TDDD05 Component-Based Software
DF14900 Software Engineering CUGS

Component-based Software

Introduction and overview

Christoph Kessler

Christoph Kessler, IDA,
Linköpings universitet.

Recommended Reading

- Szyperski: *Component Software – Beyond Object-Oriented Programming, 2nd edition*. Addison-Wesley, 2002.
- Douglas McIlroy. *Mass-produced software components*. http://cm.bell-labs.com/cm/cs/who/doug/components.txt
  in:
  P. Naur and B. Randell, "*Software Engineering, Report on a conference sponsored by the NATO Science Committee, Garmisch, Germany, 7th to 11th October 1968*", Scientific Affairs Division, NATO, Brussels, 1969, 138-155.

Motivation for Component Based Development

- **Managing system complexity**:
  Divide-and-conquer (Alexander the Great)
- **Well known in other disciplines**
  - Mechanical engineering (e.g., German DIN 2221; IEEE standards)
  - Electrical engineering
  - Architecture
  - Computer architecture
- **Outsourcing** to component producers
- Goal: **Reuse** of partial solutions
- **Easy configurability of the systems**
  - Variants, versions, product families

Mass-produced Software Components

- Garmisch 1968, NATO conference on software engineering
- McIlroy:
  - Every ripe industry is based on components, since these allow to manage large systems
  - Components should be produced in masses and composed to systems afterwards

Mass-produced Software Components

In the phrase `*mass production techniques*,' my emphasis is on `*techniques*' and not on mass production plain.
Of course, mass production, in the sense of limitless replication of a prototype, is trivial for software.

But certain ideas from industrial technique I claim are relevant.
- The idea of subassemblies carries over directly and is well exploited.
- The idea of interchangeable parts corresponds roughly to our term `modularity,' and is fitfully respected.
- The idea of machine tools has an analogue in assembly programs and compilers.

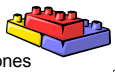
Yet this fragile analogy is belied when we seek for analogues of other tangible symbols of mass production.
- There do not exist manufacturers of standard parts, much less catalogues of standard parts.
- One may not order parts to individual specifications of size, ruggedness, speed, capacity, precision or character set.

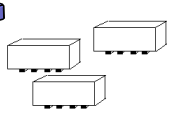
Mass-produced Software Components

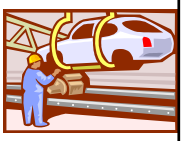
- Later McIlroy was with Bell Labs ...
  - ... and invented pipes, diff, join, echo (UNIX).
  - Pipes are still today the most employed component system!
- Where are we today?

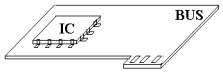
"Real-world" Component Systems

- Lego
  - Square stones
  - Building plans
- Car assembly
- IC's
- Hardware bus
- …









- How do they differ from software?

Definition of "Component"

"A **software component** is a unit of composition with contractually specified interfaces and explicit context dependencies only.

A software component can be deployed independently and is subject to composition by third parties."

- C. Szyperski, ECOOP Workshop WCOP 1997.

More Definitions of "Component"

"A reusable software component is a logically cohesive, loosely coupled module that denotes a single abstraction"
- Grady Booch

MetaGroup (OpenDoc):
"Software components are defined as prefabricated, pretested, self-contained, reusable software modules bundles of data and procedures - that perform specific functions."

"A software component is a static abstraction with plugs."
- Nierstrasz/Dami

Sametinger:
"Reusable software components are self-contained, clearly identifyable pieces that describe and/or perform specific functions, have clear interfaces, appropriate documentation, and a defined reuse status."

More Definitions of "Component" (cont.)

- Heineman / Councill [Ch.1]:

  "A *software component* is a software element that conforms to a component model and can be independently deployed and composed without modification according to a composition standard.

  A *component model* defines specific interaction and composition standards.

  Composition is the combination of two or more software components yielding a new component behavior at a different level of abstraction ... [which is] determined by the components being combined and the way how they are combined."

Component as unit of composition

U. Assmann (2003):

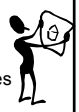
- A *component* is a *container with*
  - *variation points*
  - *extension points*
  - that are adapted during composition
- A component is a reusable *unit for composition*
- A component underlies a *component model*
  - abstraction level
  - composition time (static or runtime?)

Are Objects Components??

Szyperski [CS 4.1]: **No!**

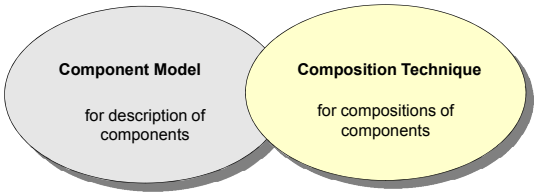
- An **object** is a unit of instantiation.
- It has a unique identity.
- It may have state, and this can be (externally) observed
- It encapsulates its state and behavior.

Components are rather prototypes / blueprints / plans from which (stateful) objects can be instantiated
  - e.g., a function definition, type definition, class or set of classes
- No (externally observable) state
  - Only one copy required per context (e.g., process)
- Unit of independent deployment
- Unit of third-party composition



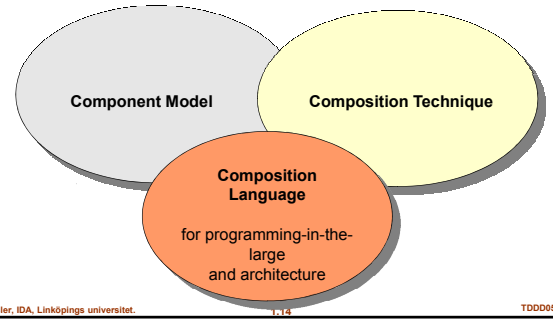
Component Systems
(Component Platforms)

- We call a technology in which component-based systems can be produced a *component system* or *component platform*.
- A component system has



Software Composition Systems

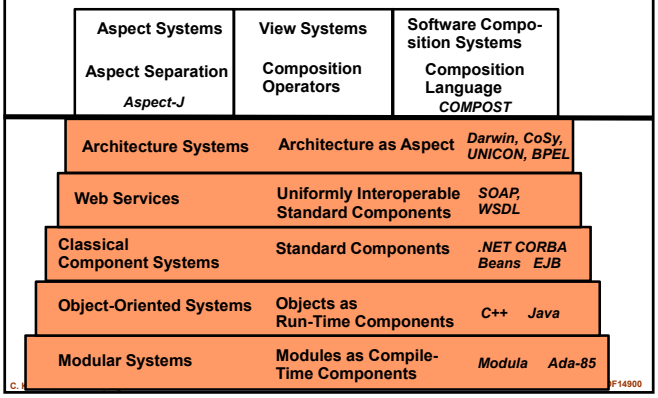
- A *composition system* has



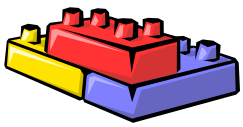
Issues in Component/Composition Systems

- **Component Model**
  - How do components look like?
  - Secrets? (Location, lifetime, language, platform, …)?
  - Binding points, binding time?
  - Interfaces, contracts, substitutability?
  - Parameterizability? Adaptability? Extensibility?
  - Standardization of execution environment, services?
- **Composition Technique**
  - How are components glued together, composed, merged, applied?
  - Composition time (Compile- / Link- / Deployment- / Connection- / Run-time ...)
- **Composition Language**
  - How are compositions of large systems described and managed?

The Ladder of Component and Composition Systems



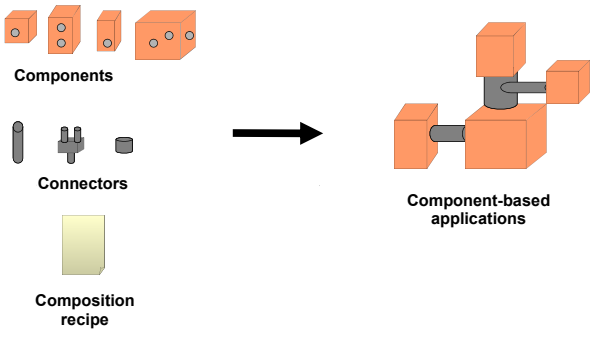
The Essence of the 60s-90s: LEGO Software



- Procedural systems
- Modular systems
- Object-oriented technology
- Component-based programming with COTS (Components-off-the-shelf) systems
  - CORBA, EJB, DCOM, COM+, .NET
- Software architecture description languages

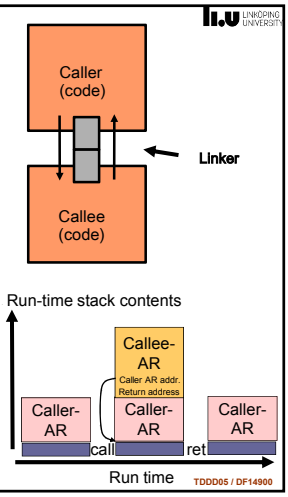
Blackbox composition

Blackbox Composition

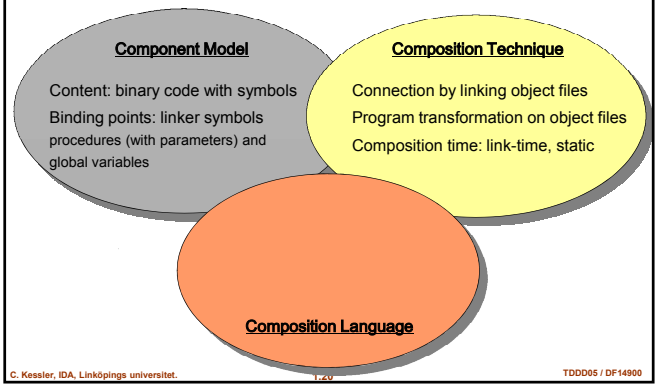


Procedural Systems

- Fortran, Algol, Pascal, C, ...
- The *procedure* is the component
- The *activation record* the instantiation
- Component model is supported by almost all processors directly
  - JumpSubroutine instruction
  - Return instruction

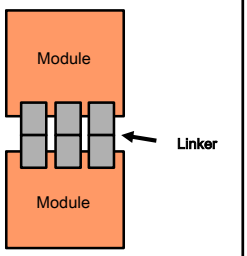


Procedures as Composition System

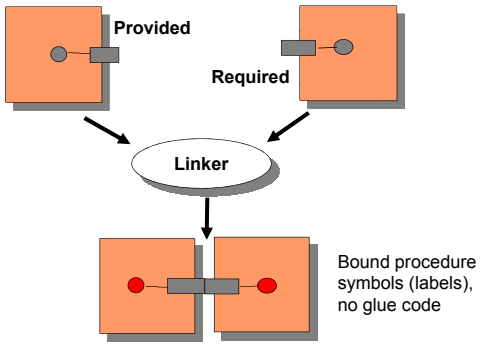


Modules

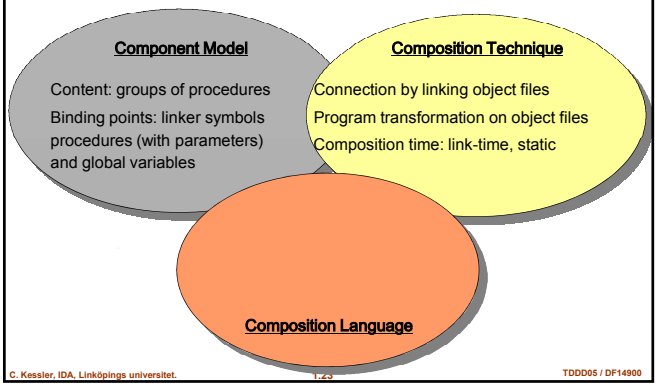
- Implementation of a module hidden behind a functional interface
- Static binding of functional interfaces to each other
- Concept has penetrated almost all programming languages (Modula, Ada, Java, C++, Standard ML, C#)



A Linker is a Composition Operator That Composes Modules

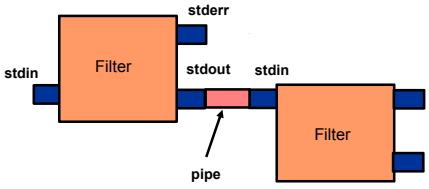


Modules as Composition System

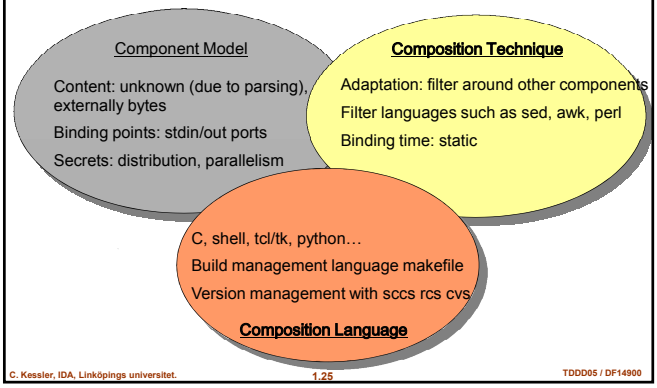


UNIX Filters and Pipes [McIlroy]

- UNIX shells style still offers the most used component paradigm:
  - Communication with byte streams via standard I/O ports
  - Parsing and linearizing the objects
  - Extremely flexible, simple

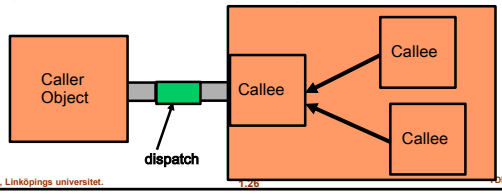


Unix Filters and Pipes as Composition System

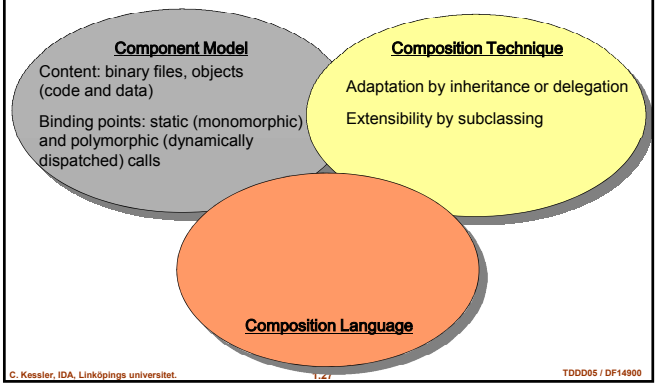


Object-Oriented Systems

- Components: classes
  - Objects are instances of classes (modules) with unique identity
  - Objects have runtime state
  - Late binding of calls by search/dispatch at runtime

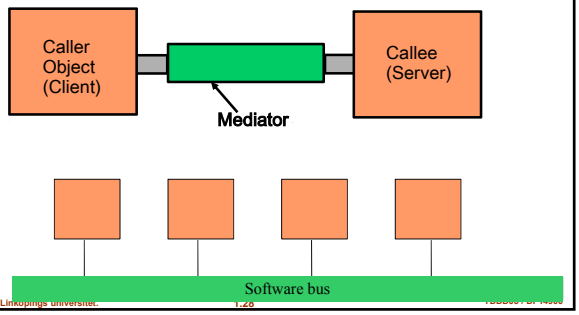


Object-Orientation as Composition System



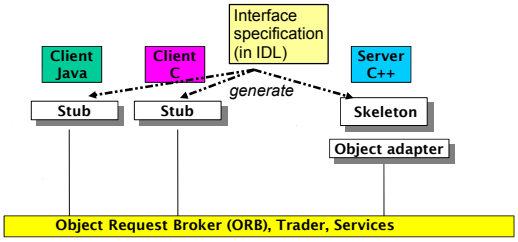
Commercial Component Systems

- CORBA / COM / .NET / EJB
- Although different on the first sight, turn out to be rather similar



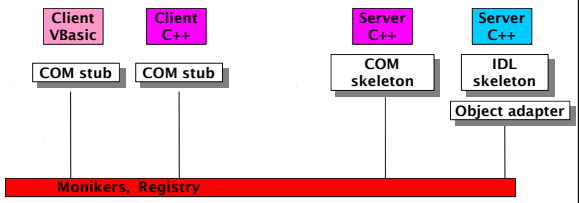
CORBA

- Language independent, location/distribution transparent
- interface definition language IDL
- source code or binary



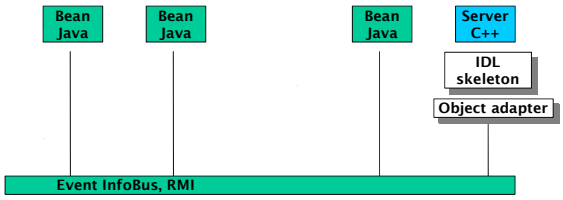
(D)COM, ActiveX

- Microsoft's model is similar to CORBA. Proprietary
- (D)COM is a binary standard



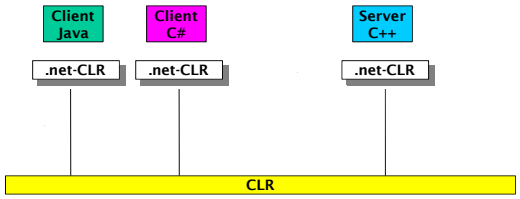
Java Beans

- Java only: source code / bytecode-based
- Event-based, transparent distribution by remote method invocation (RMI – includes Java Object Serialization)

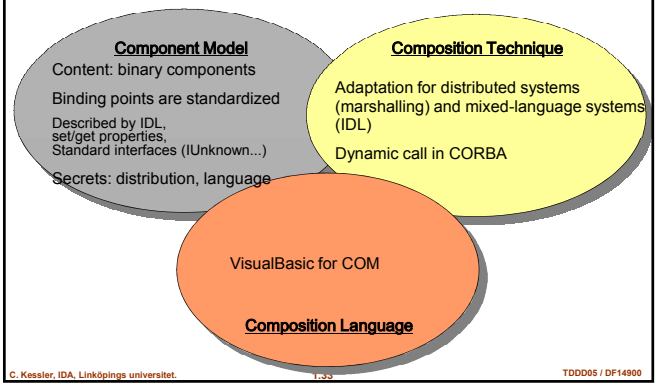


DOT-NET

- Language independent, distribution transparent
- NO interface definition language IDL (at least for C#)
- source code or bytecode MSIL
- Common Language Runtime CLR

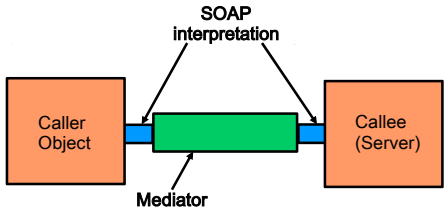


CORBA/DCOM/JavaBeans/EJB/...: Components Off-The-Shelf (COTS)

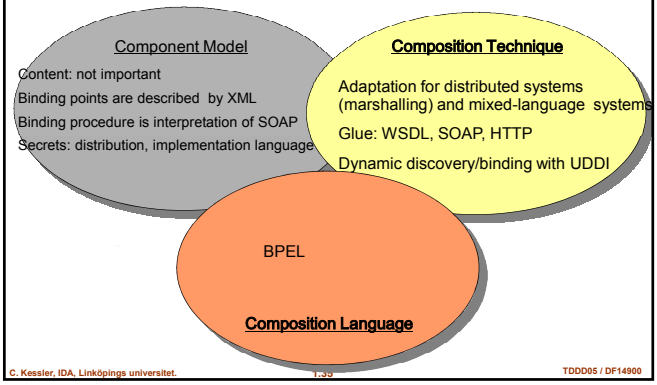


Web Services

- Binding procedure is interpreted, not compiled
- More flexible:
  - When interface changes, no recompilation and rebinding
  - Ubiquitous http protocol – independent of a specific ORB

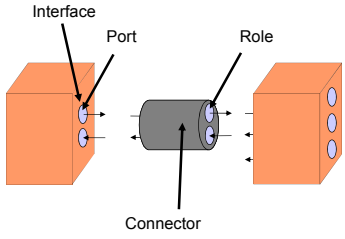


Web Services as Composition System



Component Model in Software Architecture Systems

- ***Ports*** abstract interface points (as in Linda)
  - in(data), out(data)
  - Components may be nested
- ***Connectors*** are special communication components
  - Abstract from technology (e.g. component system)
  - Specify connectivity (topology, system architecture)

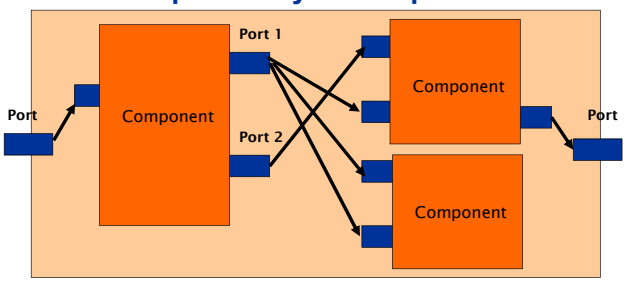


Software Architecture Systems

- Unicon, ACME, Darwin, …
  - feature an Architecture Description Language (ADL)
- Split an application into two concerns:
  - Application-specific part (encapsulated in components)
  - Architecture and communication (in connectors defined in architecture description, written in ADL)

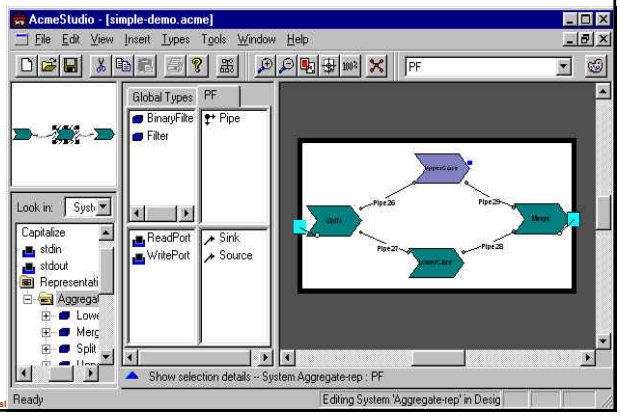
→ Better reuse since both dimensions can be varied independently

Architecture / Communication can be varied independently of components

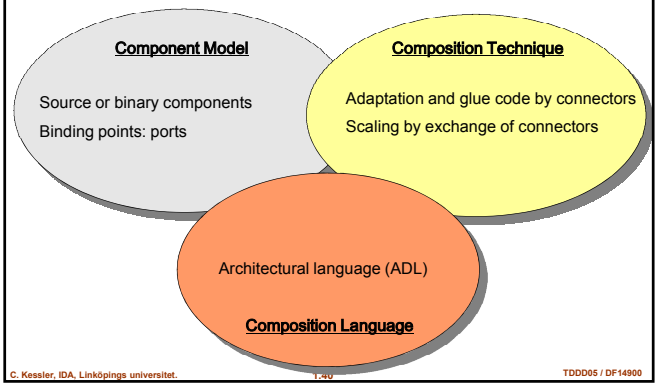


- Reuse of components and architectures is fundamentally improved
- High-level system analysis, verification, testing

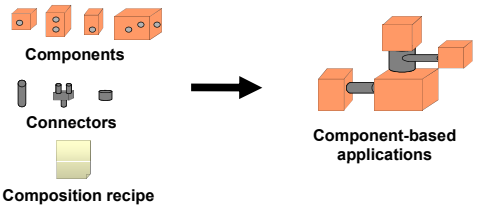
ACME Studio



Software Architecture Systems as Composition Systems



The Essence of Blackbox Composition



- Blackbox composition supports variability and adaptation
  - but not extensibility

The Ladder of Component and Composition Systems

Aspect Systems Aspect Separation *Aspect-J*	View Systems Composition Operators *Composition Filters Hyperslices*	Software Compo-sition Systems Composition Language *COMPOST*
Architecture Systems	Architecture as Aspect	*Darwin, CoSy, UNICON, BPEL*
Web Services	Uniformly Interoperable Standard Components	*SOAP, WSDL*
Classical Component Systems	Standard Components	*.NET CORBA Beans EJB*
Object-Oriented Systems	Objects as Run-Time Components	*C++ Java*
Modular Systems	Modules as Compile-Time Components	*Modula Ada-85*

TDDD05 Component-Based Software
DF14900 Software Engineering CUGS

Graybox Component Models

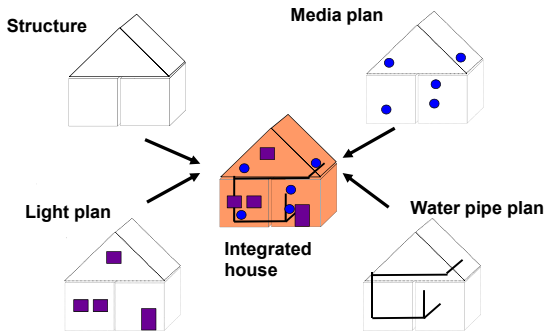
Component integration

- Aspect oriented programming

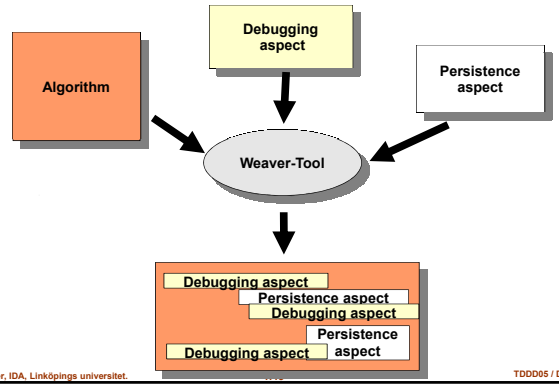
- View-based composition

Christoph Kessler, IDA,
Linköpings universitet.

Aspects in Architecture



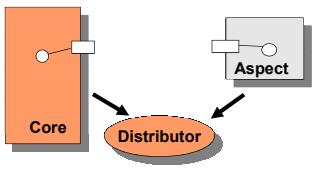
Aspects in Software



Aspect Systems

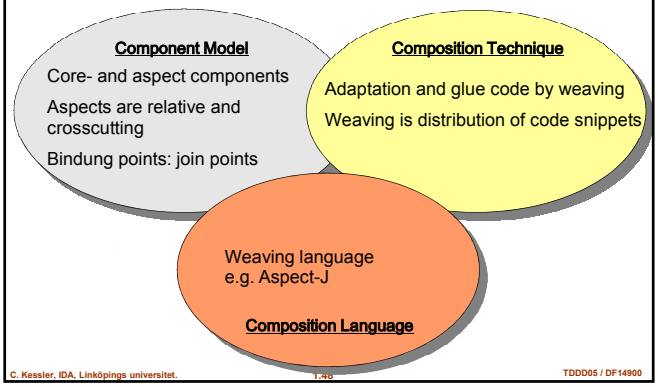
- Aspect languages
  - Every aspect in a separate language
  - Domain specific
  - Weaver must be built (is a compiler, much effort)
- Script-based Weavers
  - The weaver interprets a specific script or aspect program
  - This introduces the aspect into the core

Aspect Weavers Distribute Advice Components over Core Components



- Aspects are *crosscutting*
- Hence, aspect functionality must be *distributed* over the core

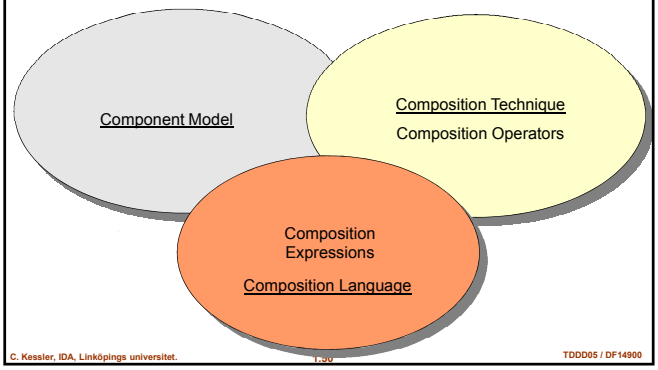
Aspect Systems as Composition Systems



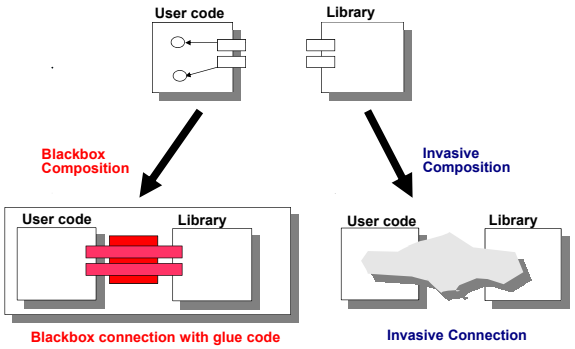
Composition Systems
with composition operators and expressions

- Hyperspace Programming [Ossher *et al.*, IBM]
- Piccola [Nierstrasz, et.al., Berne]
- Metaclass composition [Forman/Danforth, Cointe]
- **Invasive software composition** [Aßmann 2003]
- Formal calculi
  - Lambda-N calculus [Dami]
  - Pi-L calculus [Lumpe]

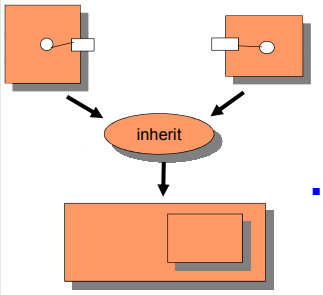
Composition Systems
with composition operators and expressions



Invasive Composition of Components



Composers can be used for inheritance

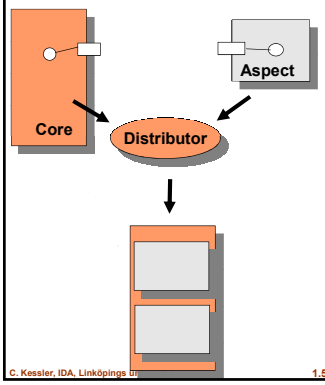


- Extension can be used for inheritance (mixins)

  A *mixin* is a class (i.e., a set of features) by which a superclass can be extended to derive a subclass. The mixin class itself is final, i.e., cannot be subclassed.

- Mixin-based inheritance:
  - copy first superclass
  - extend with fragments of second superclass (mixin)

Composers Generalize Aspect Weavers in AOP



- Complex composers distribute aspect fragments over core fragments
- *Distributors* extend the core
- Distributors are more complex operators, defined from basic ones

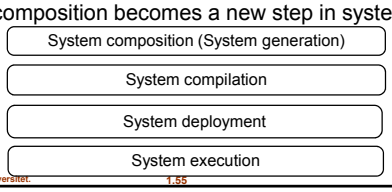
Composition Languages

- **Composition languages** describe the structure and build process of the system in-the-large (“programming in the large”)
- **Composition programs** combine the basic composition operations of the composition language
- Composition languages can look quite different
  - Imperative: e.g. Java+library (in COMPOST)
  - Declarative: e.g. ADL, Aspect-J, Makefiles, C++ templates
- Enables us to describe large systems

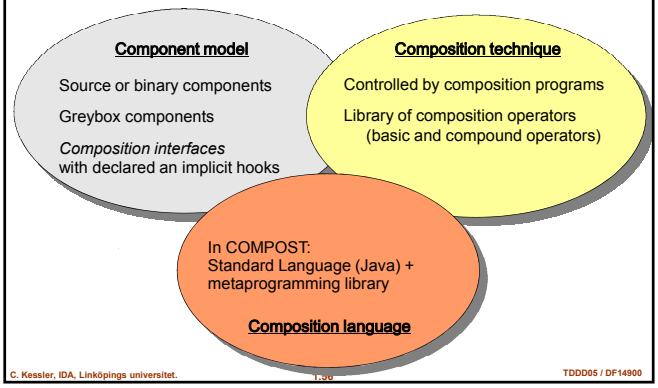
Composition program size	1
System size	10

Conclusions for Composition Systems

- Components have a *composition interface*
  - Composition interface is different from functional interface
    - Marks possible places for code injection in components
  - The composition is running usually *before* the execution of the system
    - Usually, at/before compile time or deployment time
- System composition becomes a new step in system build



Invasive Software Composition as Composition System



Summary: Component-based Systems

- ... are produced by component systems or composition systems
- ... support a component model
- Blackbox composition supports variability and adaptation
- Greybox composition also supports extensibility