Software Architecture

Lecture 2
Data Flow Systems

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last class

- Software Architecture is about 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…

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

in data flow styles
data flow dominates structure and control

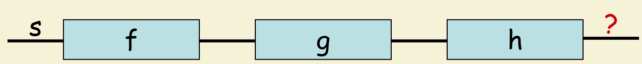
- a data flow system is one in which:
  - the structure of the design is determined
    by the motion of data from component to component
  - the availability of data controls the computation
  - the pattern of data flow is explicit
  - this is the only form of communication between components
- variations 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)

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

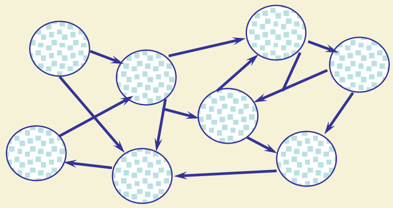
in data flow styles
availability of data controls the computation

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

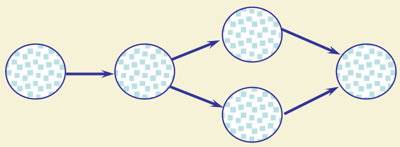


h(g(f(s)))

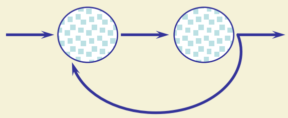
data flow styles
structure is an arbitrary graph



in general,
data can flow in
arbitrary patterns

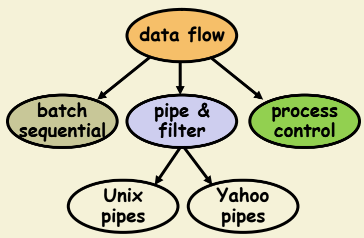


however, frequently
data flows in "stages"



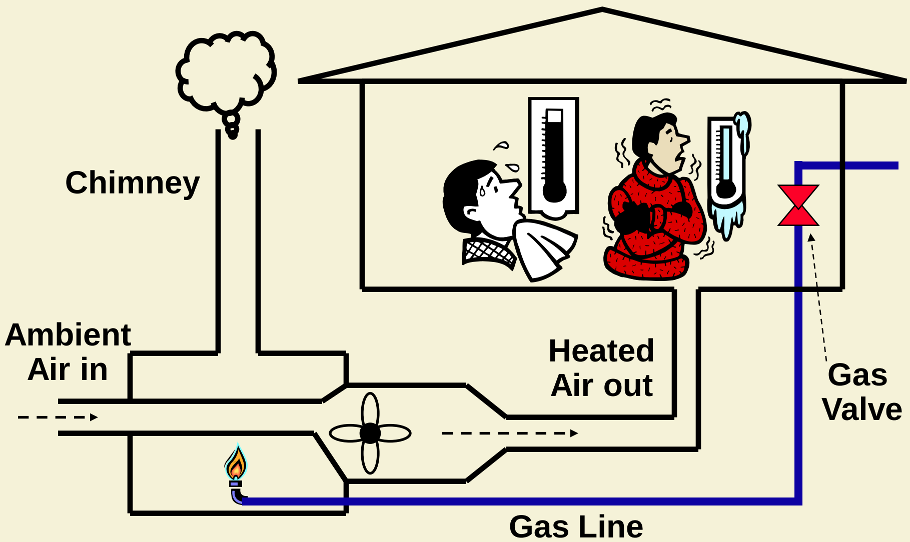
or in simple, highly
constrained cyclic
structures

three major
data flow styles

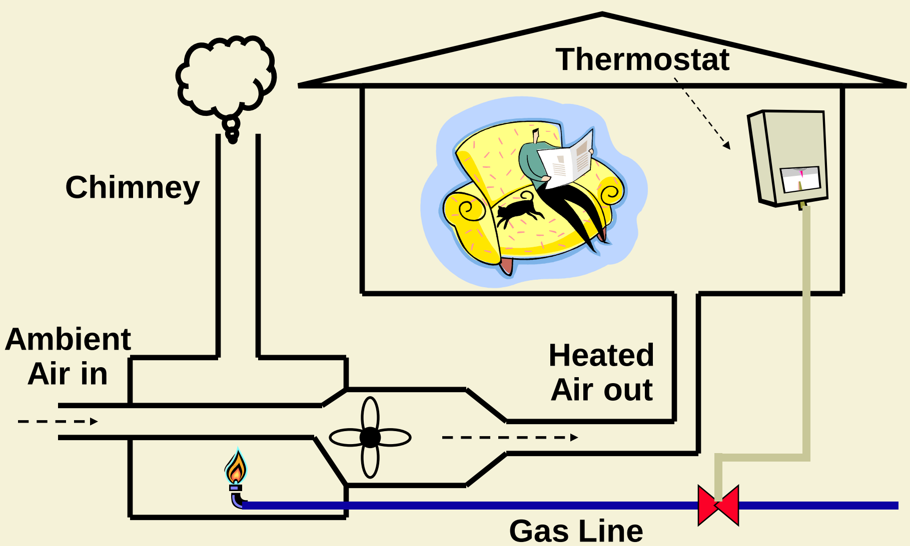


- process control
  - looping structure to control environment variables
- batch sequential
  - sequential processing steps, run to completion
  - typical of early MIS applications
- pipe & filter
  - incremental transformation of streams
  - Unix pipes and Yahoo pipes are special cases (sub-styles)

example of process control
open-loop control system



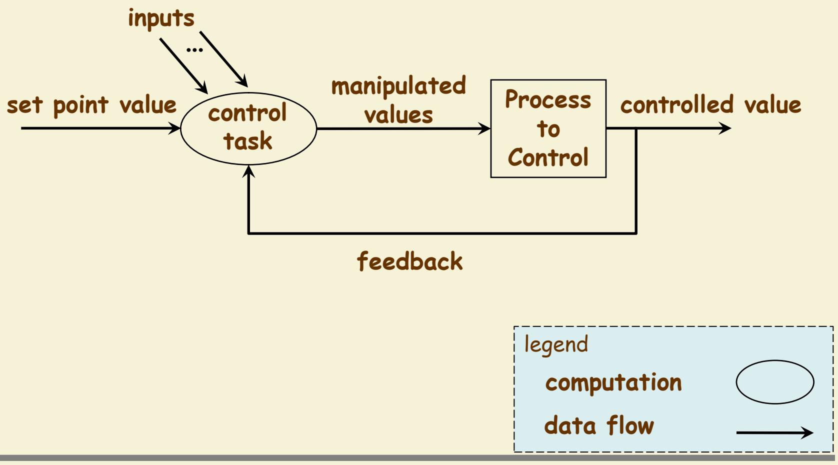
example of process control
closed-loop control system



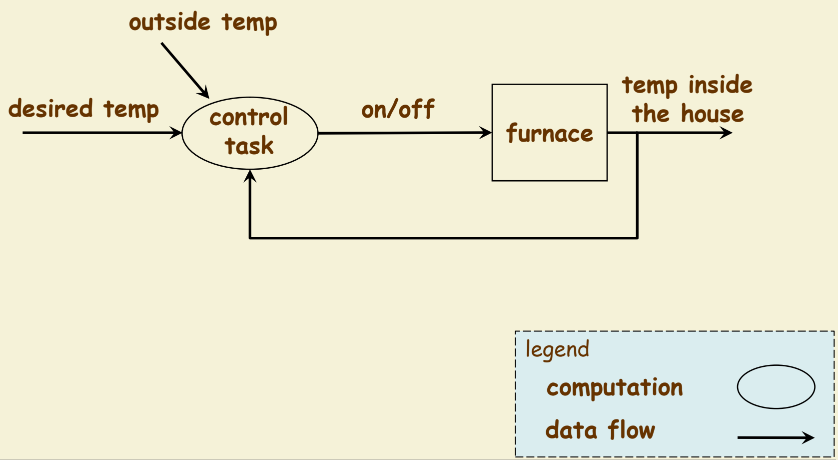
process control notions

- 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

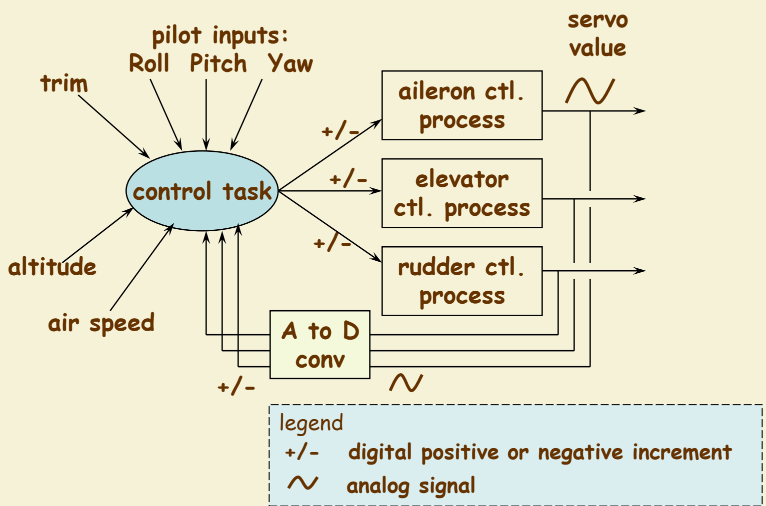
architecture of closed-loop process control



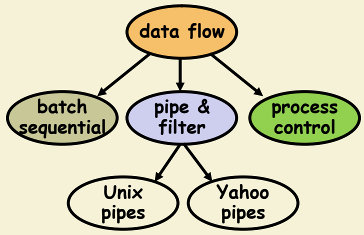
example architecture
heating closed-loop control



example architecture
very simplified avionics



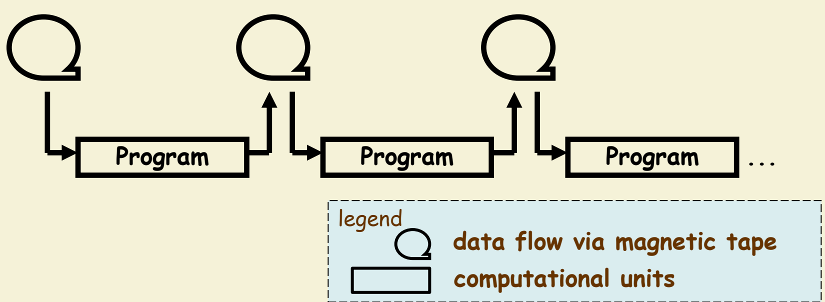
three major data flow styles



- 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)

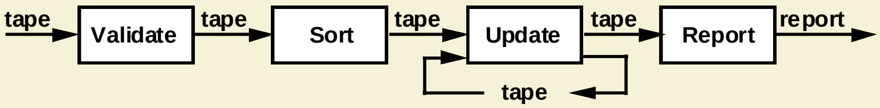
batch sequential assumes:

- 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

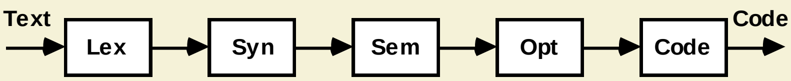


examples of batch sequential systems

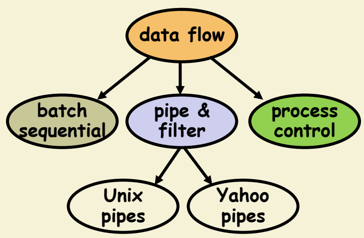
- classical data processing
  - payroll computations
  - IRS tax return computations



- early software development environments



three major data flow styles



- process control
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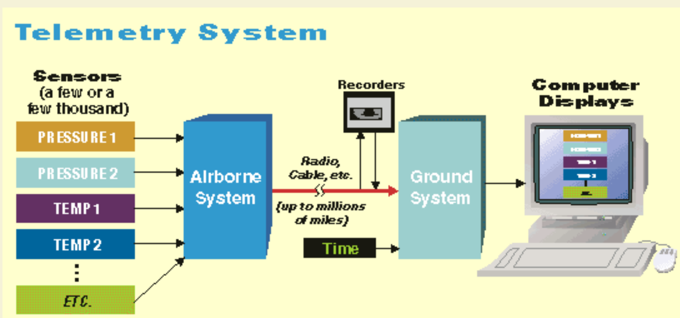
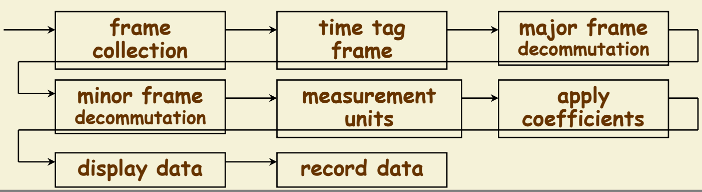
pipe & filter assumes:

- 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

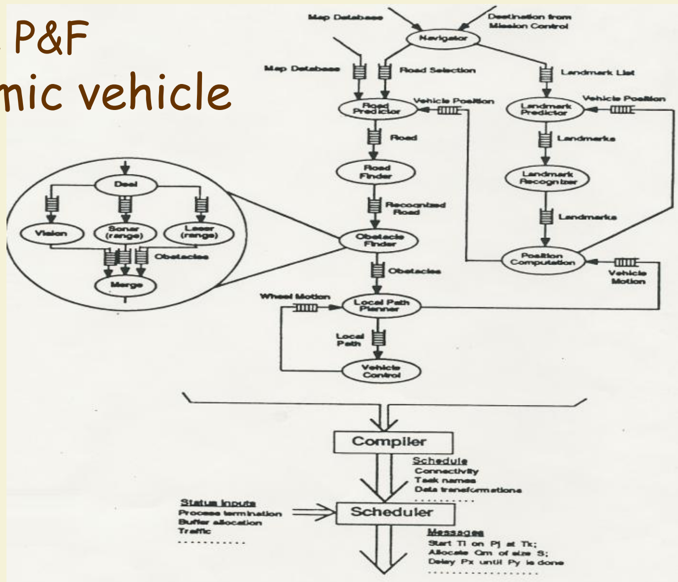


Figure 1-2: Compilation of a PMS-Level Program Graph

Programming at the Processor-Memory-Switch Level, M.R. Barbacci, C.B. Weinstock, and J.M. 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)

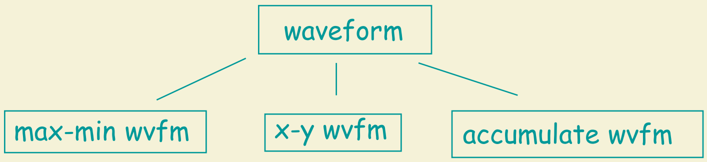
- increasing complexity of instrumentation systems
  - increasing role of software in products that were once largely hardware
  - raised expectations of users
- separate development cultures
  - similar products developed by different divisions
  - little sharing
- build-from-scratch methods
  - new 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

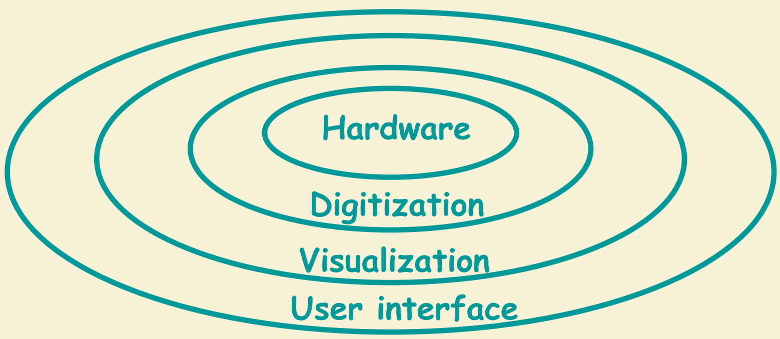



```
waveform
   w: time-> voltage
   max: -> voltage
   min: -> voltage
   invert: ...
   add: ...
```

result:

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

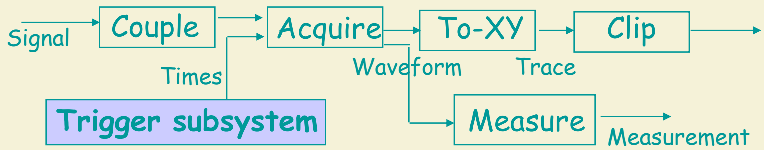
next, Tektronix tried
layered approach also with mixed results



result:

- designers found layer boundaries hard to enforce and unrealistic

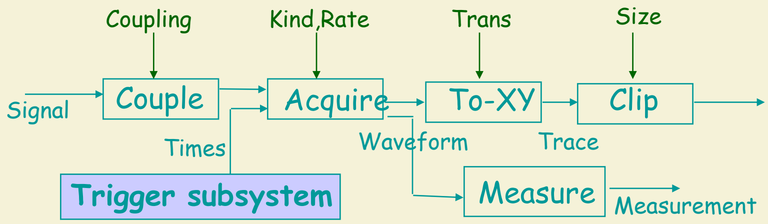
third, Tektronix tried pipe & filter with better results



result:

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

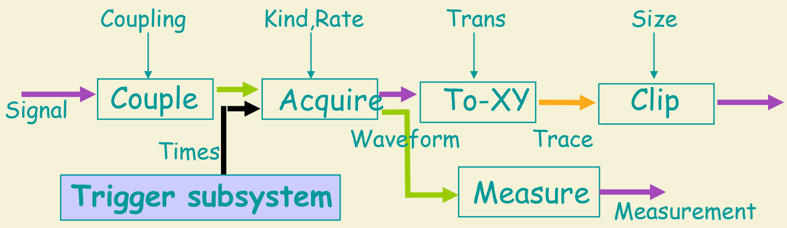
fourth, Tektronix tried extending p & f with parameterized filters



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

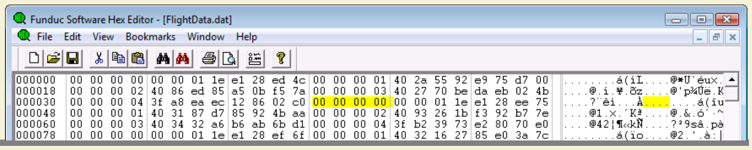
lab 1: pipe & filter system
build avionics instrumentation systems

- 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

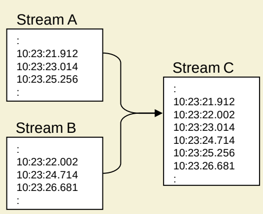
- framed as

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
  - includes pressure data
  - removes pressure outliers > 80psi or <50 psi
    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

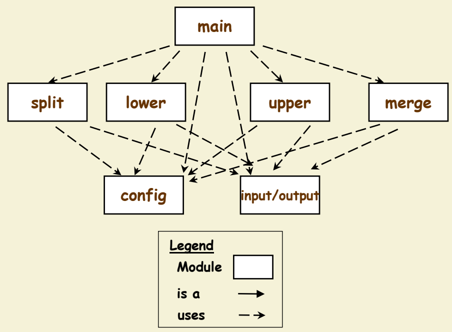


lab 1: pipe & filter system
based on a code framework

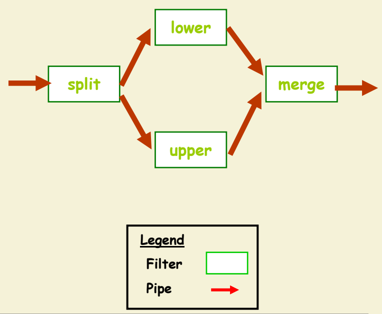
remember:

- module and C&C viewtypes show different aspects

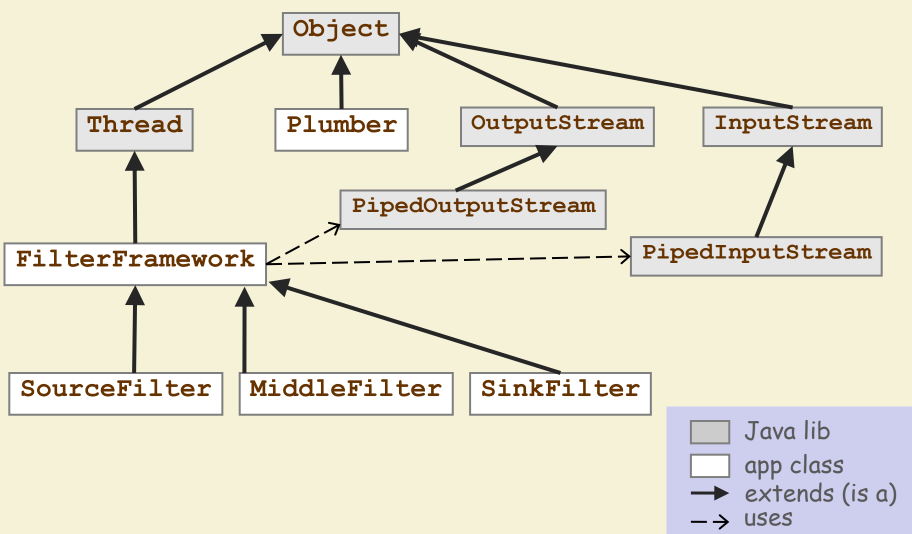
module view



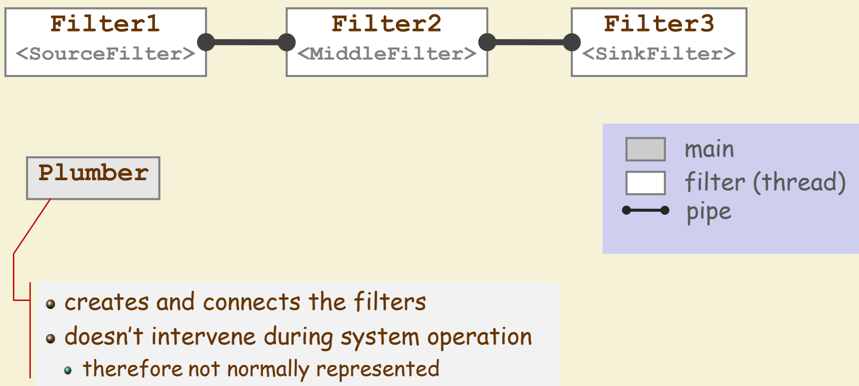
C&C view



lab 1
module view



lab 1
C&C view



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 '$\tau\upsilon$'
- 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

pipe & filter sub-styles & implementation
system level

- topological constraints
  - some styles insist on a pipeline, or no cycles
    that is, some styles are hierarchical, some aren't
- 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 can 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

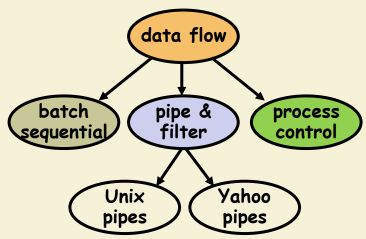
pipe-and-filter architectures are good choices for many data flow applications because

- 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