Software architecture for reactive systems

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- Introduction
- What is Software Architecture?
- Architectural Styles
- Evolution & Challenges
- Course perspective: Architecture for Reactive Systems

What is software architecture?

[Garlan & Shaw, 1993]

the systematic study of the overall structure of software systems

[Perry & Wolf, 1992]

SA = { Elements (*what*), Form (*how*), Rationale (*why*) }

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deals with the design and implementation of the high-level structure of software

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What is software architecture?

[Garlan & Perry, 1995]

the structure of the components of a program/system, their interrelationships, and principles and guidelines governing their design and evolution over time

[ANSI/IEEE Std 1471-2000]

the fundamental organisation of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution.

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What is software architecture?

The architecture of a system describes its gross structure which illuminates the top level design decisions, namely

- how is it composed and of which interacting parts?
- where are the pathways of interaction?
- which are the key properties of the parts the architecture rely and/or enforce?

Note:

architectural design *vs* non functional properties

- performance, reliability, dependability, portability, scalability, interoperability ...
- not covered in this course

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What is software architecture?

But what kind of structure have we in mind in this course?

- code-based structures: such as modules, classes, packages and relationships like uses, inherits from or depends on.
- run-time structures: such as object instances, clients, servers, databases, browsers, channels, broadcasters, software buses, ...
- allocation structures: intended to map code-based and run-time structures to external items, such as network locations, physical devices, managerial structures ...
- entails the need for

Architectural views

- a main issue in Software Architecture research
- this course focus on run-time structures entails a particular view

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What is software architecture?

Components:

Loci of computation and data stores, encapsulating subsets of the system's functionality and/or data;
Equipped with run-time interfaces defining their interaction points and restricting access to those subsets;
May explicitly define dependencies on their required execution contexts;
Typically provide application-specific services

Connectors:

Pathways of interaction between components;
Ensure the flow of data and regulates interaction;
Typically provide application-independent interaction facilities;
Examples: procedure calls, pipes, wrappers, shared data structures, synchronisation barriers, etc.

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What is software architecture?

Configurations:	Specifications of how components and connectors are associated; Examples: relations associating component ports to connector roles, mapping diagrams, etc.
Properties:	Set of non functional properties associated to any architectural element; Examples (for components): availability, location, priority, CPU usage, ... Examples (for connectors): reliability, latency, throughput, ...
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A mix of examples

from the micro level (a Unix shell script)

```
cat invoices | grep january | sort
```

- Application architecture can be understood based on very few rules
- Applications can be composed by non-programmers
- ... a simple architectural concept that can be comprehended and applied by a broad audience

A mix of examples

to the macro level (the WWW architecture)

- The Web is a collection of resources, each of which has a unique name (URL)
- URIs used to determine the identity of a machine on the web
- Communication is initiated by clients (e.g. a web server) who make requests to servers.
- Resources can be manipulated through their representations (e.g. HTML)
- All communication between user agents and origin servers must be performed by a simple, generic protocol (HTTP), which offers the command methods GET, POST, etc.
- All communication between user agents and servers is fully self-contained

A mix of examples

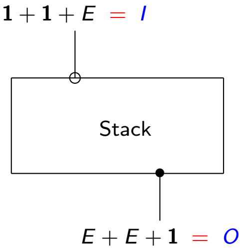
to the macro level (the WWW architecture)

- Architecture is totally separated from the code
- There is no single piece of code that implements the architecture
- There are multiple pieces of code that implement the various components of the architecture (e.g., different browsers)
- One of the most successful applications is only understood adequately from an architectural point of view

A mix of examples

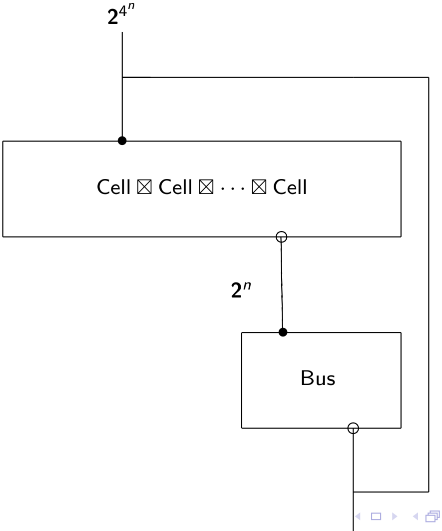
components & ports (the Stack diagram in a component calculus)

$$\begin{cases} \text{pop}: & \mathbf{1} \longrightarrow E \\ \text{top}: & \mathbf{1} \longrightarrow E \\ \text{push}: & E \longrightarrow \mathbf{1} \end{cases}$$



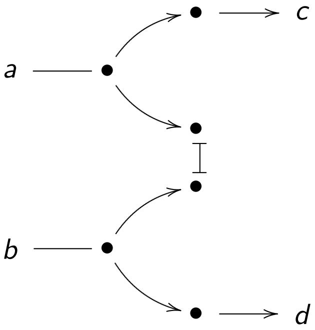
A mix of examples

new components from old (assembling the Game of Life)



A mix of examples

a connector (synchronization barrier in REO)



A mix of examples

a configuration (client-server in ACME)

```
System CS = {
   component client = { port call }
   component server = { port request }
      property max-clients-supported = 10;
   connector rpc = { role plug-cl; role plug-sv}
   }
   attachments = {
      { call to plug-cl ; server to plug-sv }
   }
```

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Architectural style (or pattern)

- classify families of software architectures
- act as types for configurations
- provide
  - domain-specific design vocabulary (eg, set of connector and component types admissible)
  - a set of constraints to single out which configurations are well-formed. Eg, a pipeline architecture might constraint valid configurations to be linear sequences of pipes and filters.

Examples

- Layers
- Client & Server
- Master & Slave
- Publish & Subscribe
- Peer2Peer
- Pipes and Filters
- Event-bus
- Repositories
  - triggering by transactions: databases
  - triggering by current state: blackboard
- Table-driven (virtual machines)
- ...

Pattern: Layers

- helps to structure applications that can be decomposed into groups of subtasks at different levels of abstraction
- Layer n provides services to layer $n+1$ implementing them through services of the lyer $n+1$
- Typically, service requests resort to synchronous procedure calls

Examples:

virtual machines (eg, JVM)
APIs (eg, C standard library on top of Unix system calls)
operating systems (eg, Windows NT microkernel)
networking protocols (eg, ISO OSI 7-layer model; TCP/IP)

Pattern: Client-Server

- permanently active servers supporting multiple clients
- requests typically handled in separate threads
- stateless (session state maintained by the client) vs stateful servers
- interaction by some inter-process communication mechanism

Examples:

remote DB access
web-based applications
interactive shells

Pattern: Peer-2-Peer

- symmetric Client-Service pattern
- peers may change roles dynamically
- services can be implicit (eg, through the use of a data stream)

Examples:

multi-user applications
P2P file sharing

Pattern: Publish-Subscribe

- used to structure distributed systems whose components interact through remote service invocations
- servers publish their capabilities (services + characteristics) to a broker component, which accepts client requests and coordinate communication
- allows dynamic reconfiguration
- requires standardisation of service descriptions through IDL (eg CORBA IDL, .Net, WSDL) or a binary standard (eg, Microsoft OLE — methods are called indirectly using pointers)

Examples:

web services
CORBA (for cooperation among heterogeneous OO systems)

Pattern: Master-Slave

- a master component distributes work load to similar slave components and computes a final result from the results these slaves return
- isolated slaves; no sharing of data
- supports fault-tolerance and parallel computation

Examples:

dependable systems

Pattern: Event-Bus

- event sources publish messages to particular channels on an event bus
- event listeners subscribe to particular channels and are notified of message availability
- asynchronous interaction
- channels can be implicit (eg, using event patterns)
- allows dynamic reconfiguration
- variant of so-called event-driven architectures

Examples:

process monitoring
trading systems

Pattern: Pipe & Filter

- suitable for data stream processing
- each processing step is encapsulated into a filter component
- uniform data format
- no shared state
- concurrent processing is natural

Examples:

compilers

Unix shell commands

Pattern: Blackboard

- suitable for problems with non deterministic solution strategy known
- all components have access to a shared data store
- components feed the blackboard and inspect it for new partial data
- extending the data space is easy, but changing its structure may be hard

Examples:

complex IA problems (eg, planning, machine learning)
complex applications in computing science (eg, speech recognition; computational chemistry)

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Origins

- Until the 90's, SA was largely an ad hoc affair (but see [Dijkstra,69], [Parnas79], ...)
- Descriptions relied on informal box-and-line diagrams, rarely maintained once the system was built

Challenges

- recognition of a shared repertoire of methods, techniques and patterns for structuring complex systems
- quest for reusable frameworks for the development of product families

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The last 15 years

- Formal notations for representing and analysing SA: ADL
- Examples: Wright, Rapide, SADL, Darwin, C2, Aesop, Piccola ...

ADLs provide:

- conceptual framework + concrete syntax
- tools for parsing, displaying, analysing or simulating architectural descriptions

- ACME [Garlan et al, 97] as an architectural interchange language (a sort of XML for architectural description)
- Use of model-based prototyping tools (eg Z, VDM) or model-checkers (eg Alloy) to analyse architectural descriptions

The last 15 years

- Classification of architectural styles characterising families of SA and acting as types for configurations
- Standardisation efforts: ANSI/IEEE Std 1471-2000, but also 'local' standards (eg, Sun's Enterprise JavaBeans architecture)
- Impact of the emergence of a general purpose (object-oriented) design notation — UML — closer to practitioners and with a direct link to OO implementations
- SA becomes a mature discipline in Software Engineering; new fields include documentation and architectural recovery from legacy code

Current trends

Not only the world of software development, but also the contexts in which software is being used are changing quickly and in significant ways ...
... whose impact on Software Engineering, in general, is still emerging

- Software sub-contracting: many companies look at themselves more as system integrators than as software developers:

the code they write is glue code ...
which entails the need for common frameworks to reduce architectural mismatchs

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Current trends

- From object-oriented to component-based development:

> - In OO the architecture is implicit: source code exposes class hierarchies but not the run-time interaction and configuration
> - Objects are wired at a very low level and the description of the wiring patterns is distributed among them

Current trends

- CBD retains the basic encapsulation of data and code principle to increase modularity
- ... but shifts the emphasis from class inheritance to object composition
- to avoid interference between inheritance and encapsulation and pave the way to a development methodology based on third-party assembly of components

Current trends

- Software as a service (and not essentially a product) : open and dynamic systems (able to move, to reconfigure themselves, ...) and often asynchronous (cf the publish-subscribe style)
- From programming-in-the-large to programming-in-the-world:

> 'not only the complexity of building a large application that one needs to deliver, in time and budget, to a client, but of managing an open-ended structure of autonomous components, possibly distributed and highly heterogeneous.
> This means developing software components that are autonomous and can be interconnected with other components, software or otherwise, and managing the interconnections themselves as new components may be required to join in and others to be removed.'
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Challenges

Such trends entails a number of challenges to the way we think about SA

- new target: need for an architectural discipline for reactive systems
  (often complex, time critical, mobile, etc ...)
- from composition to coordination (orchestration)
- interaction as a first-class citizen and the main form of software composition

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Starting point

SA as studied at MFES (until now):

the architecture of functional designs

Interfaces:	$f :: \cdots \longrightarrow \cdots$
Components:	$f = \cdots$
Connectors:	$\cdot$, $\langle\ ,\ \rangle$, $\times$, $+$, ...
Configurations:	functions assembled by composition
Properties:	invariants (pre-, post-conditions)
Behavioural effects:	monads and Kleisli compostion
Underlying maths:	universal algebra and relational calculus

To be extended to reactive systems

Software Architecture is challenged by the continuous evolution towards very large, heterogeneous, highly dynamic computing systems, whose behaviour cannot be characterized in terms of a io-relation In most cases, such a behaviour

- is potentially non-terminating,
- expresses a continued interaction with the system´s environment and sub-systems which execute concurrently in distributed, often loosely coupled configurations.

Our approach

No general-purpose, universally tailored, approach to the architectural design of reactive systems

- concentrate in two particular classes of reactive systems
- addressed from both a foundational and methodological perspective
- with suitable computer-based support for modelling and analysis

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- Service-oriented applications. Services are dynamic entities, running on different platforms often owned by different organisations, interacting through public interfaces, and typically remaining loosely coupled, if not utterly unaware of each other. Open, dynamic reconfigurable and evolutive structure.

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Our approach

+ a module on performance and dependability analysis in software architecture

- to model unreliable behaviour
- to forecast system performance and dependability

Syllabus

- Introduction to software architecture
- (*Background*) Transition systems as a basic architectural design structure
  - (modelling) State, transition, interaction, bisimulation
  - (foundations) Algebraic structure *vs* coalgebraic behaviour
  - (composition) Process algebra
  - (logic) Expressing and verifying behavioural properties
- (*Case-study 1*) Time-critical architectures
  - (characterisation) Problems and examples
  - (semantics) Timed automata and their calculus
  - (logic) Behavioural properties with time-constraints
  - (tool support) UPPAAL

Syllabus

- (*Case-study 2*) Service-oriented architectures
  - (characterisation) Problems and examples
  - (semantics) Exogenous coordination models
  - (method & tool support) ORC (asynchronous, dynamic coordination language)
  - (method & tool support) REO (connector-based coordination language)
- Performance and dependability in software architecture
  - (modelling) Stochastic behaviour, dependability and performance evaluation
  - (foundations) Markov chains and markovean decision processes
  - (tool support) PRISM