Whither

Software Architecture?

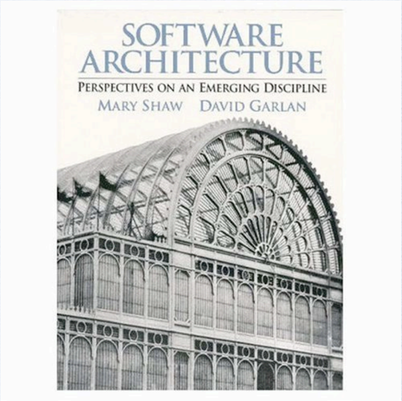
Jeff Kramer

Imperial College London

software architecture

with lots and lots of publications and books

almost 30 years research ...



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software architecture

with lots and lots and lots of definitions

"... **software architecture** is a set of **architectural** (or, if you will, **design**) **elements** that have a particular form." (Perry,Wolf)

"The **software architecture** of a system is the set of **structures** needed to reason about the system, which comprise software elements, relations among them, and properties of both." (SEI)

"A **software system's architecture** is the set of principal **design decisions** made during its development and any subsequent **evolution**." (Taylor,Medvidovic,Dashofy)

Image: Tina Phillips / FreeDigitalPhotos.net

Whither software architecture

- how did we get here?
- impact?
- where are we going?

a "soap opera" based on my personal research experience

unintentional stepping on toes

my formative project

CONIC –
"configuration
programming"

the CONIC project

Computer Control & Monitoring of underground systems in coal mining.

The investigators:

Guess Who and Morris Sloman

The research assistant:

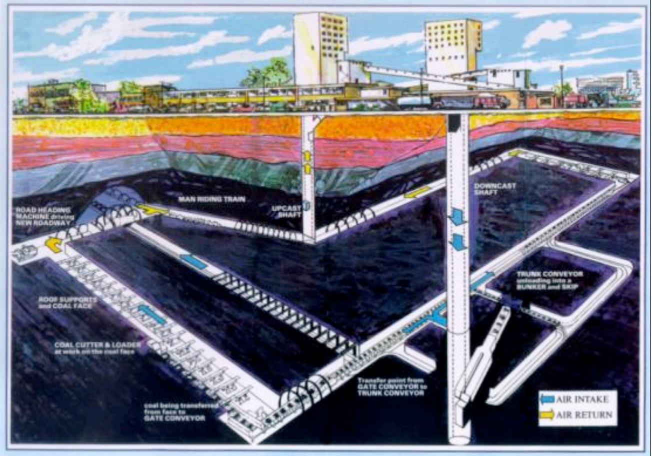
Jeff Magee

coal mines

Underground, coal mines consist of a number of **interacting subsystems**:

- coal cutting
- transport
- ventilation
- drainage
- …

… **changes** as the mine topography changes.


ROAD HEADING MACHINE driving NEW ROADWAY
MAN RIDING TRAIN
UPCAST SHAFT
DOWNCAST SHAFT
TRUNK CONVEYOR unloading into a BUNKER and SKIP
ROOF SUPPORTS and COAL FACE
COAL CUTTER & LOADER at work on the coal face
Transfer point from GATE CONVEYOR to TRUNK CONVEYOR
coal being transferred from face to GATE CONVEYOR
AIR INTAKE
AIR RETURN

requirements elicitation

- ➡ complex

  large number of interconnected devices, sensors, actuators, controllers, ...

- ➡ highly distributed

  over the mine site, both above and below ground

- ➡ evolving

  new coal faces open, old faces close

- ➡ robust

  against failures

ROAD HEADING MACHINE driving NEW ROADWAY
ROOF SUPPORTS and COAL FACE
COAL CUTTER & LOADER at work on the coal face
coal being tran
from face to
GATE CONVEY

Software structure should mirror the physical mine

engineering distributed software

- ■ **Information Hiding**

  Encapsulation of design behind an interface

  David Parnas, CACM, 1972

- ■ **Abstraction**

  Programming-in-the-small Vs
  Programming-in-the-large

  deRemer and Kron, TSE 1975

- ■ **Composition**

  "Having divided to conquer,
  we must reunite to rule"

  Michael Jackson, CompEuro 1990

CONIC research elements

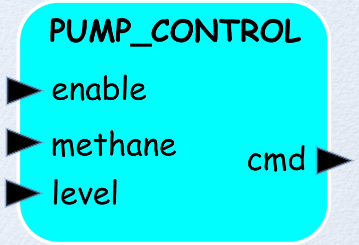
1. distributable components
2. transparent local/remote communication
3. separate configuration description (architecture)
4. construction and modification/evolution ("configuration programming")

1. distributable components

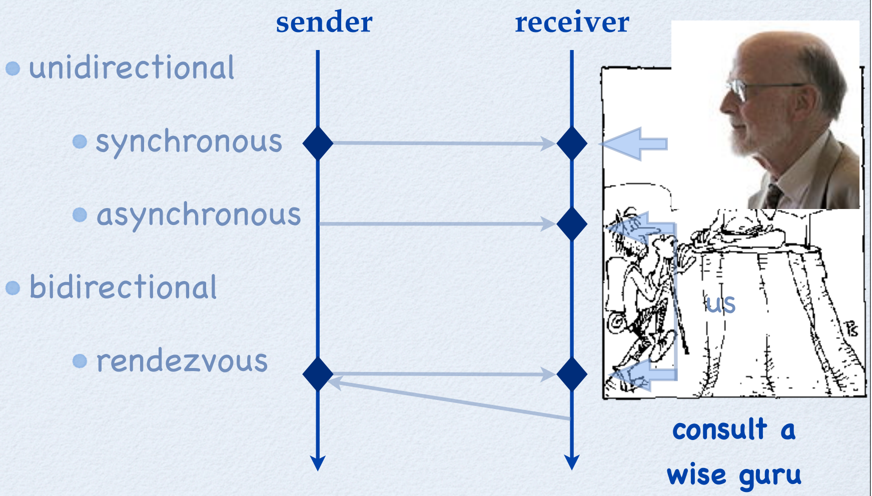
Key property of **context independence**.

- ✱ communication via a well-defined interface.
- ✱ third party instantiation and binding
- ✱ reuse in the same system (multiple pumps), and in different systems (other mines).

- **input** and **output** ports (indirection)
- parameterised component types



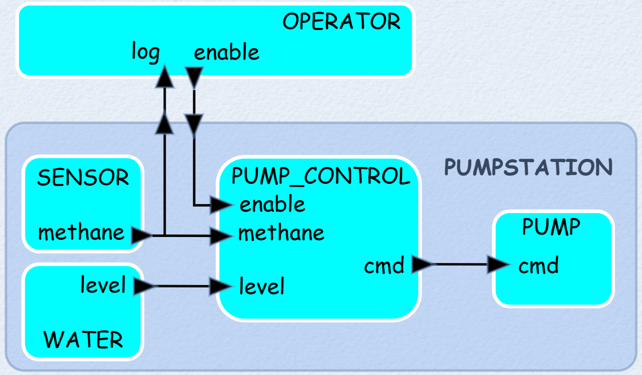
2. local/remote communication



consult a wise guru

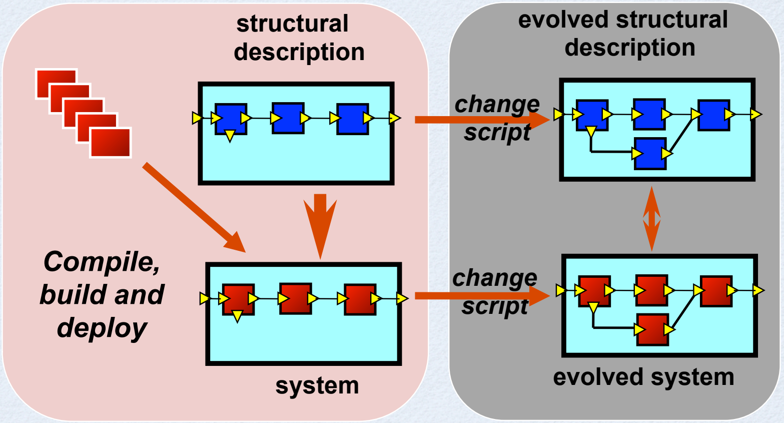
3. configuration

Separate explicit description of the **structure** of the system in terms of the **composition** of component **instances** and **connections** (ie. third party instantiation and binding).



Hierarchical composition helps to hide complexity.

4. "configuration programming"



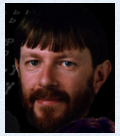
TSE 1985

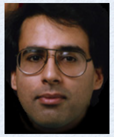
CONIC

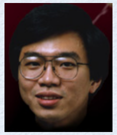
- Reusable components
  The control software for a particular coal mine could be assembled from a set of components.

- On-line change
  Once installed, the software could be dynamically modified without stopping the entire system to deal with new coalfaces.

Research team:


Kevin Twidle


Naranker Dulay


Keng Ng

CONIC

- The Iron Lady effect!

However ….

- Wider application than coal mining.
- Distributed worldwide to academic and industrial research institutions.
- Exciting and a lot of fun

TSE 1989

CONIC was not general

- …. was programming language dependent (Pascal)
- …. had fixed communications primitives
- …. had simple single message interfaces for bindings

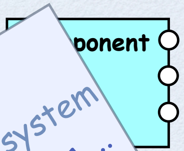
Structural view provides a useful level of abstraction.

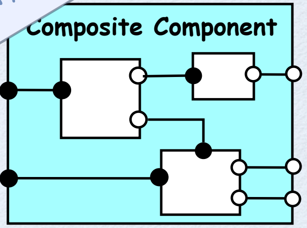
Darwin - a general purpose ADL

- **Component types** have one or more interfaces. An interface is simply a set of names referring to actions in a specification or services in an implementation, **provided** by the component.
- **Struct** **Syste** **types** a by compo nically tion and interface b

Tool support

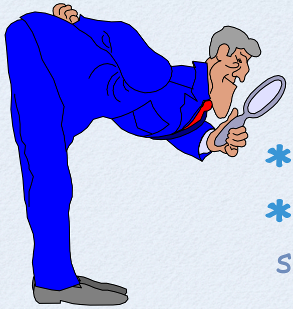
graphical design and software system generation, deployment, as well as …





ESEC/FSE 1995, FSE 1996

… associated Modelling support



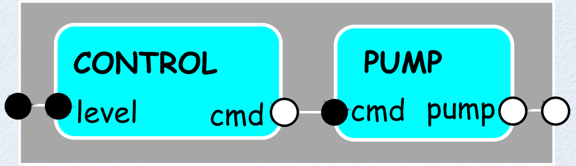
- ✱ model component behaviour
- ✱ compose behaviours using the same structural information as the software architecture

… compositional reasoning using model checking

Process Calculus - FSP

component behaviour

```
PUMP = STOPPED,
STOPPED = ( cmd.start -> STARTED),
STARTED = ( pump -> STARTED
          | cmd.stop -> STOPPED
          ).
```



model architecture

```
||PUMP_CONTROL =(c:CONTROL || p:PUMP)
               /{c.cmd/p.cmd,
                level/c.level,
                pump/p.pump}.
```

Analysis - LTSA

```
fluent RUNNING = <start,stop>
fluent METHANE = <methane.high, methane.low>

assert SAFE = [](tick->(METHANE -> !RUNNING))
```

ESEC/FSE 2005

… in collaboration as always …

Jeff Magee

Shing-Chi Cheung
- LTS, CRA & Safety

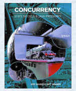
Dimitra Giannakopoulou
- Liveness & Fluent LTL

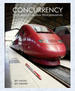
Nat Pryce
- Animation

Emmanuel Letier
- AFLTL

Sebastian Uchitel
- Synthesis

ICSE 1996, FSE 1999, ICSE 2000, ESEC/FSE 2003, ESEC/FSE 2005, and Wiley 1999 & 2006

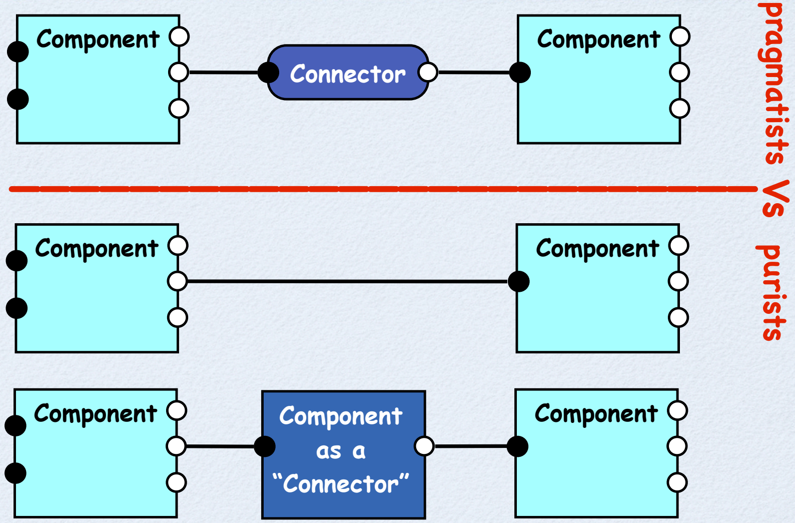




connector wars

pragmatists Vs purists?

connector wars



connector wars

impact?

Image: Salvatore Vuono / FreeDigitalPhotos.net

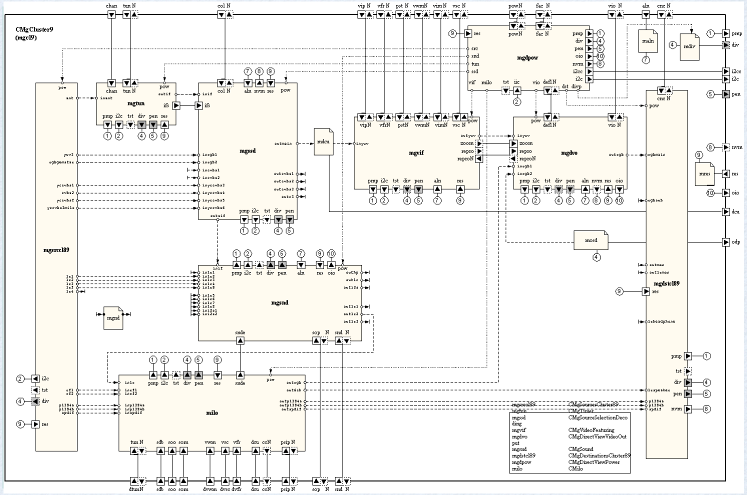
Koala

In the ARES project **Rob van Ommering** saw potential of Darwin in specifying television product architectures and developed **Koala**, based on Darwin, for Philips.

First large-scale industrial application of an ADL.

Computer 2000

Koala - example



Success.

... and is still in use.

But ...

Koala

Not more widely adopted, even in Philips!

- ... despite right level of abstraction
- ... despite compiler + code generation
- ... despite support for diversity

WHY???

“not invented elsewhere”

Is Koala the only ADL in use?

ROOM
MetaH
AADL
UNICON
WRIGHT
ACME
Rapide
C2
xADL
ArchJava
SADL
UML2?
...

ADLs have not been widely adopted!

Disappointed
but not
downhearted
...

" All hat and no cattle! "

Architecture research is a success

The abstractions pioneered in software architecture research have actually been very influential.

- qualitative aspects
- reviews/style guides
- architectural patterns
- provides and requires
- UML2
- modelling and analysis

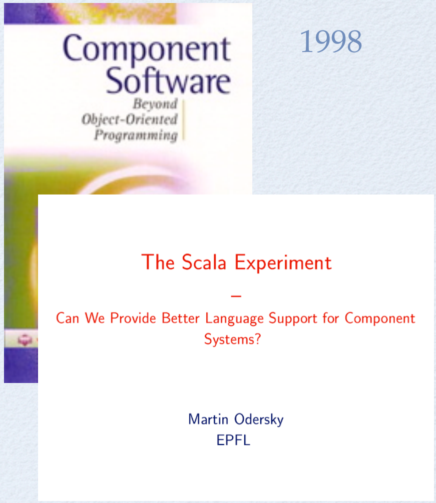
Why were ADLs not widely adopted?

Object-O gramming
became ma

- focus rarchy
- impl ructure
- implicit interfaces
- objects rather than components

components vs objects

- benefits of a component oriented view are recognised
- we can gain the benefits even with objects.



Component Software

Beyond Object-Oriented Programming

1998

The Scala Experiment

–

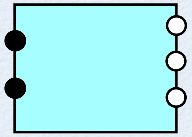
Can We Provide Better Language Support for Component Systems?

Martin Odersky

EPFL

2006

components from objects

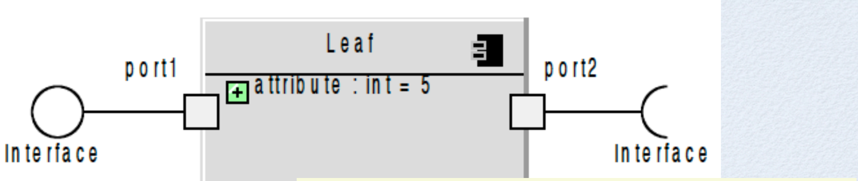


provided methods/services

required methods/services

- component type as an OO class
- **dependency injection** (or inversion of control):
  - "**new**" and connections are no longer in the component code
  - supports 3rd party instantiation and binding

components from objects

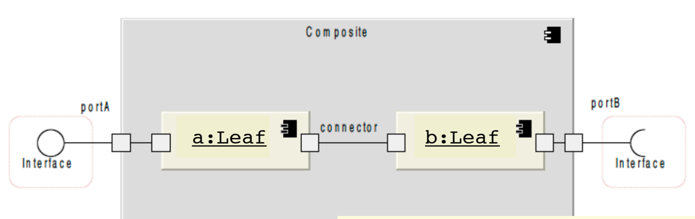


provides →

requires →

```
public class Leaf
{
  public int attribute = 5;
  private Interface port1 =
                     new Interface();
    {...Interface methods ...};
  public Interface getPort1()
    { return port1(); }
  private Interface port2;
  public void setPort2(Interface i)
  { port2 = i; }
}
```

composite components



instantiation →

connector →

provides →

requires →

```
public class Composite
{
  private Leaf a = new Leaf();
  private Leaf b = new Leaf();
  public Composite()
    { a.setPort2(b.getPort1()); }
  public Interface getPortA()
    { return a.getPort1(); }
  public void setPortB(Interface i)
    { b.setPort2(i); }
}
```

dependency injection

Permits separation of configuration from use

- **current EJB** (CDI) – "… server-side component architecture for Java"
  - **Spring** – "… application development framework for enterprise Java"
    - **Guice** – …"lightweight dependency injection framework for Java 5 and above"
      - **Autofac** – … "IOC container for .NET classes by treating them as components.

rays of hope for ADLs

some current practice in programming languages and some application domains

1. software maintenance and evolution
2. adaptive software

1. ADLs for software evolution

Change as fundamental in architecture definition – rather than making change management systems aware of architectural concepts.

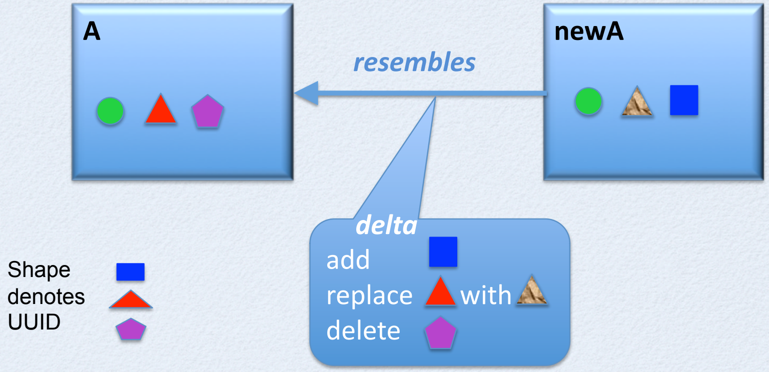
- add three basic constructs to a Darwin-like ADL (Backbone) to support arbitrary extension:

  resemblance, replacement, strata
- **Evolve Tool** uses UML2 graphical notation

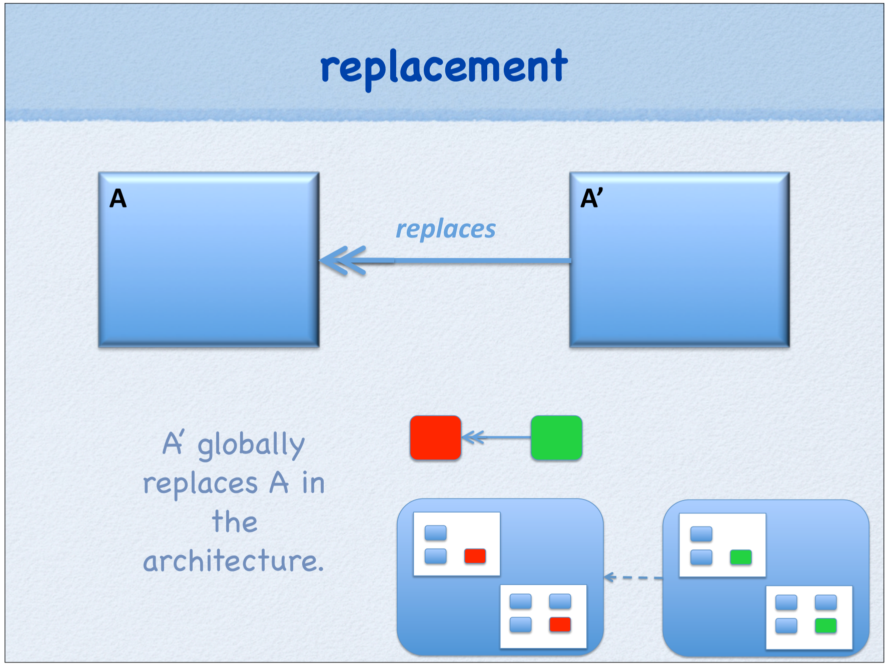
Andrew McVeigh

Jeff Magee

resemblance



define new components as a delta from the structure of one or more existing components (ie. reuse)



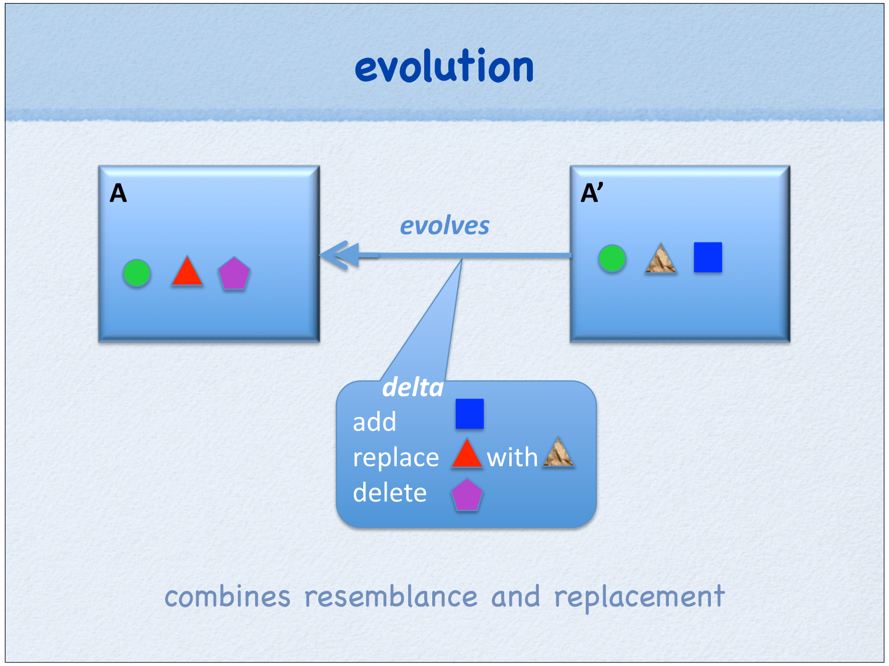
replacement

A

A′

replaces

A′ globally replaces A in the architecture.



evolution

A

A′

evolves

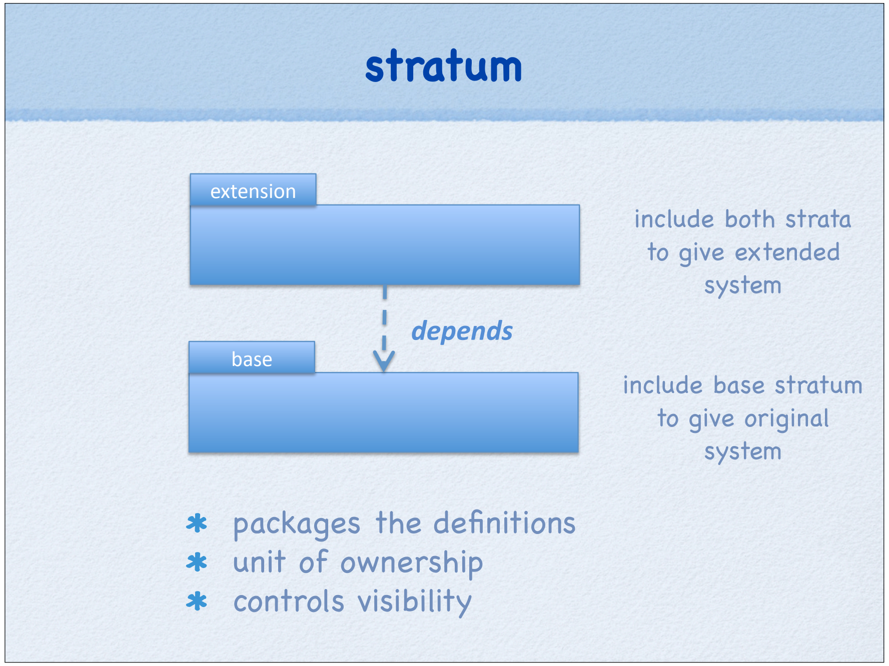
delta

add ■

replace ▲ with ▲

delete ⬟

combines resemblance and replacement



stratum

extension

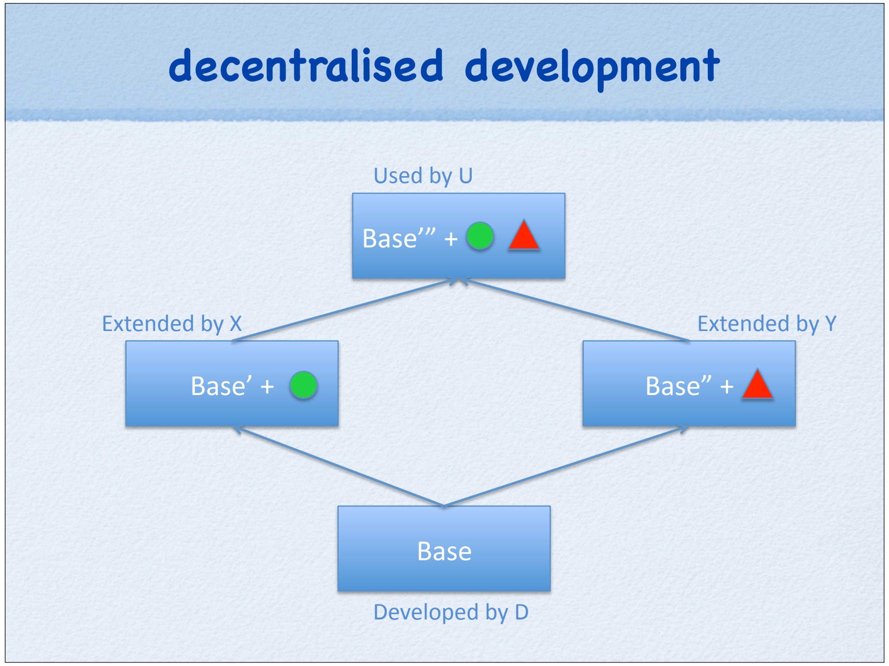
include both strata to give extended system

depends

base

include base stratum to give original system

- packages the definitions
- unit of ownership
- controls visibility



decentralised development

Used by U

Base′′′ + ● ▲

Extended by X

Base′ + ●

Extended by Y

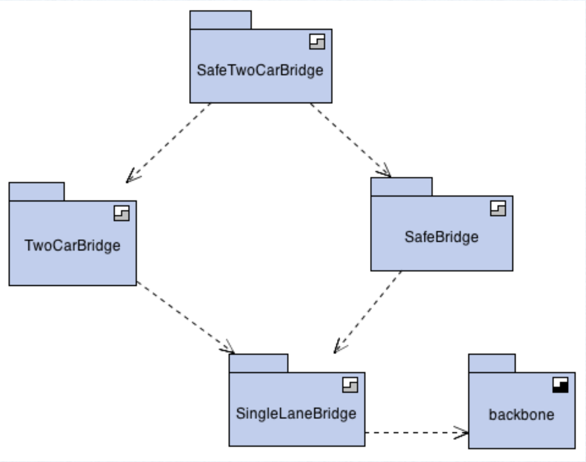
Base′′ + ▲

Base

Developed by D

Evolve demo

- Evolve design tool
- Backbone ADL



ICSE demo 2011

http://www.intrinsarc.com/evolve

incremental extension properties

- ALTER
  Allows any possible extension even if unplanned
- NO IMPACT
  Others are not impacted by extensions they don't want
- DECENTRALIZED
  Supports a fully decentralized environment
- COMBINE
  Extensions / upgrades can be combined, problems rectified
- NO SOURCE
  Works even without source code!

conformance

- "What are the prospects for showing conformance between architecture and code?"

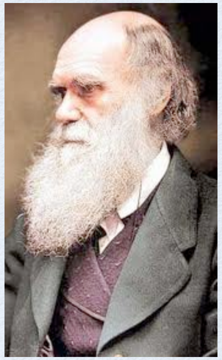
question posed by Garlan and Shaw
(ESEC/FSE 2011)

Generate it!

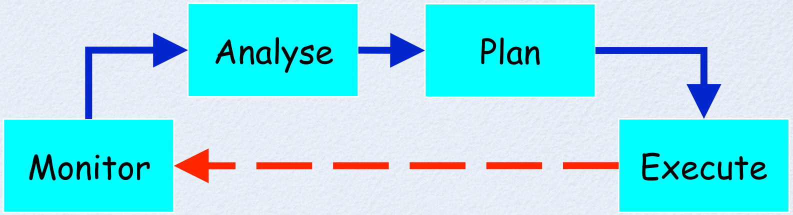
2. ADLs for adaptive software

" It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."

Charles Darwin

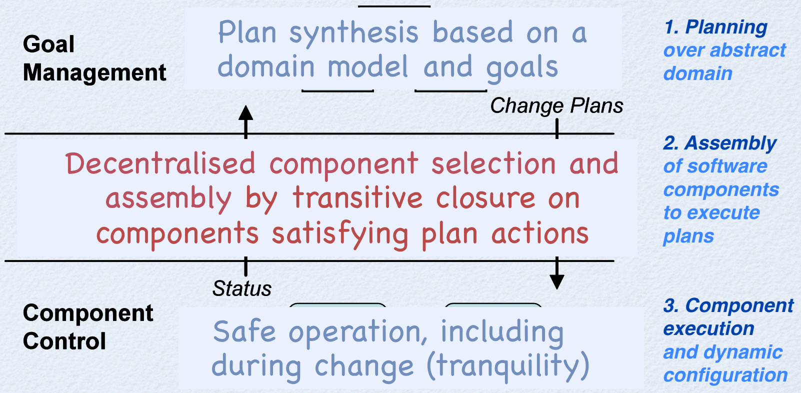


MAPE cycle



- a single feedback loop?
- response times?
- complexity?

three layer architecture model


Goal Management

Plan synthesis based on a domain model and goals

1. Planning over abstract domain

Change Plans

Decentralised component selection and assembly by transitive closure on components satisfying plan actions

2. Assembly of software components to execute plans

Status

Component Control

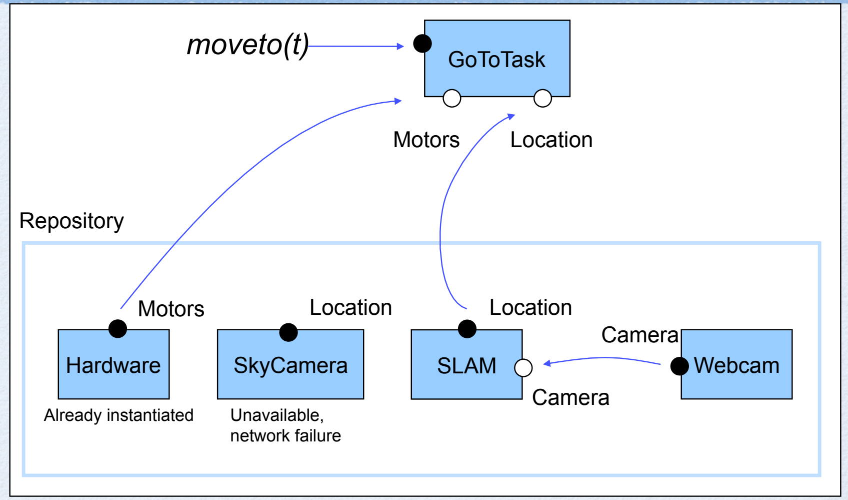
Safe operation, including during change (tranquility)

3. Component execution and dynamic configuration

a separation of timescales and concerns

ICSE FOSE '07, SEAMS 2008, SEAMS 2011

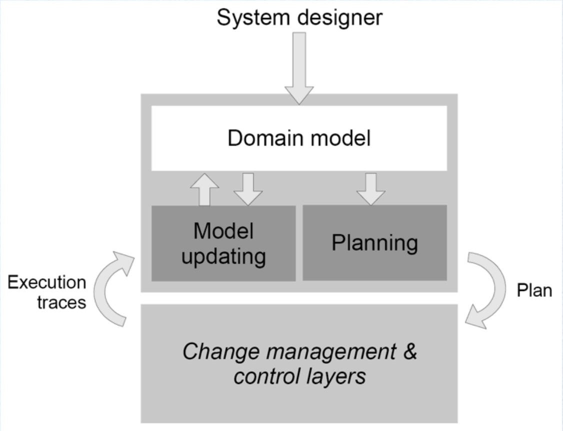
generating the architecture



generating revised plans

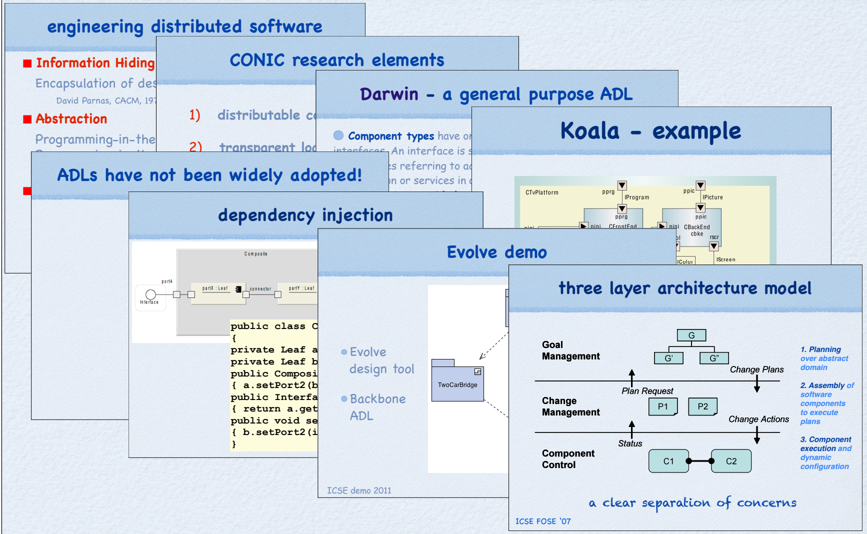
- Plan revision through model revision using observations and probabilistic rule learning

Learning through experience!



In conclusion…

Previously "What is Software Architecture" / What does it all mean?



engineering distributed software

- Information Hiding
  Encapsulation of des
  David Parnas, CACM, 197
- Abstraction
  Programming-in-the

CONIC research elements

1) distributable c
2) transparent loc

Darwin – a general purpose ADL

- Component types have o
  interfaces. An interface is s
  s referring to ac
  n or services in c

Koala – example

ADLs have not been widely adopted!

dependency injection

```
public class C
{
private Leaf a
private Leaf b
public Composi
{ a.setPort2(b
public Interfa
{ return a.get
public void se
{ b.setPort2(i
}
```

Evolve demo

- Evolve design tool
- Backbone ADL

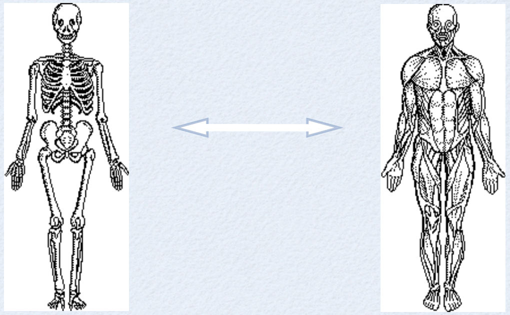
ICSE demo 2011

three layer architecture model

a clear separation of concerns

ICSE FOSE '07

Architecture as an Abstraction



… the same architectural description can be used as the structural framework to elicit requirements, to compose behaviours for analysis, to compose component implementations for systems, ….

… there's plenty of life left in the concept …

continuing research…

- partial component model synthesis from goals and scenarios for architectural fragments,
  - ➡ merge overlapping models,
  - ➡ compose component models according to the system architecture

Sebastian Uchitel

- requirements elaboration and revision using a combination of model checking and machine learning

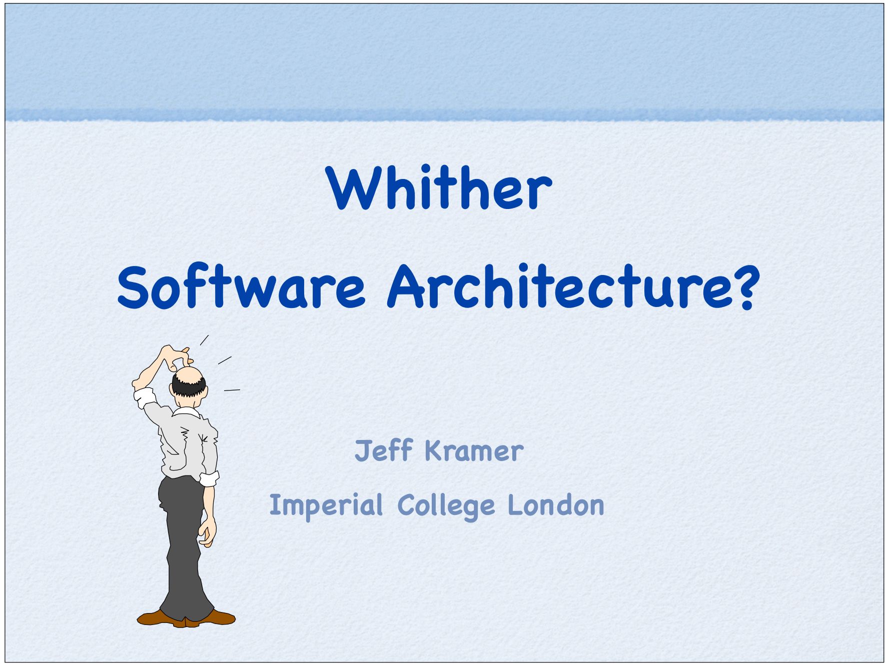
Dalal Alrajeh

Alessandra Russo

Axel van Lamsweerde

FSE 2004, ICSE 2009, ICSE 2012

a life of research
a life of collaborative research



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Imperial College London