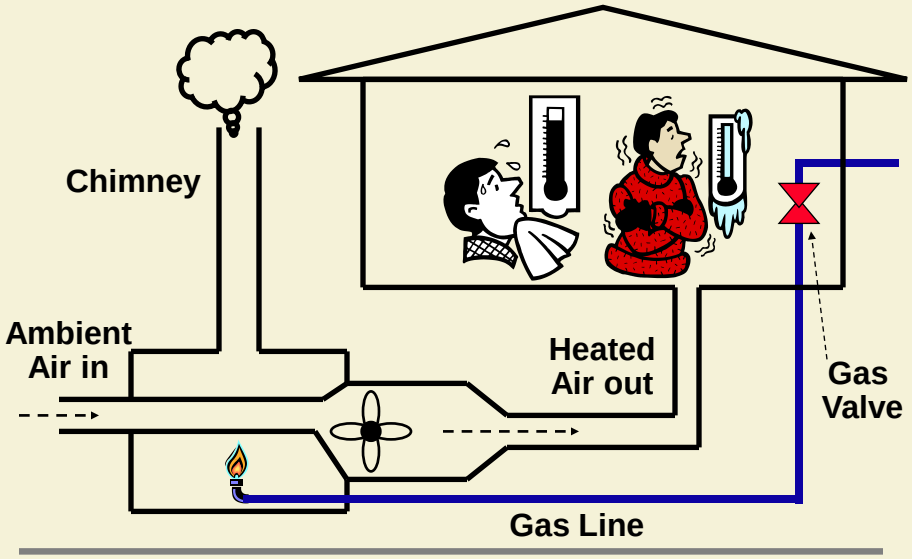
# three major data flow styles



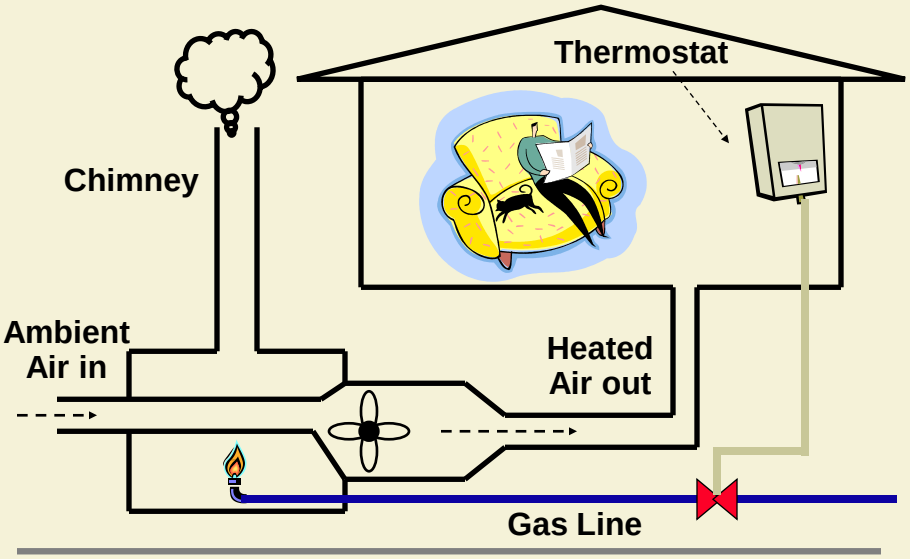

- process control
  - looping structure to control environment variables
- batch sequential
  - sequential processing steps, run to completion
  - typical of early MIS applications
- pipe & filter
  - incremental transformation of streams
  - Unix pipes and Yahoo pipes are special cases (sub-styles)



# example of process control
## open-loop control system



## example of process control
## closed-loop control system

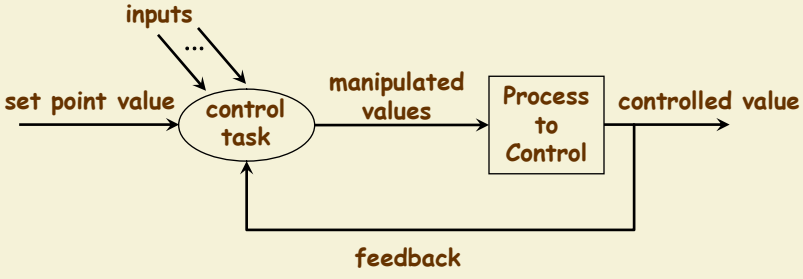





## process control notions

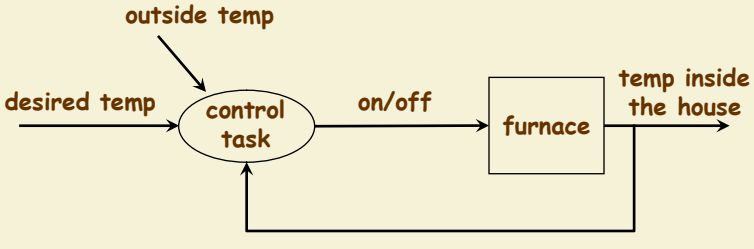
- open-loop system:
  process variables not used to control the system
- closed-loop system:
  process variables used to control the system
  - controlled variable: goal
    (ex: air temperature inside the house)
  - set Point: value for the controlled variable
  - input variable: what the system can measure
    (ex: temperature of the outside air coming into the furnace)
  - manipulated variables: what the system can affect
    (ex: turning the furnace on or off)
- feedback control
  controlled variable is measured and taken into account
- feed-forward control
  process variables other than c.v. are taken into account

# architecture of closed-loop process control

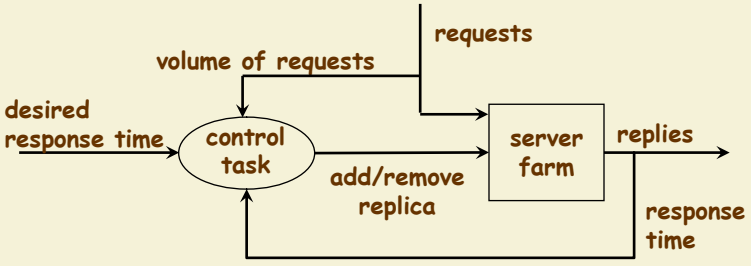





# example architecture heating closed-loop control

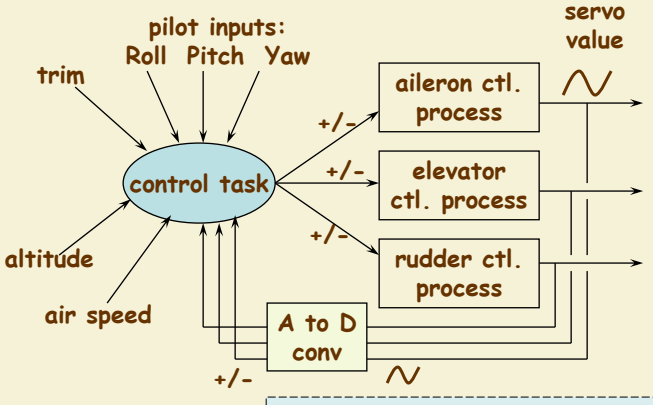


# example architecture
## adaptive server farm

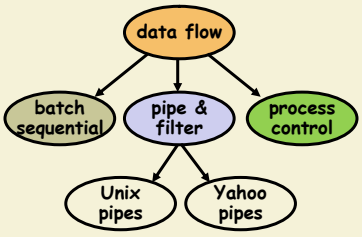





# example architecture
## simplified avionics



# three major data flow styles

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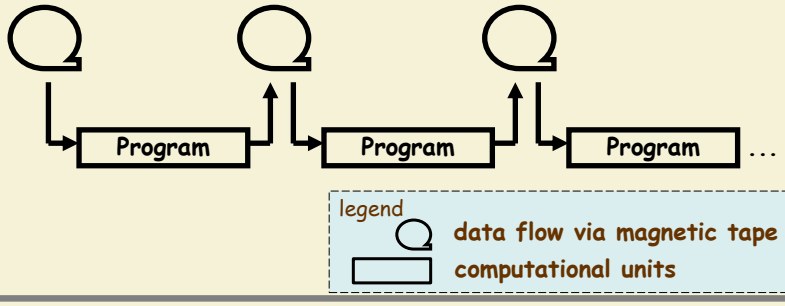
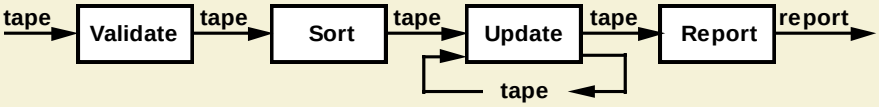
# batch sequential assumes:

- connectors
  - data is transmitted as a whole between steps
- components
  - processing steps are independent programs
  - each step runs to completion before the next step starts

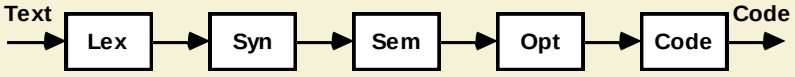


# examples of batch sequential systems

- classical data processing
  - payroll computations
  - IRS tax return computations

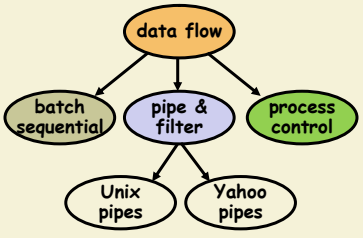



- early code compilers






# three major data flow styles

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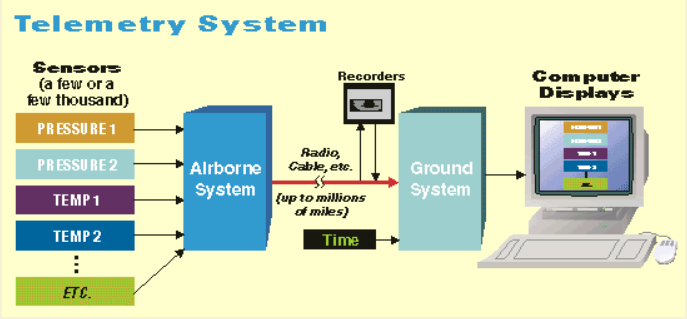
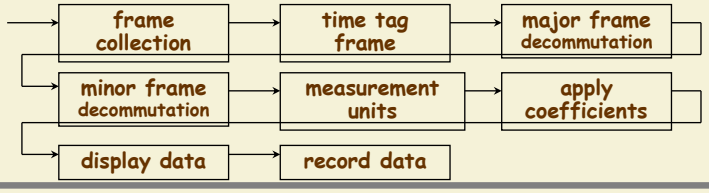
# pipe & filter assumes:

- connectors, called pipes:
  - move data from a filter output to a filter input
  - one-way, order-preserving, data-preserving
  - system action is mediated by data delivery
- components, called filters:
  - incrementally transform the input data to output data
    - enrich data by computation and adding information
    - refine by distilling data or removing irrelevant data
    - transform data by changing its representation
  - operate independently/concurrently among each other
    - no external context in processing streams
    - no state preservation between instantiations
    - no knowledge of upstream/downstream filters
    - topology determines the overall computation, not relative speed/CPU allocation of filters



# example of pipe & filter system telemetry data collection



## example P&F autonomic vehicle

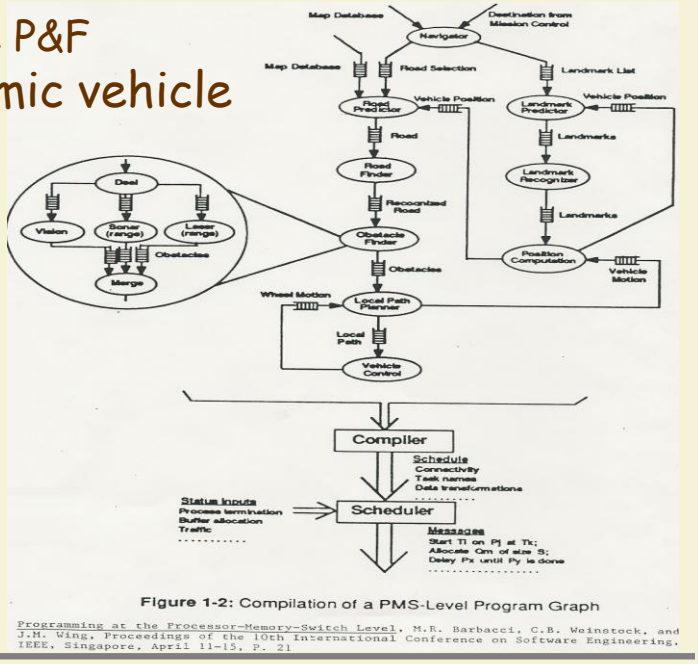



Figure 1-2: Compilation of a PMS-Level Program Graph

Programming at the Processor-Memory-Switch Level, M.R. Barbacci, C.B. Weinstock, and J.N. Wing, Proceedings of the 10th International Conference on Software Engineering, IEEE, Singapore, April 11-15, p. 21

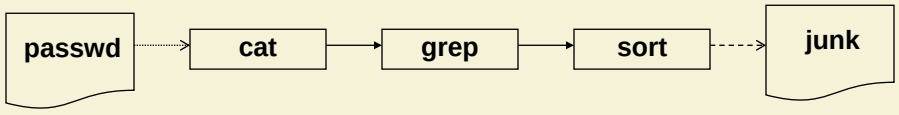


## special case of the pipe & filter style
# Unix pipes

- pipes: buffered streams supported by OS
  - assume ASCII character streams
  - can treat files as well as filters as data sources and sinks
    - the good news: anything can connect to anything
    - the bad news: everything must be encoded in ASCII, if not, it must be "translated" before piping
- filters: Unix processes
  - built-in ports: stdin, stdout, stderr
  - filters by default transform stdin to stdout

## example of Unix pipes system

```
cat /etc/passwd | grep "joe" | sort > junk
```




does this stretch any assumption of the "pure" pipe & filter style?



## special case of the pipe & filter style
# Yahoo pipes

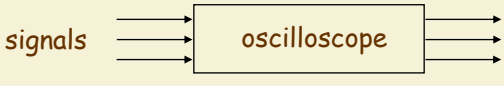
- web application for authoring *Yahoo pipes*
- *Yahoo pipe* is a data mashup
  - application hosted by Yahoo
  - combine, filter, and present data from different web sources
- http://pipes.yahoo.com/pipes/

# outline

- data flow styles
  - process control
  - batch-sequential
  - pipe & filter
    - case study: Tektronix
- lab 1
- pipe & filter sub-styles & implementation



# major manufacturer of oscilloscopes Tektronix



# Tektronix had a problem (real)

- increasing complexity of instrumentation systems
  - increasing role of software in products that were once largely hardware
  - raised expectations of users
- separate development cultures
  - similar products developed by different divisions
  - little sharing
- build-from-scratch methods
  - new hardware or new UI => new software
- products hard to develop and evolve
  - increasingly serious bugs due to concurrency
- excessive time-to-market (~ 4-5 years)

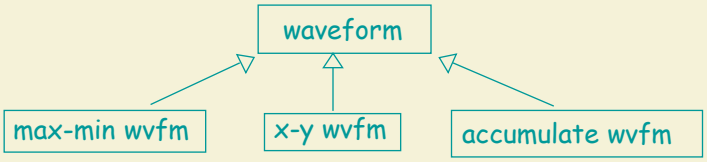


# Tektronix challenge

- build next generation instrumentation systems
- allow reuse between product divisions
- sophisticated products in response to user desires
- consistent user interface across multiple hardware platforms
- multiple user interfaces for same platform (vertical markets)
- reduce time to market

# Tektronix tried O-O approach with mixed results

created class hierarchy



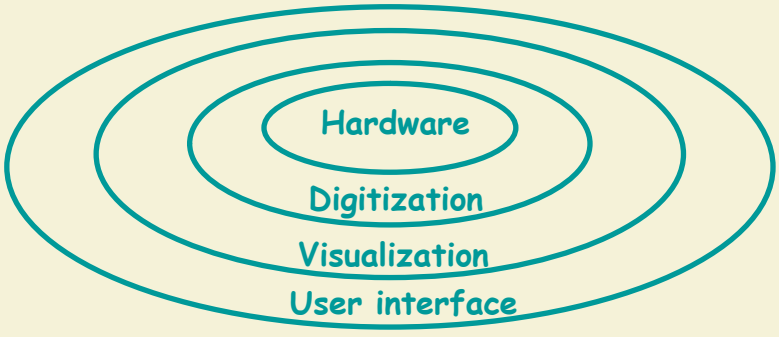

```
waveform
    w: time-> voltage
    max: -> voltage
    min: -> voltage
    invert: ...
    add: ...
```

result:

- hundreds of classes
- hard to organize hierarchy
- doesn't relate to structure of system (oscilloscope)



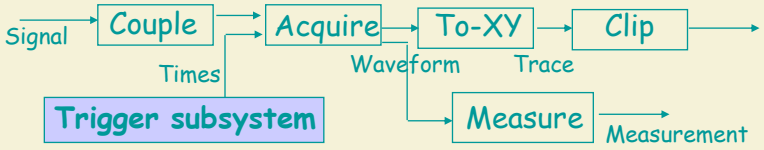
# next, Tektronix tried layered approach also with mixed results




result:

- designers found layer boundaries hard to enforce and unrealistic

## third, Tektronix tried pipe & filter with better results

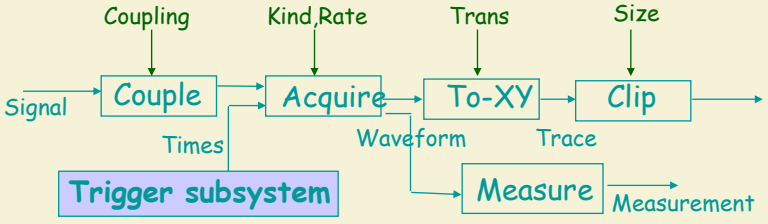



result:

- clearly reflects design organization and features
- not clear how to model user input



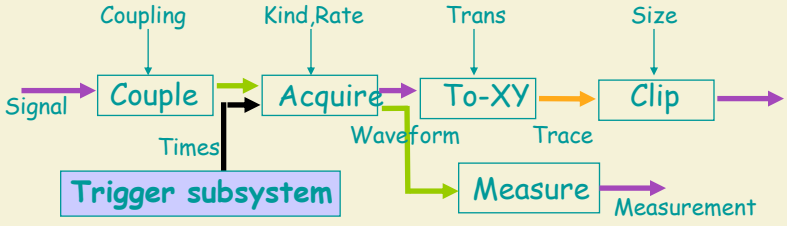
## fourth, Tektronix tried extending p & f with parameterized filters




result:

- clearly reflects design organization and features
- models user input
- not directly useful for implementors

# fifth, Tektronix
## extended p & f with colored pipes




result:

- clearly reflects design organization and features
- models user input
- describes the nature of data and performance constraints on each pipe



# software architecture
## had an impact on Tektronix business

- architectural style was used as basis for the next generation of oscilloscope products
- led to highly successful framework, in which time-to-market was cut substantially
- reliability of products was improved
- user interface was extensible
- new thrust of research/development collaborations
- led to new frameworks beyond oscilloscopes

# take 5



# outline

- data flow styles
  - process control
  - batch-sequential
  - pipe & filter
    - case study: Tektronix
- lab 1
  - recover views from the code: module, C&C
- pipe & filter sub-styles & implementation

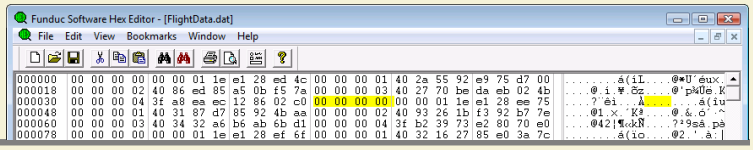
# lab 1: pipe & filter system
## build avionics instrumentation systems

- data comes in from airplane sensors

| ID | Data Descriptions and Units | Type | Number of Bytes |
|---|---|---|---|
| 00 | Time: number of milliseconds since the Epoch (00:00:00 GMT on January 1, 1970) | long int | 8 |
| 01 | Velocity: airspeed of the vehicle, measured in knots per hour | double | 8 |
| 02 | Altitude: vehicle's distance from the average surface of oceans, measured in feet | double | 8 |
| 03 | Pressure: atmospheric pressure external to the vehicle, measured in PSI | double | 8 |
| 04 | Temperature: temperature of the vehicle's hull, measured in degrees Fahrenheit | double | 8 |
| 05 | Pitch: angle of the nose of the vehicle, if positive, the vehicle is climbing | double | 8 |

- framed as

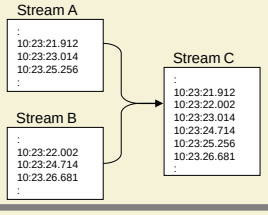
| | | | | | | |
|---|---|---|---|---|---|---|
| 0000 | Time | 0001 | Velocity | … | *n* | *data* |
| 0000 | Time | 0001 | Velocity | … | *n* | *data* |
| … | | | | | | |






# lab 1: pipe & filter system
## build avionics instrumentation systems

- system A: reads flight data and
  - converts Temp to Celsius
  - converts altitude to meters
  - removes other fields
- system B: same plus
  - include all fields
  - removes wild altitude variations >100m
    and replaces them by interpolated values (avg of previous and next)
- system C: merges streams
  from two sets of sensors
  - output frames are sorted by time

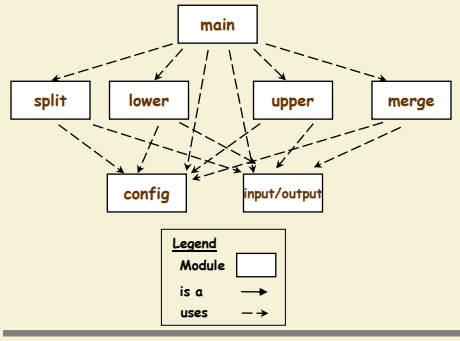


# lab 1: pipe & filter system
# based on a code framework

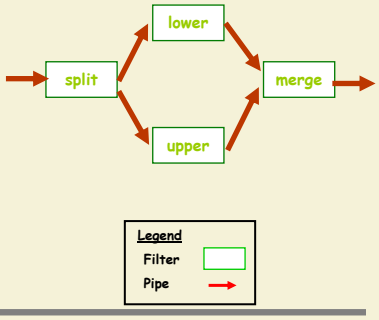
remember:

- module and C&C view types show different aspects

## module view

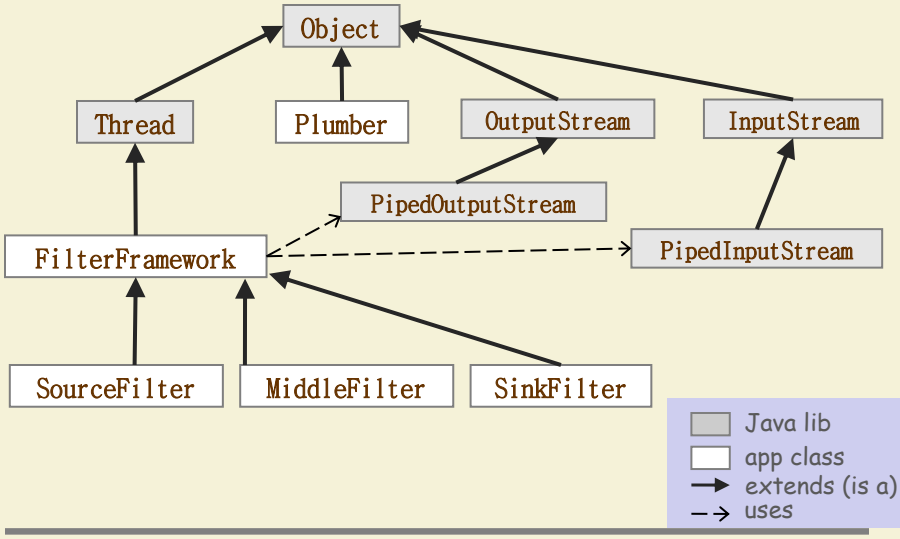



## C&C view

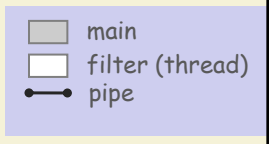





# lab 1
# module view



# lab 1
# C&C view



- creates and connects the filters
- doesn't intervene during system operation
  - therefore not normally represented



# why is the code written like this?
# …a little history

- the Greeks had the following number system:
  - separate letters for numbers between 1 and 9 (for example, υ was nine)
  - separate letters for multiples of ten between 10 and 90 (for example, π was sixty)
  - separate letters for multiples of one hundred between 100 and 900 (for example, τ was 300)
  - so 309 was written 'τυ'
- the positional system arrived in 500 AD
  - imagine someone used to the Greek system being annoyed with having to write extra digits

why is the positional system successful?

# outline

- data flow styles
  - process control
  - batch-sequential
  - pipe & filter
    - case study: Tektronix
- lab 1
- pipe & filter sub-styles & implementation



# in data flow styles
## data flow dominates structure and control

- a data flow system is one in which:
  - the structure of the design is determined by the motion of data from component to component
  - the availability of data controls the computation
  - the pattern of data flow is explicit
  - this is the only form of communication between components
- variations on this theme
  - how control is exerted (e.g., push versus pull)
  - degree of concurrency between processes
  - granularity of computation
  - topological restrictions (e.g., pipeline)

## pipe & filter sub-styles & implementation
## system level

- topological constraints
  - some styles insist on a pipeline, or no cycles
- strategies for creation of elements
  - centralized versus distributed
  - static versus dynamic
  - declarative versus operational (some systems have both)



## pipe & filter sub-styles & implementation
## components

- concurrency
  - separate processes or single address space
- constraints on ports
  - e.g., Unix components typically have 3 ports: stdin, stdout, stderr
  - e.g., some styles require single input and single output port
- computational model
  - e.g., how do you deal with multiple inputs?

## pipe & filter sub-styles & implementation
## connectors

- finite versus infinite buffering
- dealing with end of data
  - can a writer terminate the flow of data?
  - can a reader choose not to consume data on a pipe?
  - what should a reader or a writer do after data has been terminated?
- does data have different types?
- how many kinds of pipes are there? (colored pipes)



## pipe & filter sub-styles & implementation
## example: Unix pipes

- two kinds of specification
  - shell (ex:)
    infile > capitalize | rem_white_space | compress > outfile
  - programmatically:
    use stdio library to create pipes and hook them up
- topology
  - linear if from shell
  - may have cycles if done programmatically
- creation
  - static if from shell
  - dynamic if done programmatically

## pipe & filter sub-styles & implementation
# example: Unix pipes

- filters
  - concurrency: separate processes
  - ports: three for shell filters
  - computational model:
    filter chooses which ports to read and write
    (if you guess wrong deadlock may result)
- pipes
  - supported by operating system
  - buffered (e.g., 2K bytes)
  - special end-of-file marker
  - reader can close its end of a pipe at any time
  - must be aware of whether input is coming from a file or a filter
  - data has one type only: raw bytes



# references for implementation strategies

- book on Java threads
  - *Concurrent Programming in Java: Design Principles and Patterns* (2nd Edition) by Doug Lea
- online tutorial on Java threads
  - http://www.javaworld.com/jw-04-1996/jw-04-threads.html
- Design Patterns
  - book by Erich Gamma, Richard Helm, Ralph Johnson, John Vlissides

## in summary
## select a data flow style when:

- task is dominated by the availability of data
- data can be moved predictably from process to process

pipe-and-filter architectures are good choices for many data flow applications because

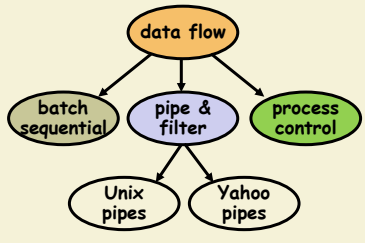
- they permit reuse and reconfiguration of filters
- generally easy to reason about
- reduce system testing
- may allow incremental AND parallel processing

there may be a performance penalty when implementing data flow styles over a single process



## in summary
## styles are rarely usable in simple pure form

- one technique is to specialize styles
  - styles become more constrained, domain-specific
  - trade generality (expressiveness) for power (analytic capability)
  - we saw this today in the examples of data flow styles



# in summary

there are many points on the spectrum of specialization

- we looked at a few example today (stars) but will be looking at lots more during the course