Software Architecture

CS 401

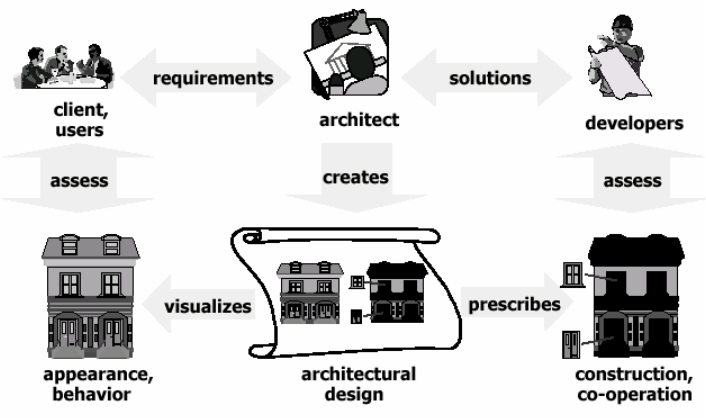
Chapter 10

Software Architecture

- Definition
  - The software architecture of a system is the structure or structures of the system that comprise software components, the externally visible properties of those components, and the relationships among them”

Role of the Architect

- Global design



Why is architecture important?

- Architecture is the vehicle for stakeholder communication
- Architecture provides insight regarding the quality of a system at an early stage
- Architecture manifests the earliest set of design decisions
- Architecture provides the means for planning and control
- Architecture is a transferable abstraction of a system

Factors that influence architecture

Other factors aside from requirements

- Development organization
  - E.g. existing hardware, systems, or modules, what worked before
- Background and expertise of the architect
  - Usually what worked before
- Technical and organizational environment
  - Domain factors, organizational techniques

Structural Organization of System Modules

- Some views of the software architecture
  - Conceptual or logical view
    - Major design elements and their interactions
    - Focus of chapter 10
  - Implementation view
    - Modules, packages, layers, etc.
  - Process view
    - Tasks, processes, their communication
    - Used mainly for concurrent systems
  - Deployment view
    - Allocation of tasks to physical nodes
    - Needed only for distributed systems
- Other views?
  - Security
  - Data

Architectural Styles

- High-level abstractions of components and communication
  - Even higher than data types, algorithmic pseudocode
  - Also known as **design patterns** or **architectural patterns**
- Architectural styles become reusable for different problems
  - Collections of modules or classes that are often used in combination to provide a useful abstraction

Some common architectural styles

- Main with Subroutines and Shared data
- Data abstraction
- Implicit invocation
- Pipes and filters
- Repository (blackboard)
- Layers of abstraction
- Model-view-controller

Example Problem: Producing a KWIC-Index

- Book title “Introduction to Software Engineering”
- Reader might look under “I” or under “S” for Software Engineering, or maybe even “E” for Engineering
- Solution: KWIC-Index (Key Word In Context)
  - Given a title generate n shifts, where n is the number of words in the title
  - w_1 w_2 w_3
  - w_2 w_3 w_1
  - w_3 w_1 w_2
  - Sort shifts, output is a KWIC-index for one title
  - Repeat for a list of titles

KWIC-Index

- Two titles, “Introduction to Software Engineering” and “Rapid Software Development”
- Introduction to Software Engineering
  - Engineering Introduction to Software
  - Introduction to Software Engineering
  - Software Engineering Introduction to
  - to Software Engineering Introduction
- Rapid Software Development
  - Development Rapid Software
  - Rapid Software Development
  - Software Development Rapid

First Architecture: Main Program and Subroutines with Shared Data

- Following tasks must be accomplished
  - Read and store the input (list of titles)
  - Determine all shifts
  - Sort the shifts
  - Output the sorted shifts
- Allocate each task to different modules
- Each module shares the same internal data representation

Module Details

- Input
  - Input stored in memory so that the lines are available for processing by later modules
  - Stored in a table called Store

0	Introduction to Software Engineering
1	Rapid Software Development

- Shift
  - Invoked after all lines are stored
  - Builds a table called Shifts that contains an array of shifts that contains, for each shift, the index in Store of the first character of that shift

0	[0, 0], [1, 13], [2, 16], [3, 25]
1	[0, 0], [1, 7], [2, 16]

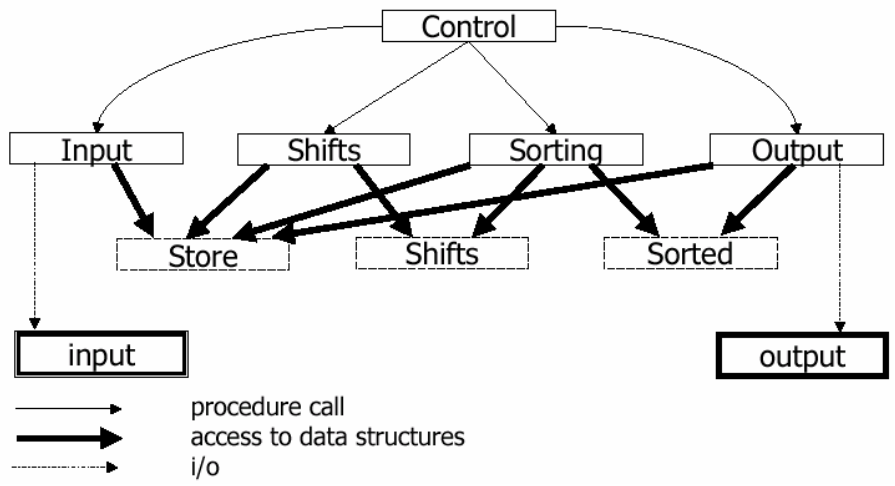
Module Details

- Sort
  - Produces a new table, Sorted, with the same structure as Shifts but the ordering is such that the corresponding shifts are in lexicographic order

0	[0, 25], [1, 0], [2, 16], [3, 13]
1	[0, 16], [1, 0], [2, 7]

- Output
  - Produces a neat output of the sorted shifts
- Control
  - Calls the other modules in the appropriate order
  - Deals with error messages, memory organization, bookkeeping duties

Module Diagram



Main Program Style

- Approach: Hierarchy of functions resulting from functional decomposition; single thread of control
- Context: programming languages allowing nested procedures
- Properties:
  - Modules in a hierarchy (weak or strong); procedures grouped into modules according to coupling/cohesion principles
  - Modules store local data and shared access to global data
  - Control structure: single thread, centralized control
- Variants: distributed processing with RPC for process invocation

Second Architecture: Abstract Data Types

- Previous decomposition required that each module had knowledge about the precise storage of data
  - Data representation must be selected early
  - What if wrong representation picked? E.g. fixed char array, perhaps too small, etc.
- One solution: Use abstract data types so that these data representation decisions are made locally within a module instead of globally
  - Implement Get/Set methods that input or return data in the desired format

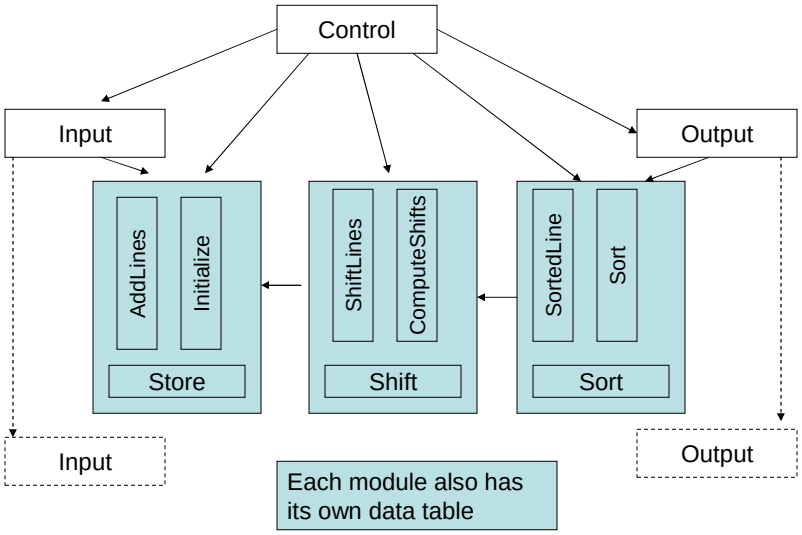
Module Details : ADT

- Store
  - Module implements methods callable by users of the module
    - Initialize()
    - AddLine(String s) - Add a new line to storage
    - Lines() – Return number of lines
    - Line(int L) – Return line L
    - Words(int r) – Return number of words in line r
    - Word(int L, int i) – Return word i of line L
- Input
  - Initializes Store module, adds lines to the module from I/O

Module Details : ADT

- Shift
  - Uses the Store module to compute shifts
  - Initialize()
  - ComputeShifts() – Computes all shifts
  - ShiftLines() – Returns total number of Lines
  - ShiftWords(int L) – Returns number of words (shifts) in shift line L
  - ShiftLine(int L, int i) – Returns entire title for shift line L ,shift i
  - ShiftWord(int L, int i,int j) – Returns word j of line L for shift i
- Sort
  - Uses Shift module to compute sort
  - Initialize()
  - Sort()
  - SortedLines() – Returns total number of lines
  - SortedWords(int L) – Returns number of words (shifts) in line L
  - SortedLine(int L, int i) – Returns entire title for line L ,shift i

ADT Module Diagram (Simplified)



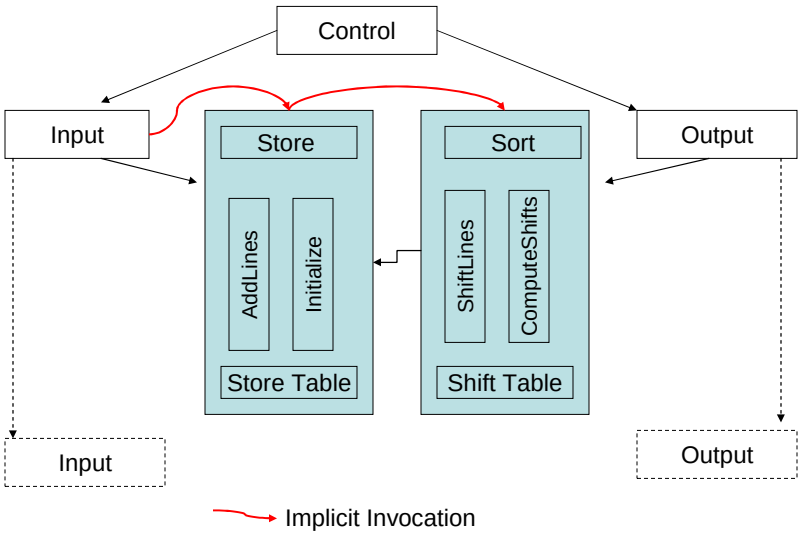
ADT Style

- Approach: Identifies and protects related bodies of information. Suited when data representation is likely to change.
- Context: OO-methods guiding the design; OO-languages which provide the class-concept
- Properties:
  - Each component has its own local data (secret it hides)
  - Messages sent via procedure calls
  - Usually a single thread of control; control is decentralized

Third Architecture: Implicit Invocation

- Event-based processing
- With Abstract data types, after the input was read, the Shifts module is invoked explicitly
- We may loosen the binding between modules by implicitly invoking modules
  - If something interesting happens, an **event** is raised
  - Any module interested in that event may react to it
  - Example: perhaps we would like to process data concurrently line by line
    - Raise an event when a line is ready to be processed by the next module

Implicit Invocation Diagram



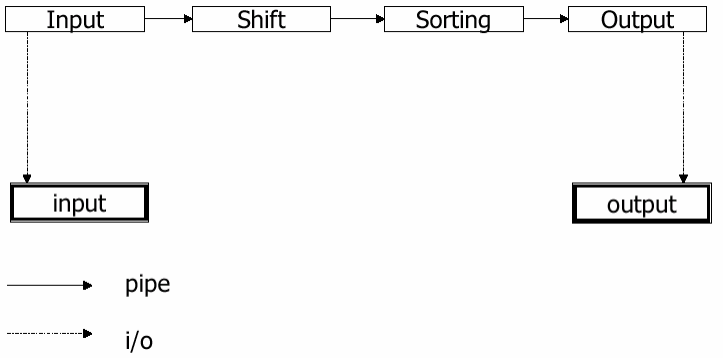
Implicit Invocation Style

- Approach: Loosely coupled collection of components. Useful for applications which must be reconfigurable.
- Context: requires event handler, through OS or language-specific features.
- Properties:
  - Independent, reactive processes, invoked when an event is raised
  - Processes signal events and react to events, or directly invoked
  - Decentralized control. Components do not know who is going to react to a particular event

Fourth Architecture: Pipes and Filters

- Major transformations in KWIC-index programs:
  - From lines to shifts
  - From shifts to sorted shifts
  - From sorted shifts to output
- Since each program in this scheme reads its input in the same order it is written by its predecessor, we can directly feed the output from one module to the input of the next
- Pipes and Filters model in UNIX
  - KWIC < input | Shift | Sort | Output > output
  - Data stream format of internal structure must be known from one program to the next
  - Enhancements are easy by adding another filter (e.g. filtering out stop words)

Pipes and Filters Diagram



Pipes and Filters Style

- Approach: independent, sequential transformations on ordered data. Usually incremental, ASCII pipes.
- Context: series of incremental transformations. OS-functions transfer data between processes. Error-handling difficult (who is doing what? Where did the error occur?)
- Properties:
  - Continuous data flow; components incrementally transform data
  - Filters for local processing
  - Data streams (usually plain ASCII)
  - Control structure: data flow between components; each component has its own thread of control
- Variants: From pure filters with little internal state to batch processes

Evaluation of the Architectures

- All of the proposed architectures will work
- Architect should evaluate the architectures with respect to
  - Changes in data representation
  - Changes in algorithms
  - Changes in functionality
  - Degree to which modules can be implemented independently
  - Comprehensibility
  - Performance
  - Reuse

Architecture Evaluation

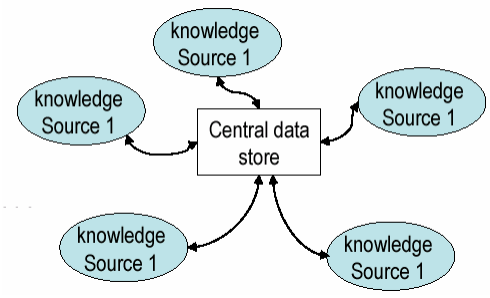
	Shared Data	**ADT**	**Implicit Invocation**	**Pipes & Filters**
Changes in data representation	**-**	**+**	**+**	**-**
Changes in algorithm	**-**	**O**	**O**	**+**
Changes in functionality	**O**	**-**	**+**	**+**
Independent Development	**-**	**+**	**+**	**+**
Comprehensibility	**-**	**+**	**O**	**+**
Performance	**+**	**+**	**-**	**-**
Reuse	**-**	**+**	**+**	**+**

Other Styles

- Repository
- Layered
- Client Server
- Model View Controller (MVC)

Repository Architecture

- Central data store
- Components to store, access, retrieve data in the data store

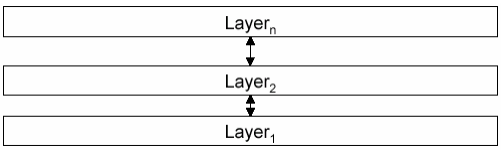


Repository or Blackboard Style

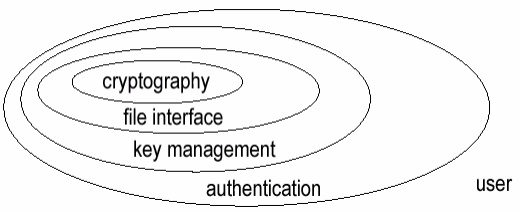
- Approach: manage richly structured information to be manipulated in many different ways. Data is long-lived.
- Context: shared data to be acted upon by multiple clients or processes
- Properties
  - Centralized body of information. Independent computational elements.
  - One shared memory component, many computational processes
  - Direct access or procedure call to the shared memory component
- Variants: traditional data base systems, compilers, blackboard systems

Layered Architecture

- Build system in terms of hierarchical layers and interaction protocols



- E.g. TCP/IP Stack, Data Access



Layered Style

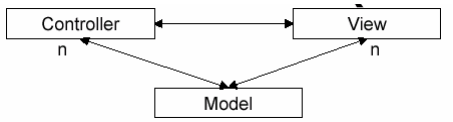
- Approach: distinct, hierarchical classes of services. “Concentric circles” of functionality
- Context: a large system that requires decomposition. E.g. OSI model, virtual machines
- Properties
  - Hierarchy of layers, often limited visibility, promotes layer reusability
  - Collections of procedures (module)
  - Limited procedure calls
  - Control structure: single or multiple threads
- Drawbacks
  - Performance
  - Not easy to construct system in layers
  - Hierarchical abstraction may not be evident from requirements

Client-Server

- Popular form of distributed system architecture
  - Client requests an action or service
  - Server responds to the request
- Often server does not know number of potential clients or their identities
- Properties
  - Information exchanged in a need basis
  - Same data can be presented in different ways in different clients
- Drawbacks
  - Security
  - System management
  - “Sophisticated” application development
  - More resources to implement and support

Model-View-Controller (MVC)

- Archetypical example of a design pattern
- Three components
  - Model : Encapsulates system data and operations on the data
  - View : Displays data obtained from the model to the user
  - Controller : Handles input actions (e.g. send requests to the model to update data, send requests to the view to update display)



- Separating user interface from computational elements considered a good design practice
  - Why?

MVC Style

- Approach: Separation of UI from application is desirable due to expected UI adaptations
- Context: interactive applications with a flexible UI
- Properties:
  - UI (View&Controller) is decoupled from the application (Model component)
  - Collections of procedures (module)
  - Procedure calls
  - Generally single thread, but multiple threads possible

Other Common Design Patterns

- Proxy Pattern
  - A client needs services from another component
  - Instead of hard-coding direct access, may have better efficiencies or security by additional control mechanisms separate from both the client and the component to access
  - The client communicates with a proxy representative rather than the component itself, which does necessary pre/post processing
- Command Processor Pattern
  - User interfaces must be flexible or provide functionality beyond direct user functions, e.g. Undo or Log facilities
  - A separate component, the command processor, takes care of all commands. The command processor schedules the execution of commands, stores them for undo, logs, etc. Execution delegated to another component.

Summary

- Software architecture is concerned with the description of elements from which systems are built, the interaction among those elements, and patterns that guide their composition
- Still a novel and immature branch of Software Engineering
- Helps to have a repertoire of known architectures and use the one most appropriate
  - E.g. Shared Data, ADT, Implicit Invocation, Pipes/Filters, Layers, Repository, Client/Server, MVC
- Architecture is important
  - Starting point for design, captures early design decisions
  - Vehicle for stakeholder communication
  - Best known practices
  - Framework for software reuse