IBM Software Group

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An Overview of UML 2.0

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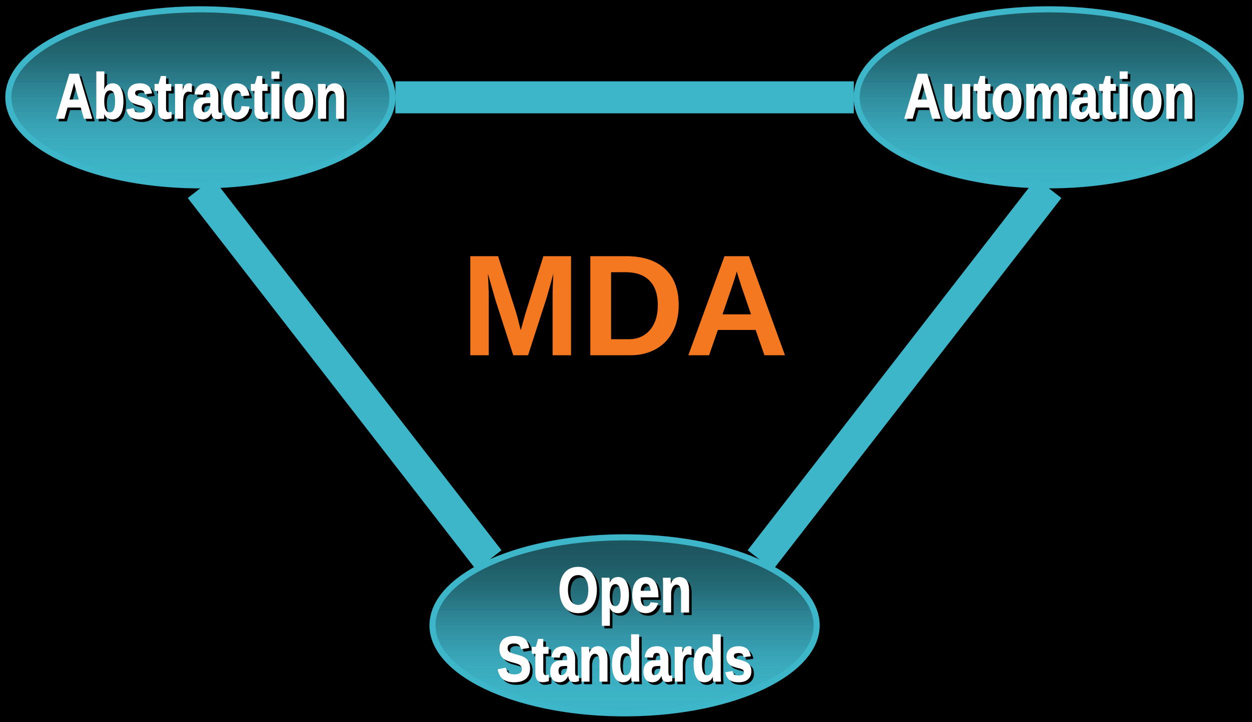
DISCLAIMER

The technical material described here is still under development and is subject to modification prior to full adoption by the Object Management Group

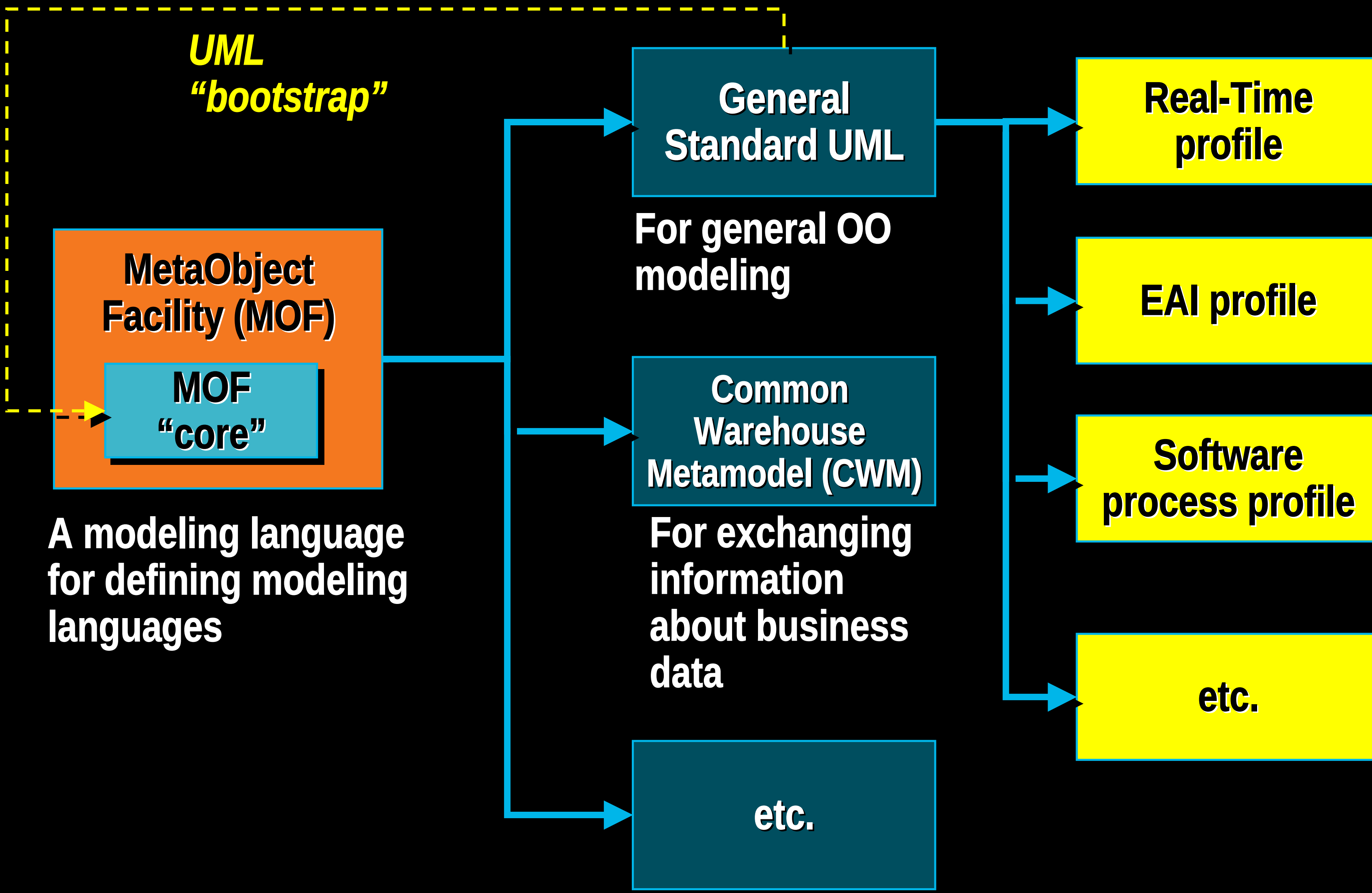
The Essence of MDA

- Support for model-driven development through *open* industry standards



The Languages of MDA

- Set of modeling languages for specific purposes



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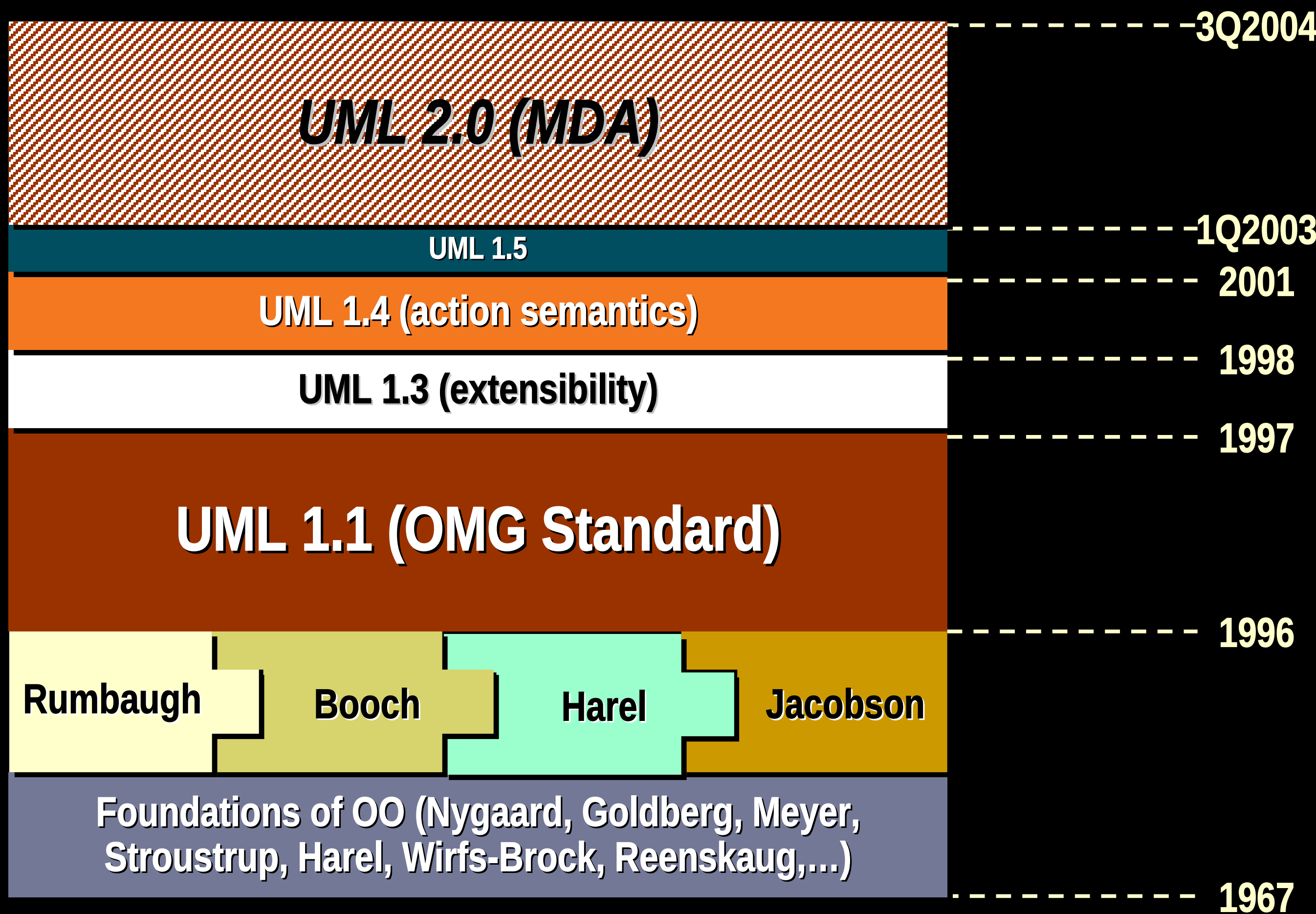
UML: The Foundation of MDA

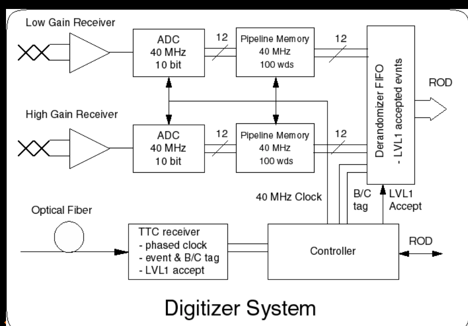


UML 1.x: What Went Right

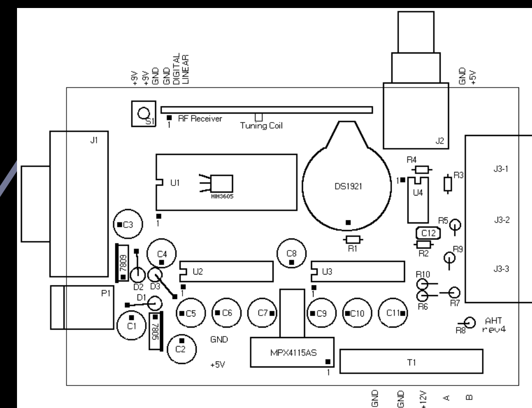
- Timeliness (meeting a real need)
- Emphasis on semantics as opposed to notation
  - model-based approach (versus view-based)
  - detailed semantic specifications
- Higher-level abstractions beyond most current OO programming language technology
  - state machines and activity diagrams
  - support for specifying inter-object behavior (interactions)
  - use cases
- Customizability (extensibility)

Traditional Approach to Views in Modeling

- Multiple, informally connected views
  - Combined in the final (integration) phase of design



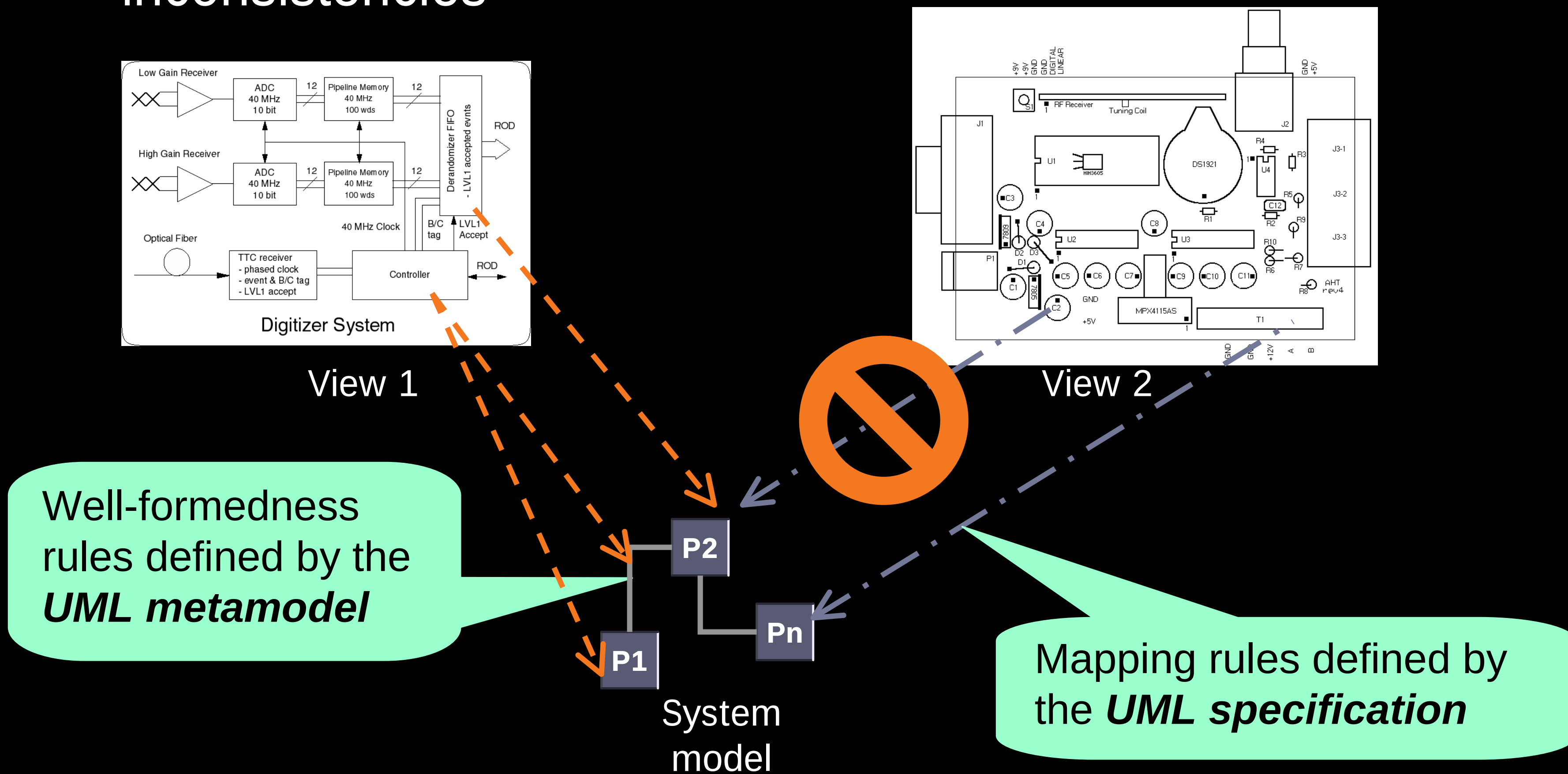
View 1



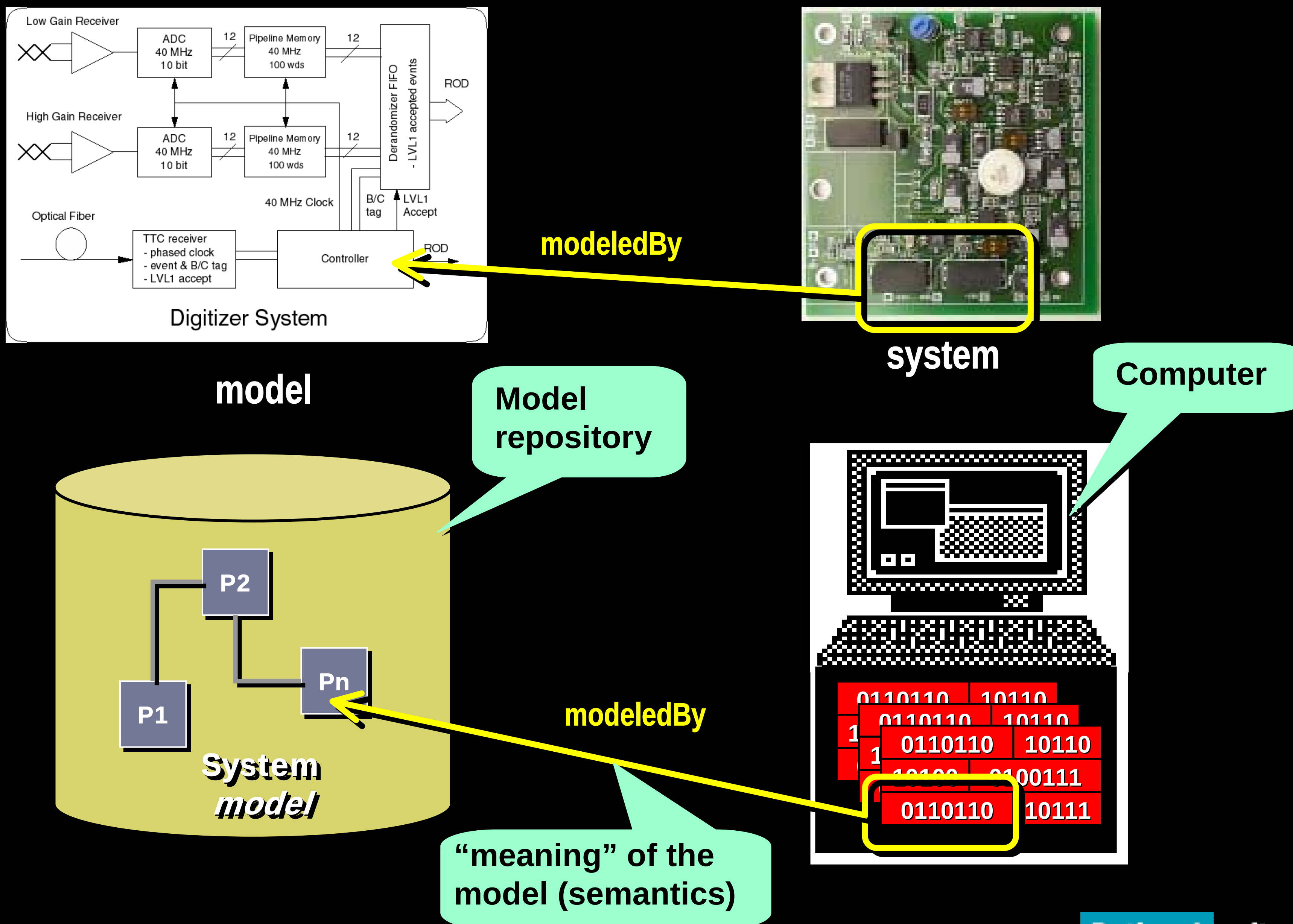
View 2

UML Approach: Single Model

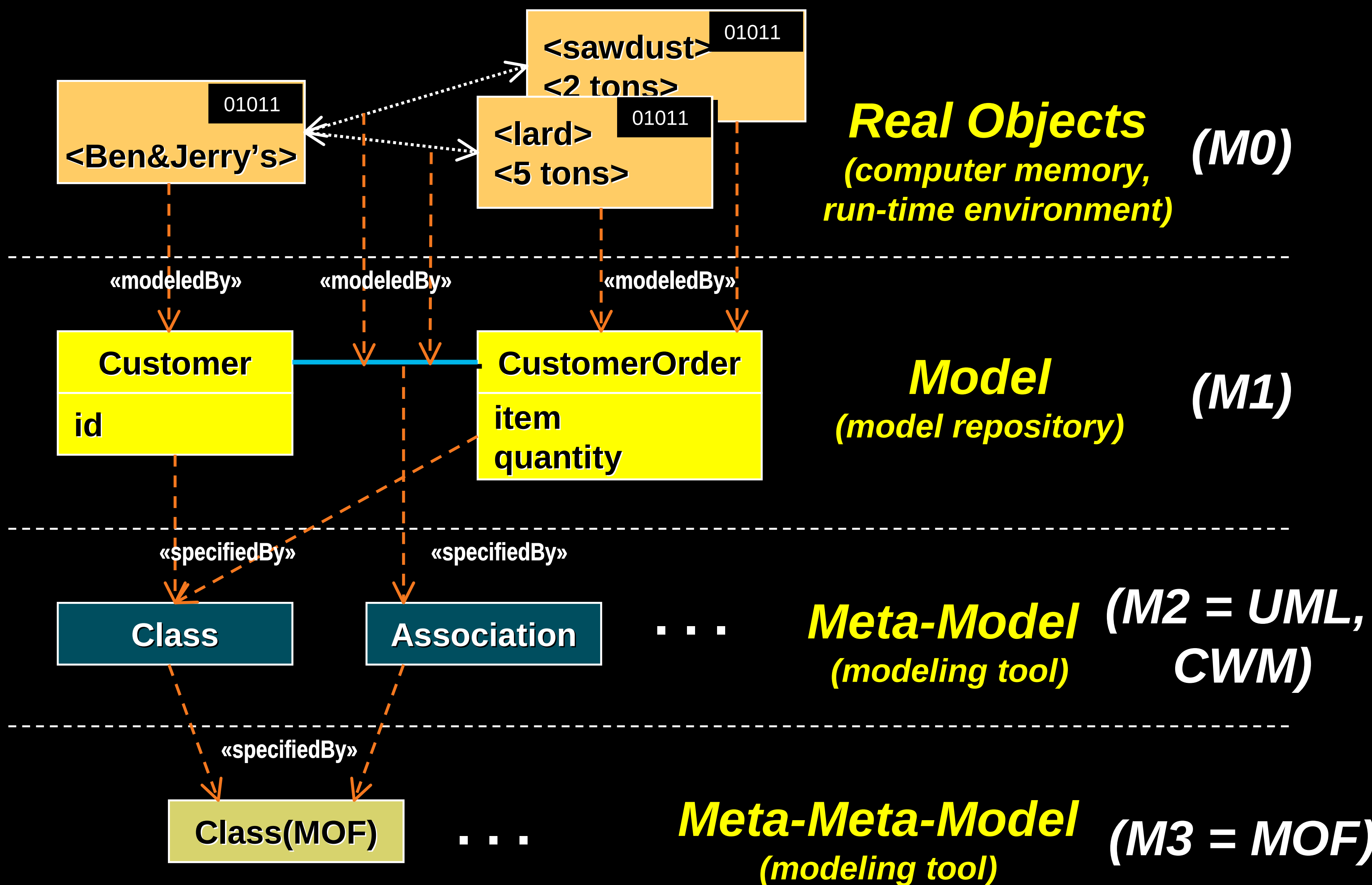
- Views are projections of a complete model
  - Continuous integration of views with dynamic detection of inconsistencies



The Model and the System

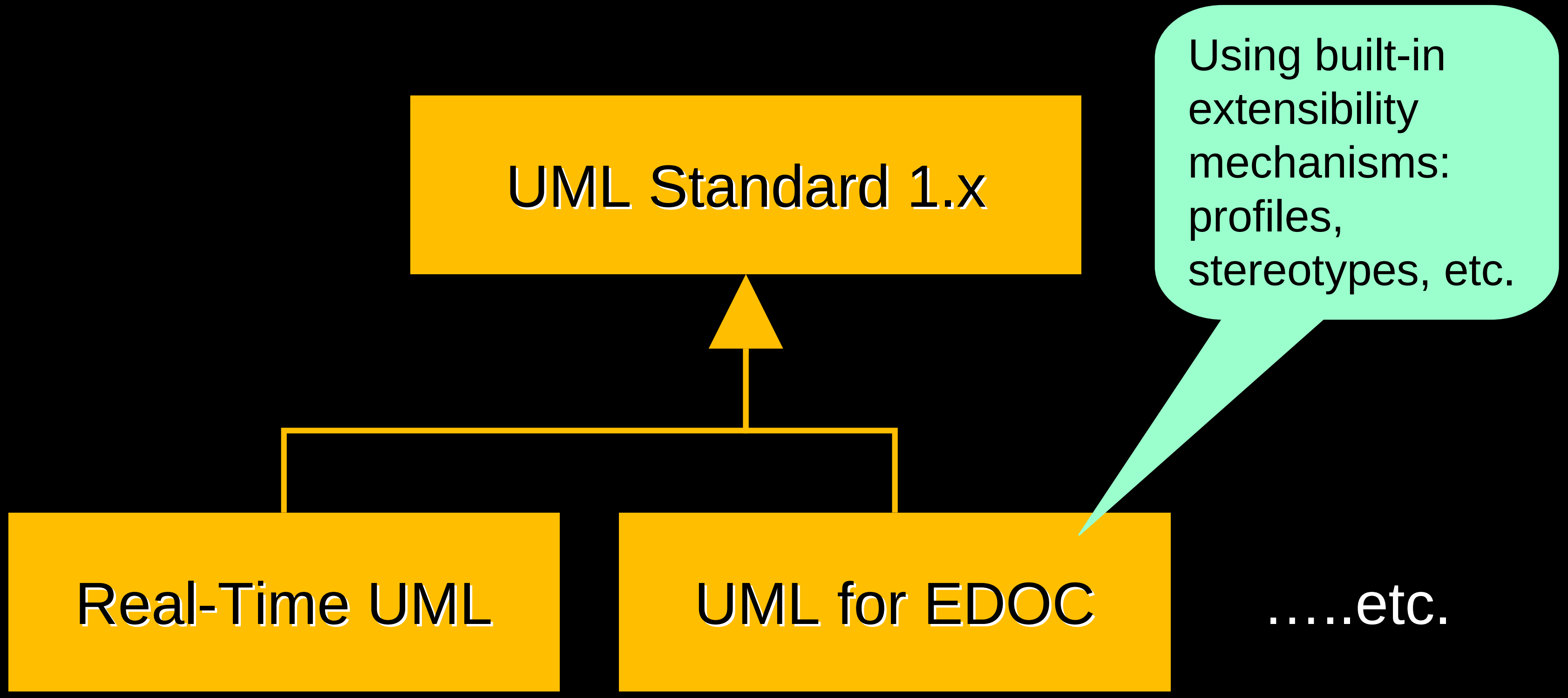


The "4-Layer" Architecture



Specializing UML

- Avoiding the PL/I syndrome (“language bloat”)
  - UML standard as a basis for a “family of languages”



UML 1.x: What Went Wrong?

- Inadequate semantics definition
  - Vague or missing (e.g., inheritance, dynamic semantics)
  - Informal definition (not suitable for code generation or executable models)
- Does not fully exploit MDD potential of models
  - E.g., “C++ in pictures”
- Inadequate modeling capabilities
  - Business and similar processes modeling
  - Large-scale systems
  - Non-functional aspects (quality of service specifications)
- Too complex
  - Too many concepts
  - Overlapping concepts
- No diagram interchange capability
- Not fully aligned with MOF
  - Leads to model interchange problems (XMI)

Contents

Sources of Requirements

- MDA (retrofit)
  - Semantic precision
  - Consolidation of concepts
  - Full MOF-UML alignment
- Practitioners
  - Conceptual clarification
  - New features, new features, new features…
- Language theoreticians
  - My new features, my new features, my new features…
  - Why not replace it with my modeling language instead?
- Dilemma: avoiding the “language bloat” syndrome

Formal RFP Requirements

1) Infrastructure – UML internals
   - More precise conceptual base for better MDA support
2) Superstructure – User-level features
   - New capabilities for large-scale software systems
   - Consolidation of existing features
3) OCL – Constraint language
   - Full conceptual alignment with UML
4) Diagram interchange standard
   - For exchanging graphic information (model diagrams)

Infrastructure Requirements

- Precise MOF alignment
  - Fully shared “common core” metamodel
- Refine the semantic foundations of UML (the UML metamodel)
  - Improve precision
  - Harmonize conceptual foundations and eliminate semantic overlaps
  - Provide clearer and more complete definition of instance semantics (static and dynamic)
- Improve extension mechanisms
  - Profiles, stereotypes
  - Support “family of languages” concept

OCL Requirements

- Define an OCL metamodel and align it with the UML metamodel
  - OCL navigates through class and object diagrams ⇒ must share a common definition of Class, Association, Multiplicity, etc.
- New modeling features available to general UML users
  - Beyond constraints
  - General-purpose query language

Diagram Interchange Requirements

- Ability to exchange graphical information between tools
  - Currently only non-graphical information is preserved during model interchange
  - Diagrams and contents (size and relative position of diagram elements, etc.)

Superstructure Requirements (1 of 2)

- More direct support for architectural modeling
  - Based on existing architectural description languages (UML-RT, ACME, SDL, etc.)
  - Reusable interaction specifications (UML-RT protocols)
- Behavior harmonization
  - Generalized notion of behavior and causality
  - Support choice of formalisms for specifying behavior
- Hierarchical interactions modeling
- Better support for component-based development
- More sophisticated activity graph modeling
  - To better support business process modeling

Superstructure Requirements (2 of 2)

- New statechart capabilities
  - Better modularity
- Clarification of semantics for key relationship types
  - Association, generalization, realization, etc.
- Remove unused and ill-defined modeling concepts
- Clearer mapping of notation to metamodel
- Backward compatibility
  - Support 1.x style of usage
  - New features only if required

Contents

Standardization Process

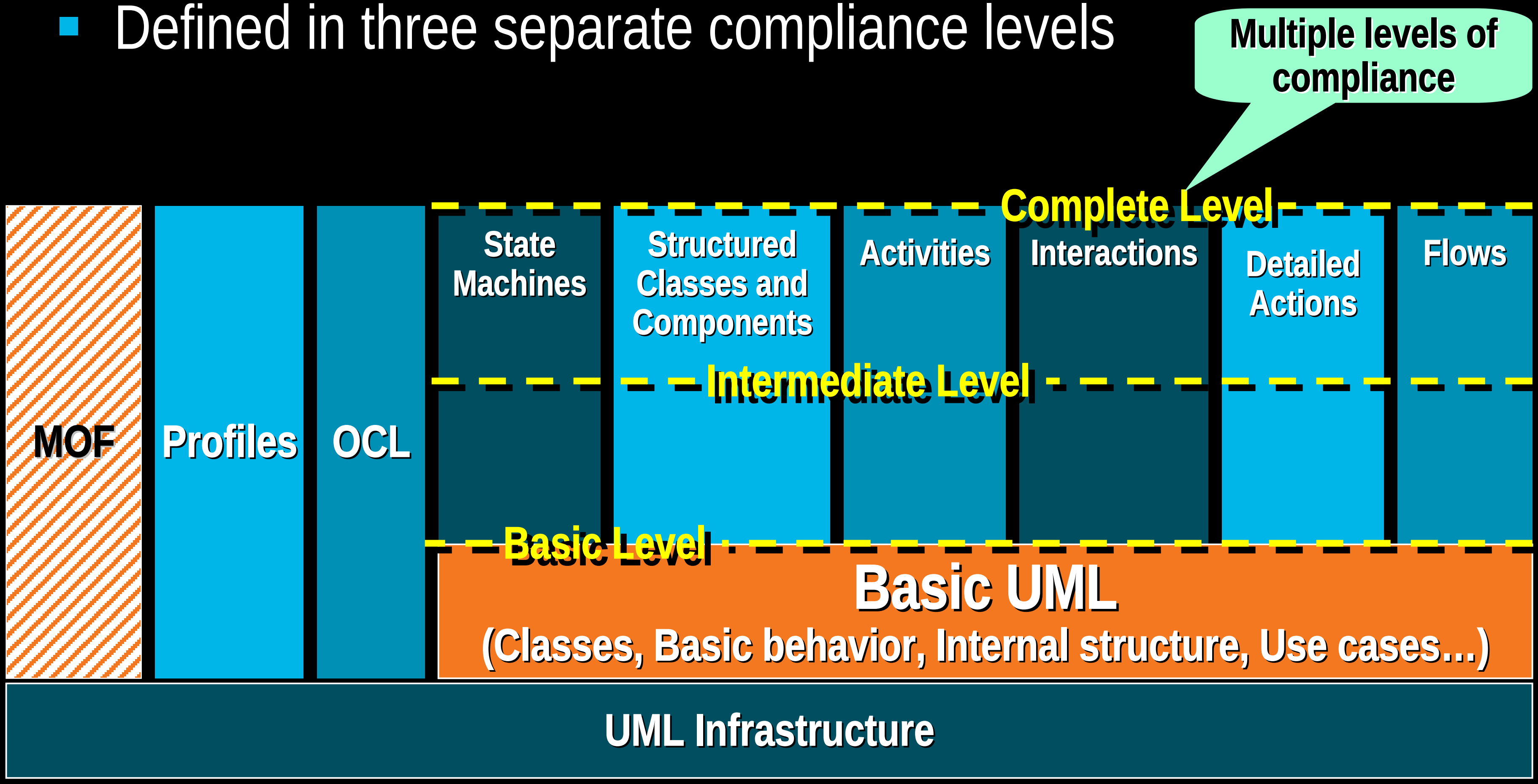
- Multiple competing submissions (5)
  - Most involved consortia of companies representing both UML tool vendors and UML users
  - One prominent (800-lb gorilla) submission team (“U2P”) with most of the major vendors (Rational, IBM, Telelogic, ...) and large user companies (Motorola, HP, Ericsson…)
- Over time:
  - Some submissions lapsed
  - Some submissions were merged into the U2P
  - Currently there is just one submission

Approach to Evolving UML 2.0

- Evolutionary rather than revolutionary
- Improved precision of the infrastructure
- Small number of new features
- New feature selection criteria
  - Required for supporting large industrial-scale applications
  - Non-intrusive on UML 1.x users (and tool builders)
- Backward compatibility with 1.x

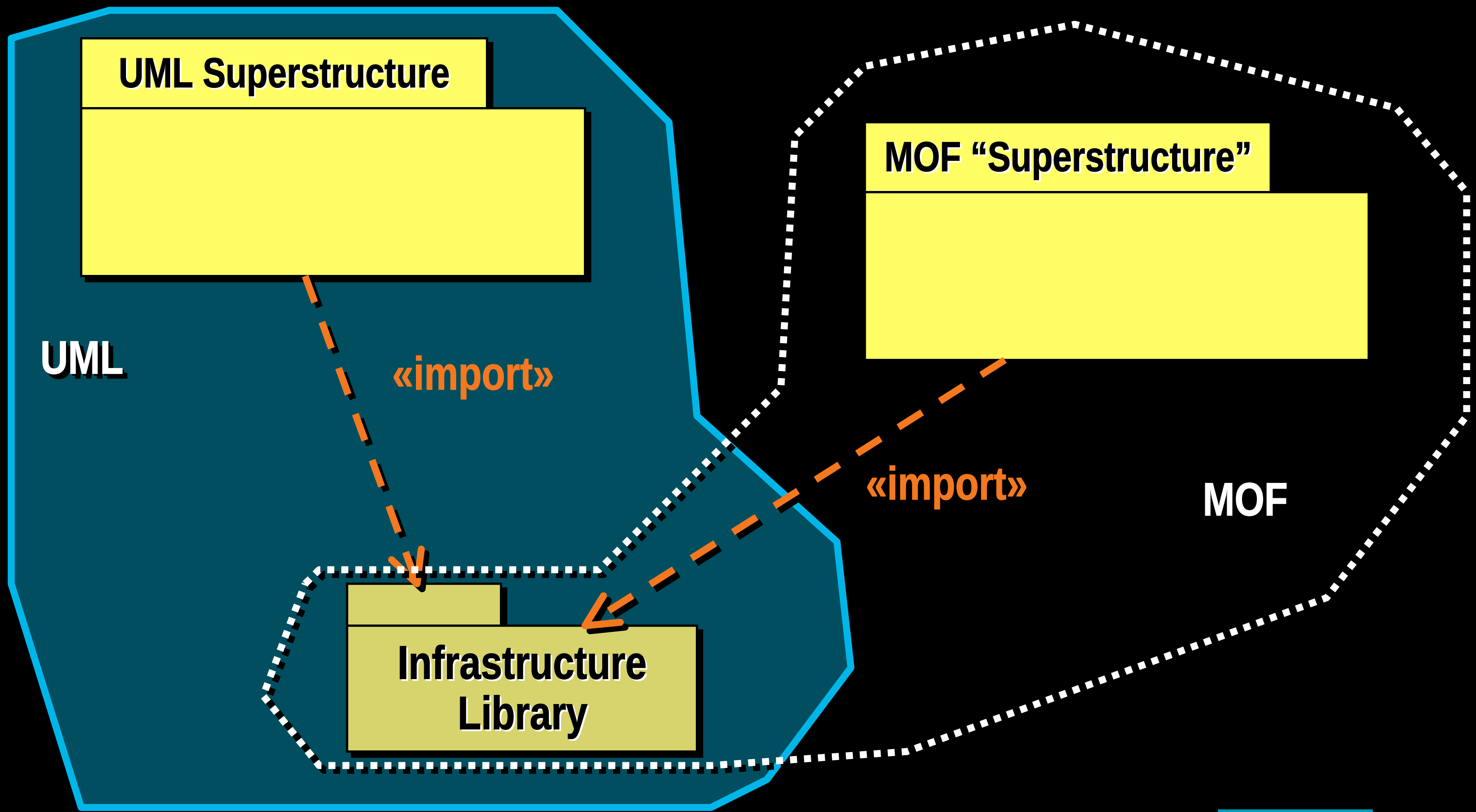
Language Structure

- A core language + a set of optional “sub-languages”
  - Defined in three separate compliance levels



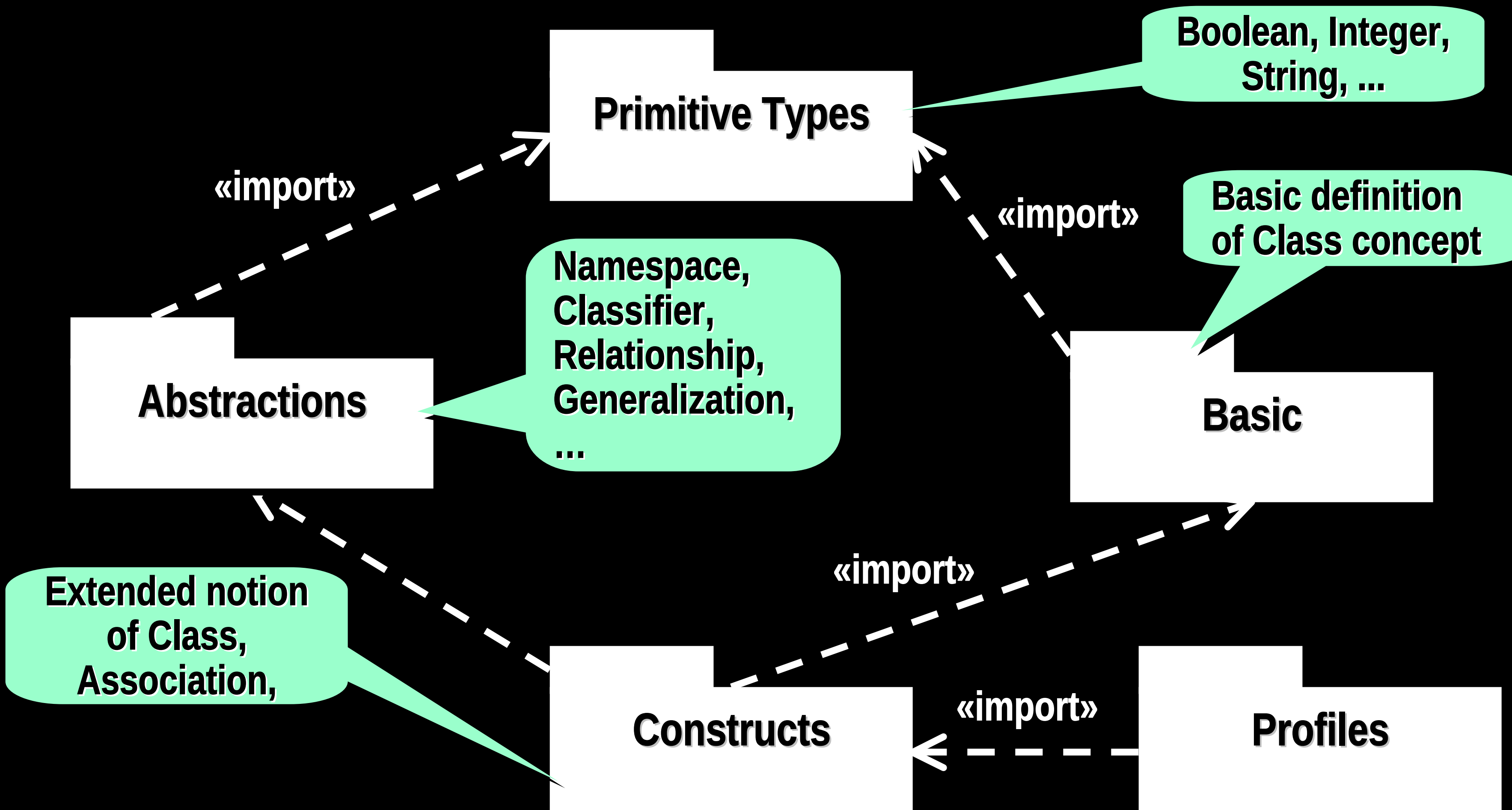
UML-MOF Alignment

- Shared conceptual base
  - MOF: language for defining modeling languages
  - UML: general purpose modeling language



Infrastructure Library – Metamodel Structure

- Shared by MOF, UML, and other languages



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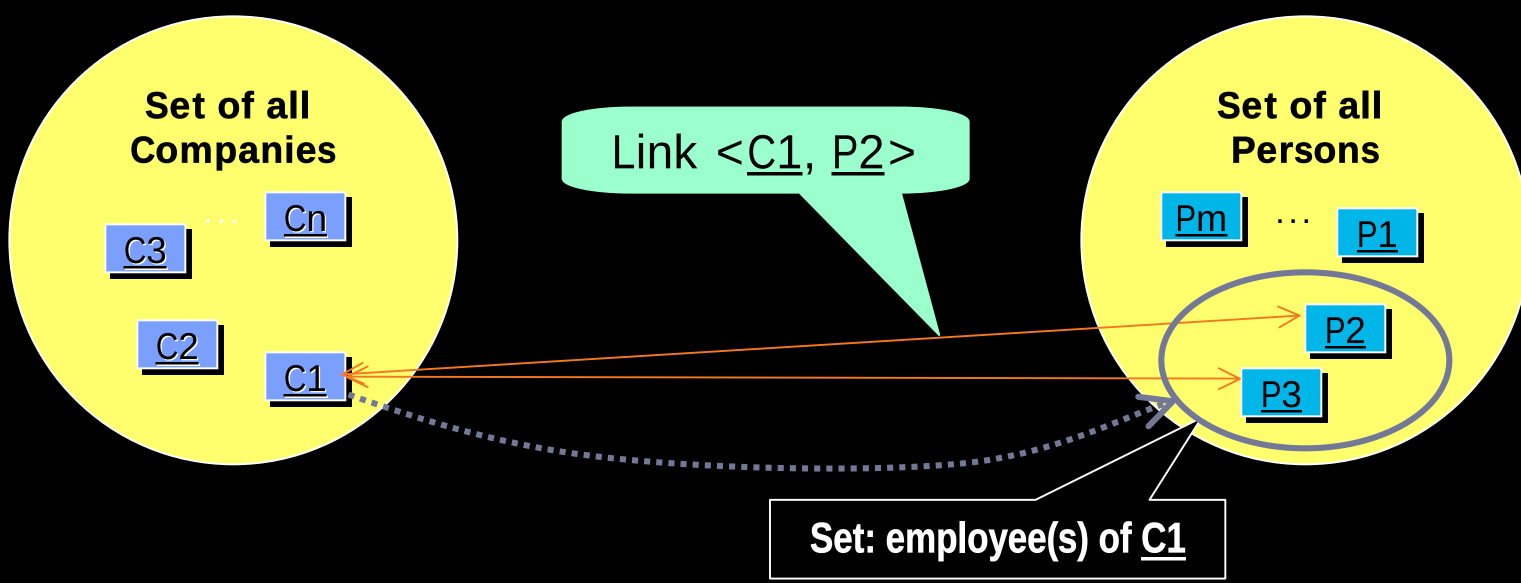
Class Diagram Semantics

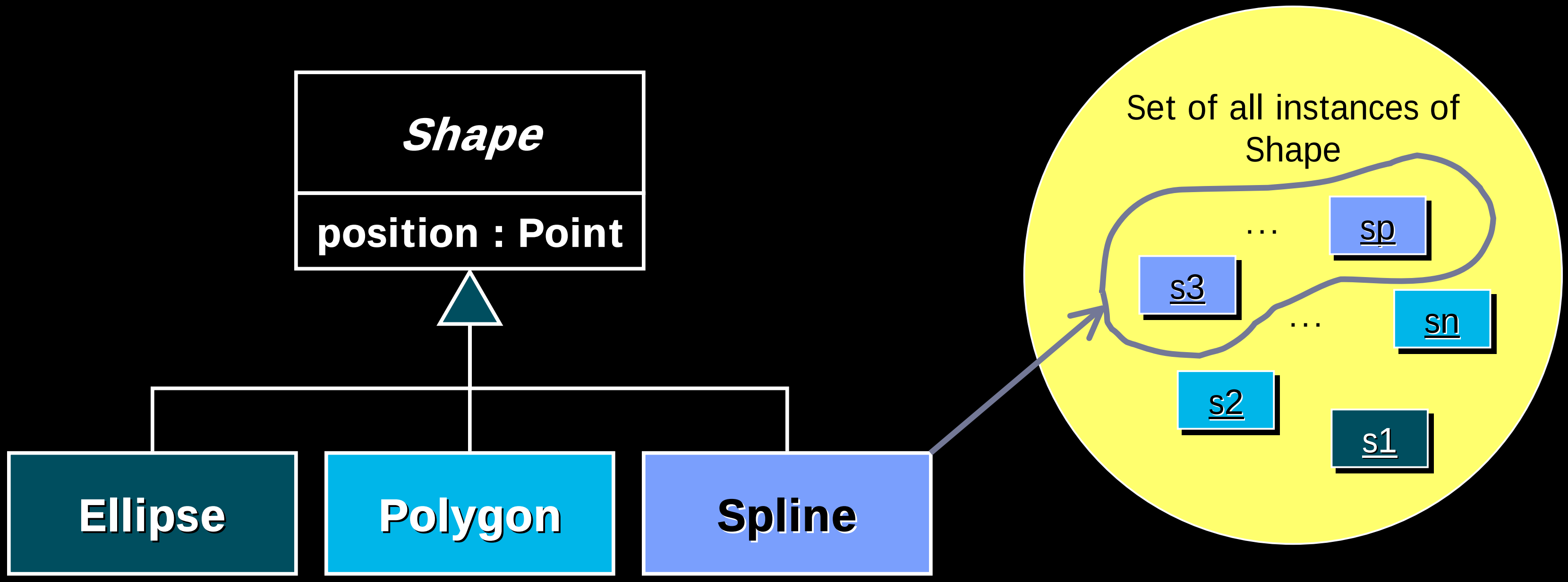
- Represent relationships between *instances* of classes

Formal (set theoretic) interpretation:



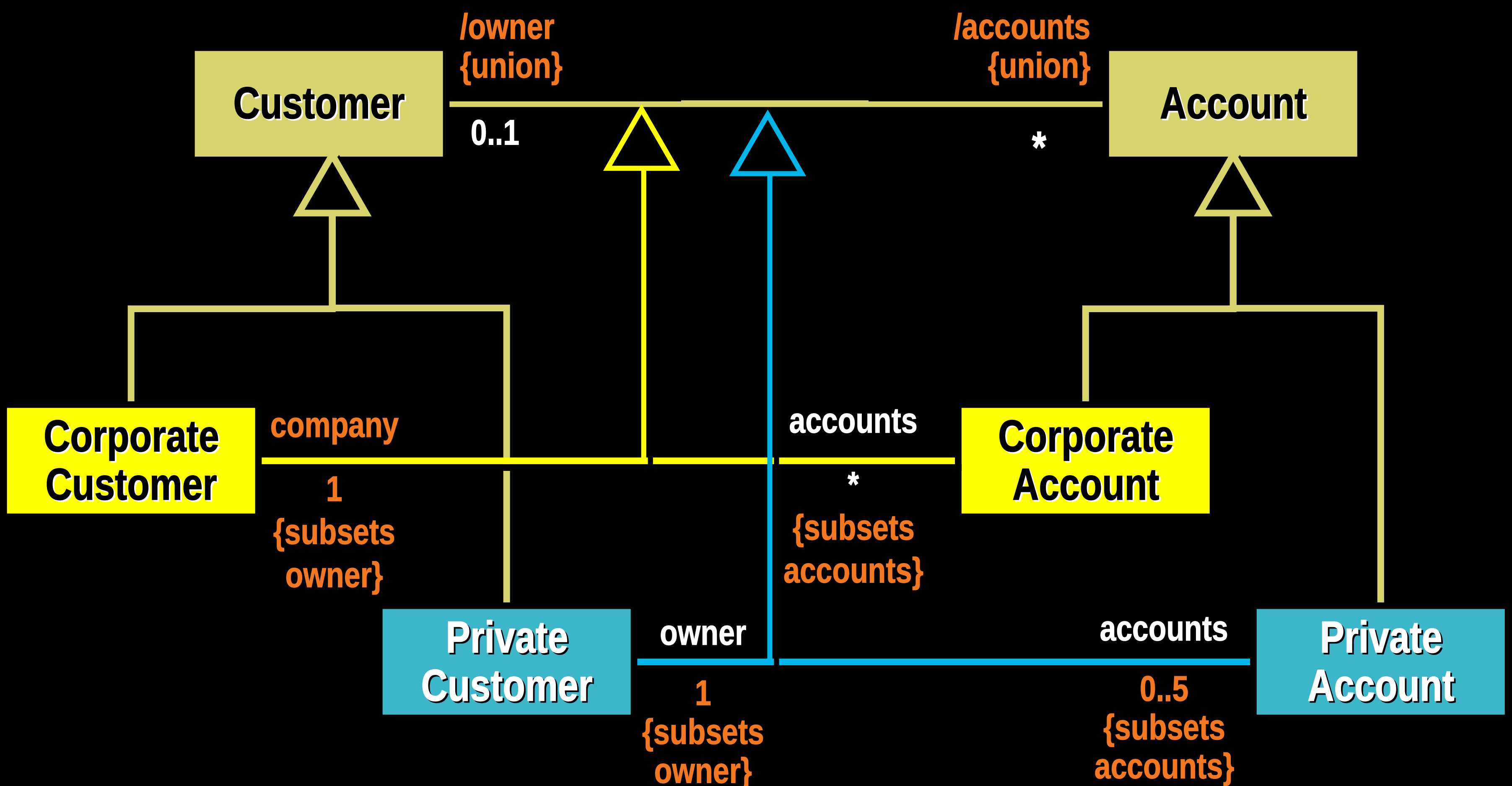
Generalization Semantics

- Subclasses = specialized subsets of parent
- Subclass inherits all features of the parent and may add its own
- Relationship between classes



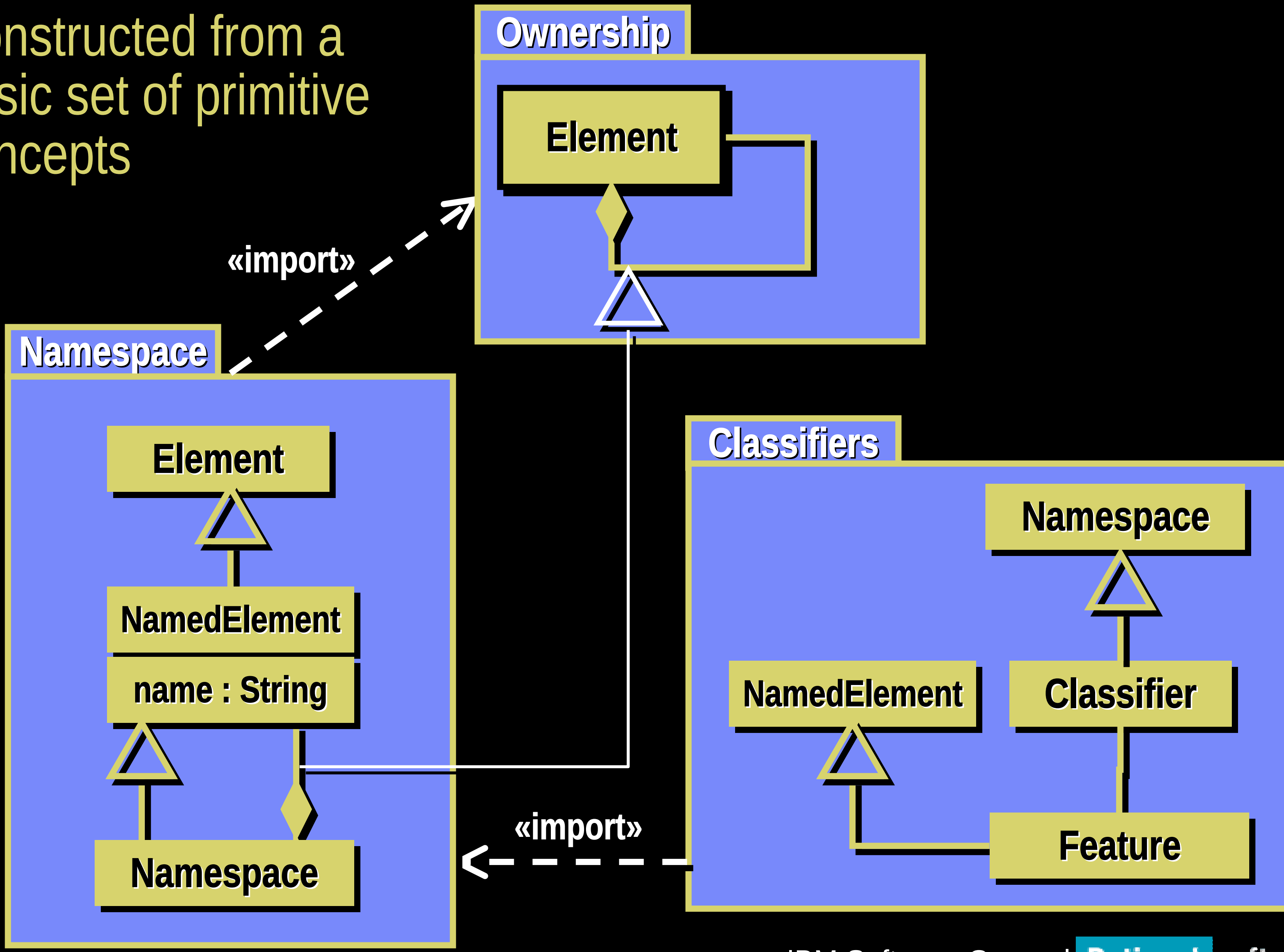
Association Specialization

- Also used widely in the definition of the UML metamodel
  - Avoids covariance problems



Example: Classifier Definition

- Constructed from a basic set of primitive concepts



Kinds of Classifiers

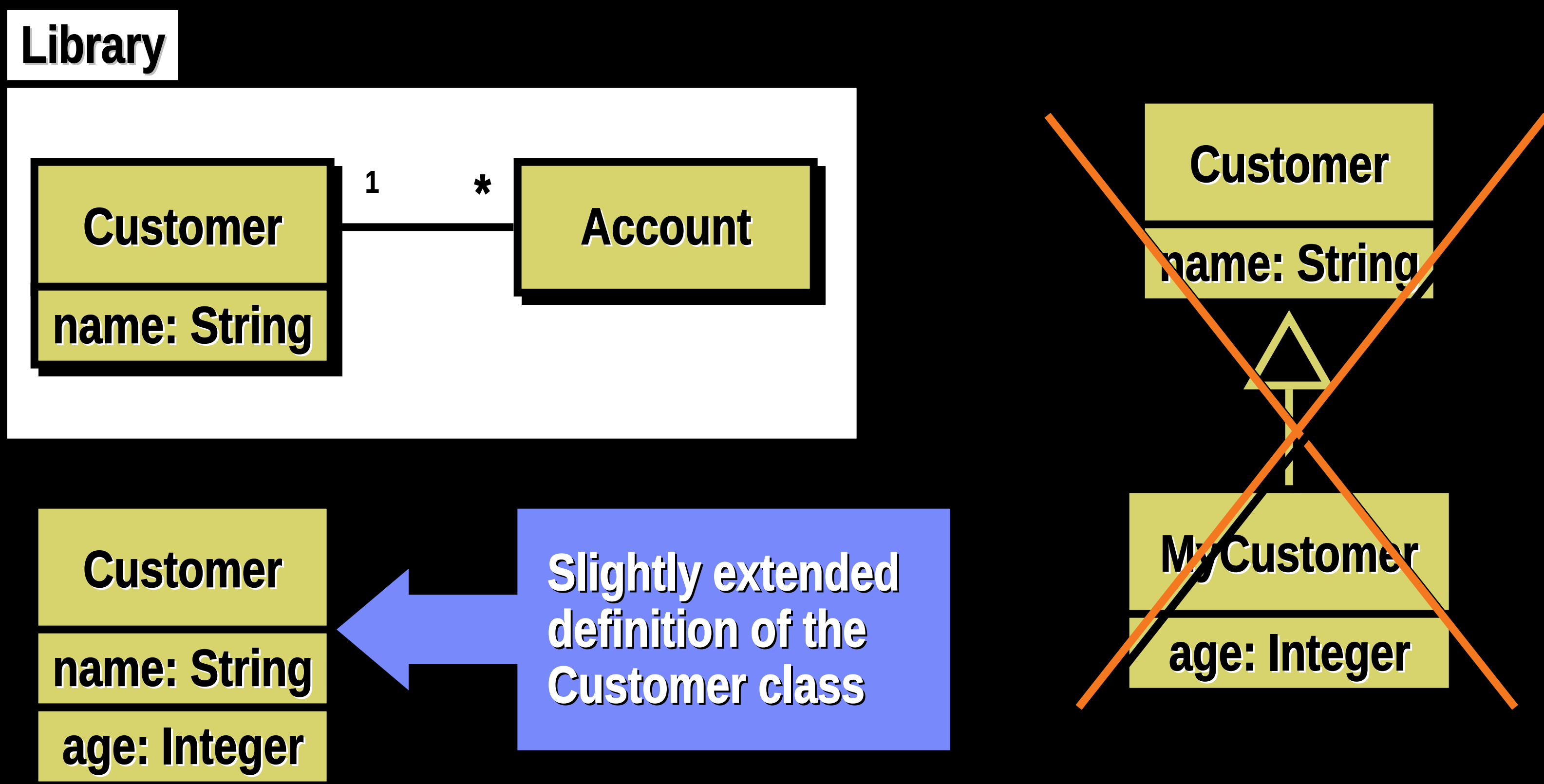
- The following are kinds of Classifier in UML 2.0:
  - Association (including AssociationClass)
  - Class (including structured classes)
  - Component
  - Collaboration
  - Interface
  - Data Type
  - Use Case
  - Signal
  - *Behavior !*
  - etc.
- Kinds of Behavior
  - Activity
  - Interaction
  - State Machine
  - Protocol State Machine

Infrastructure: Consolidation of Concepts

- The re-factoring of the UML metamodel into fine-grained independent concepts
  - Eliminates semantic overlap
  - Provides a better foundation for a precise definition of concepts and their semantics
  - Conducive to MDD

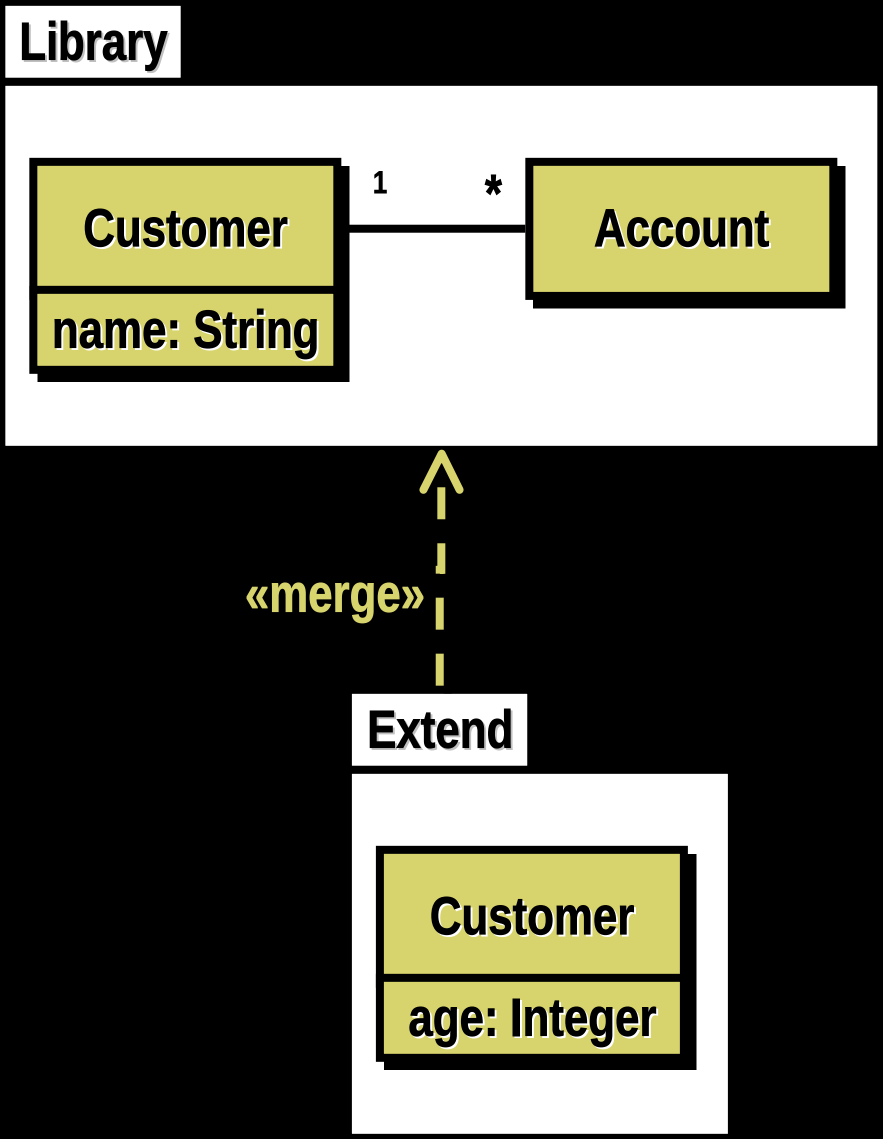
Package Merge: Motivation

- In some cases we would like to modify a definition of a class without having to define a subclass
  - To retain all the semantics (relationships, constraints, etc.) of the original



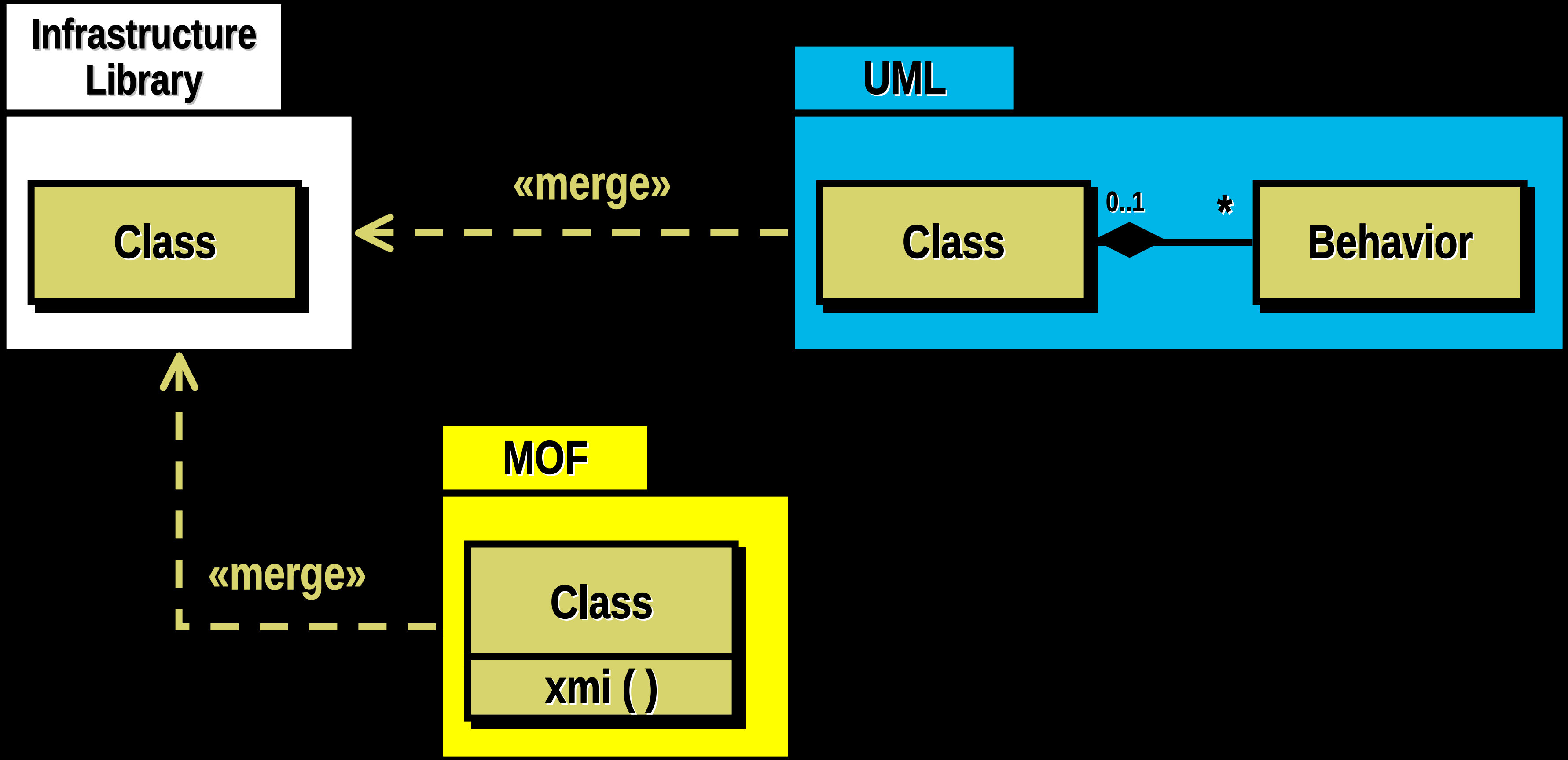
Package Merge: Semantics

- Optional incremental definition of concepts

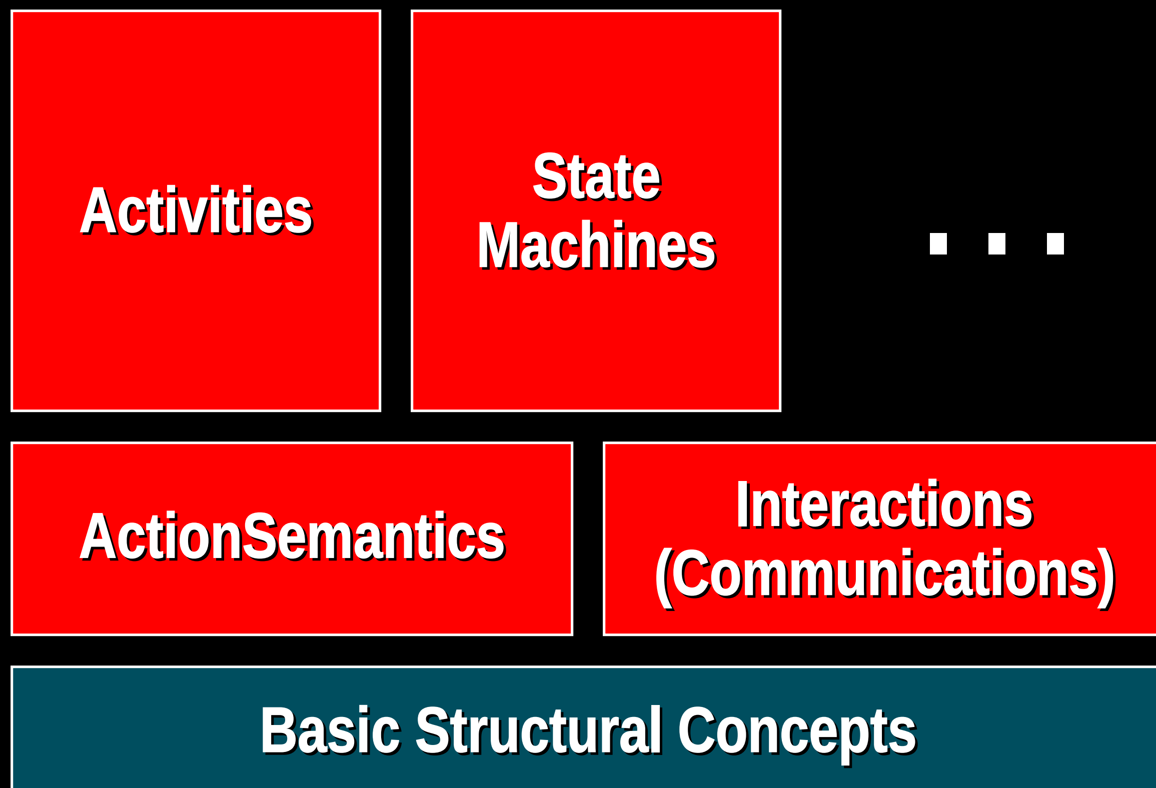


Package Merge: Metamodel Usage

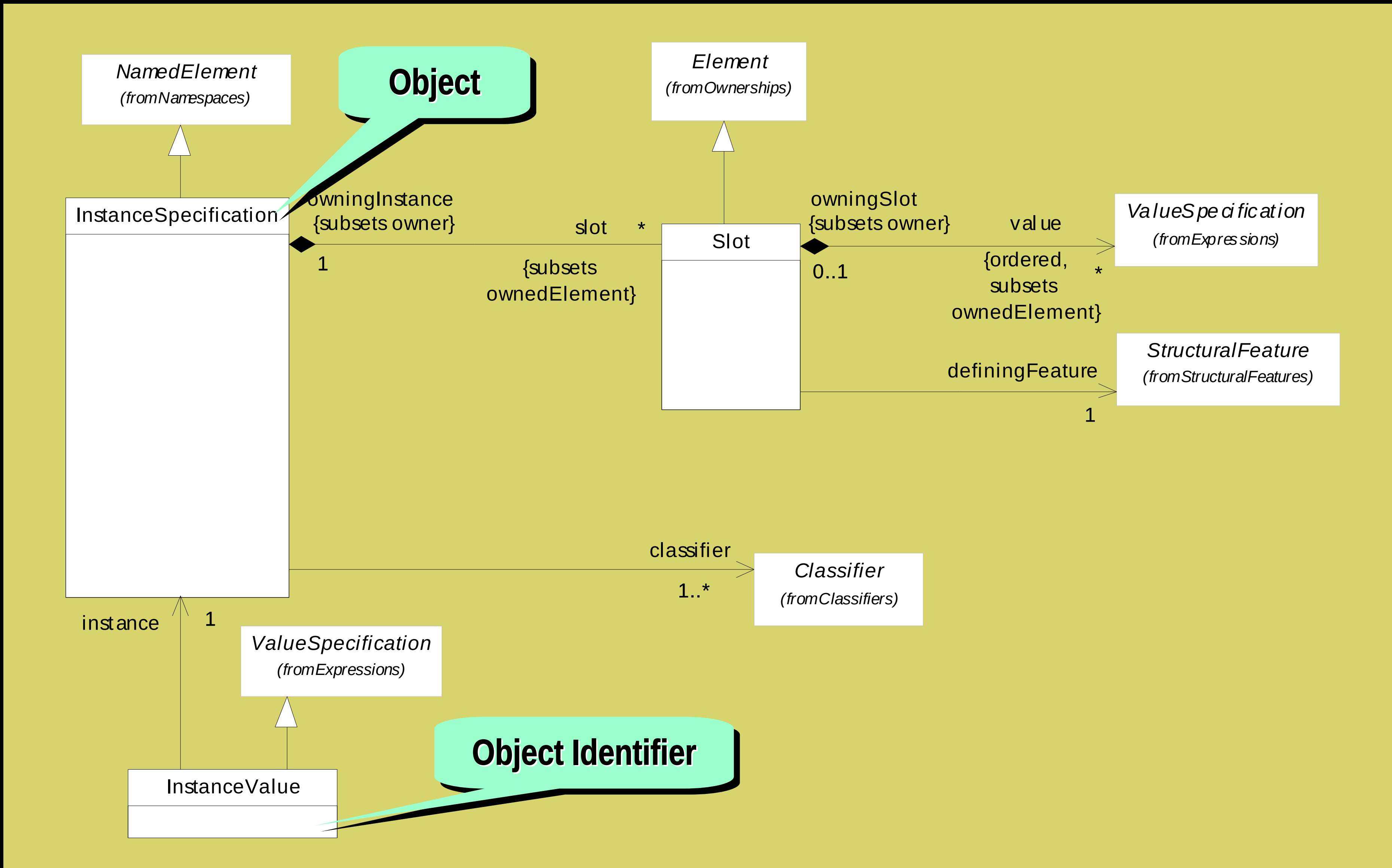
- Enables common definitions for shared concepts with the ability to extend them according to need
  - E.g. MOF and UML definitions of Class



UML 2.0: Run-Time Semantics



Metamodel Description of Objects

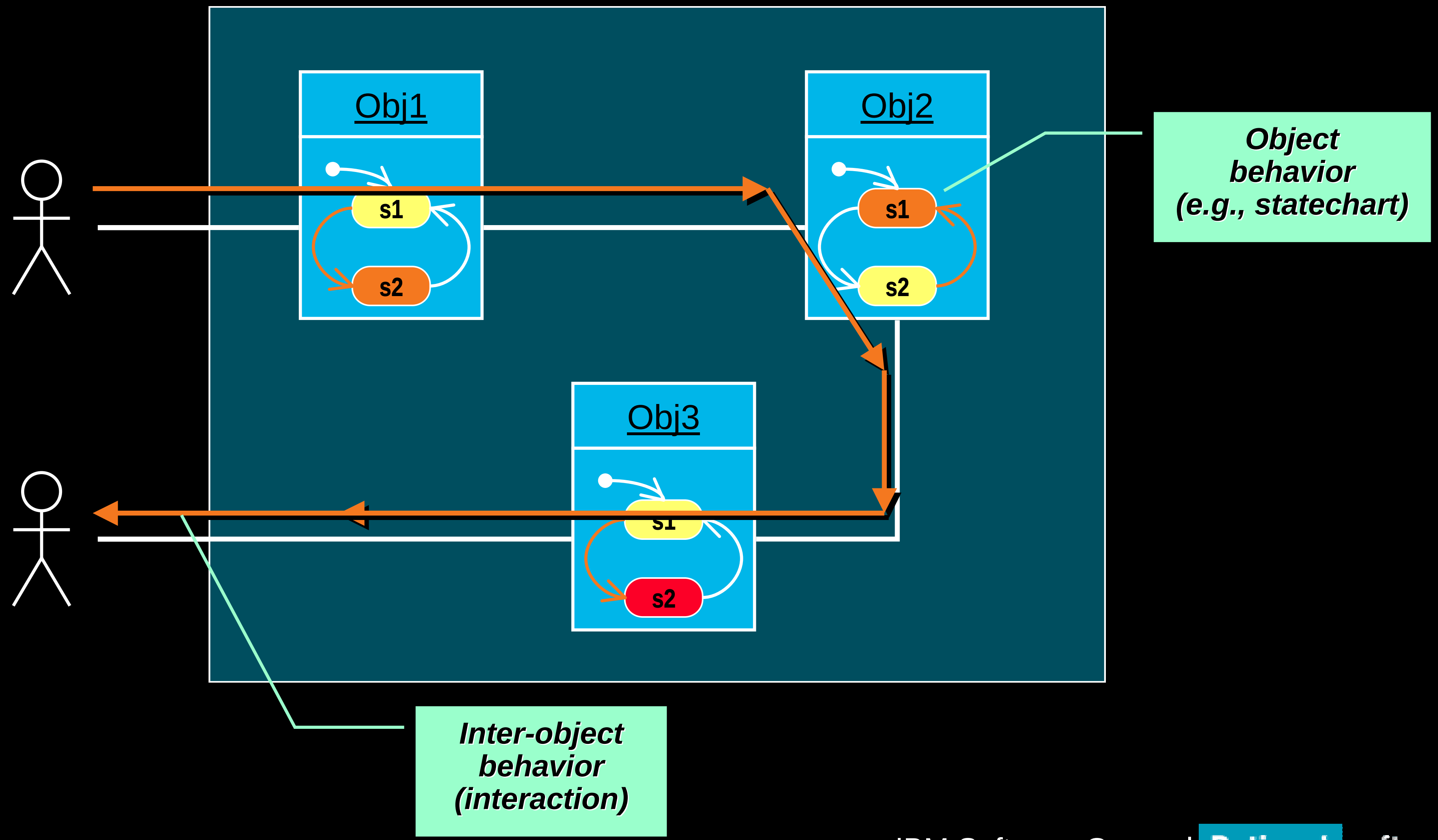


Basic Structural Elements

- Values
  - Universal, unique, constant
  - E.g. Numbers, characters, object identifiers ("instance value")
- "Cells" (Slots/Variables)
  - Container for values or objects
  - Can be created and destroyed dynamically
  - Constrained by a type
  - Have identity (independent of contents)
- Objects (Instances)
  - Containers of slots (corresponding to structural features)
  - Just a special kind of cell
- Links
  - Tuples of object identifiers
  - May have identity (i.e., some links are objects)
  - Can be created and destroyed dynamically

How Things Happen in UML

- In UML, all behavior results from the actions of (active) objects



How Things Happen in UML

- An action is executed by an object
  - May change the contents of one or more variables or slots
  - If it is a communication (“messaging”) action, it may:
    - Invoke an operation on another object
    - Send a signal to another object
    - Either one will eventually cause the execution of a procedure on the target object…
    - …which will cause other actions to be executed, etc.
  - Successor actions are executed
    - Determined either by control flow or data flow

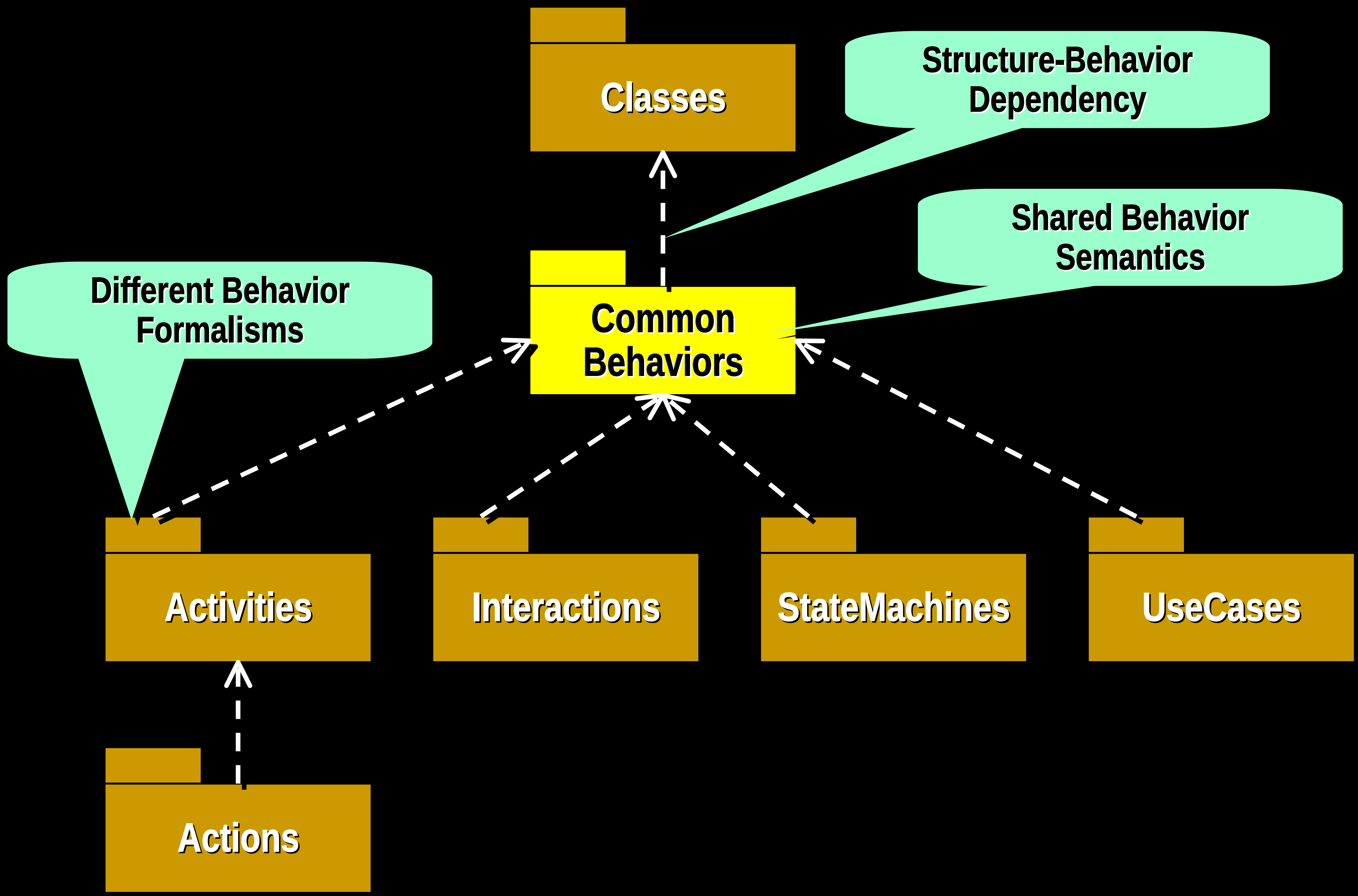
Active Object Definition

- From the spec:

An active object is an object that, as a direct consequence of its creation, [eventually] commences to execute its classifier behavior [specification], and does not cease until either the complete behavior is executed or the object is terminated by some external object.

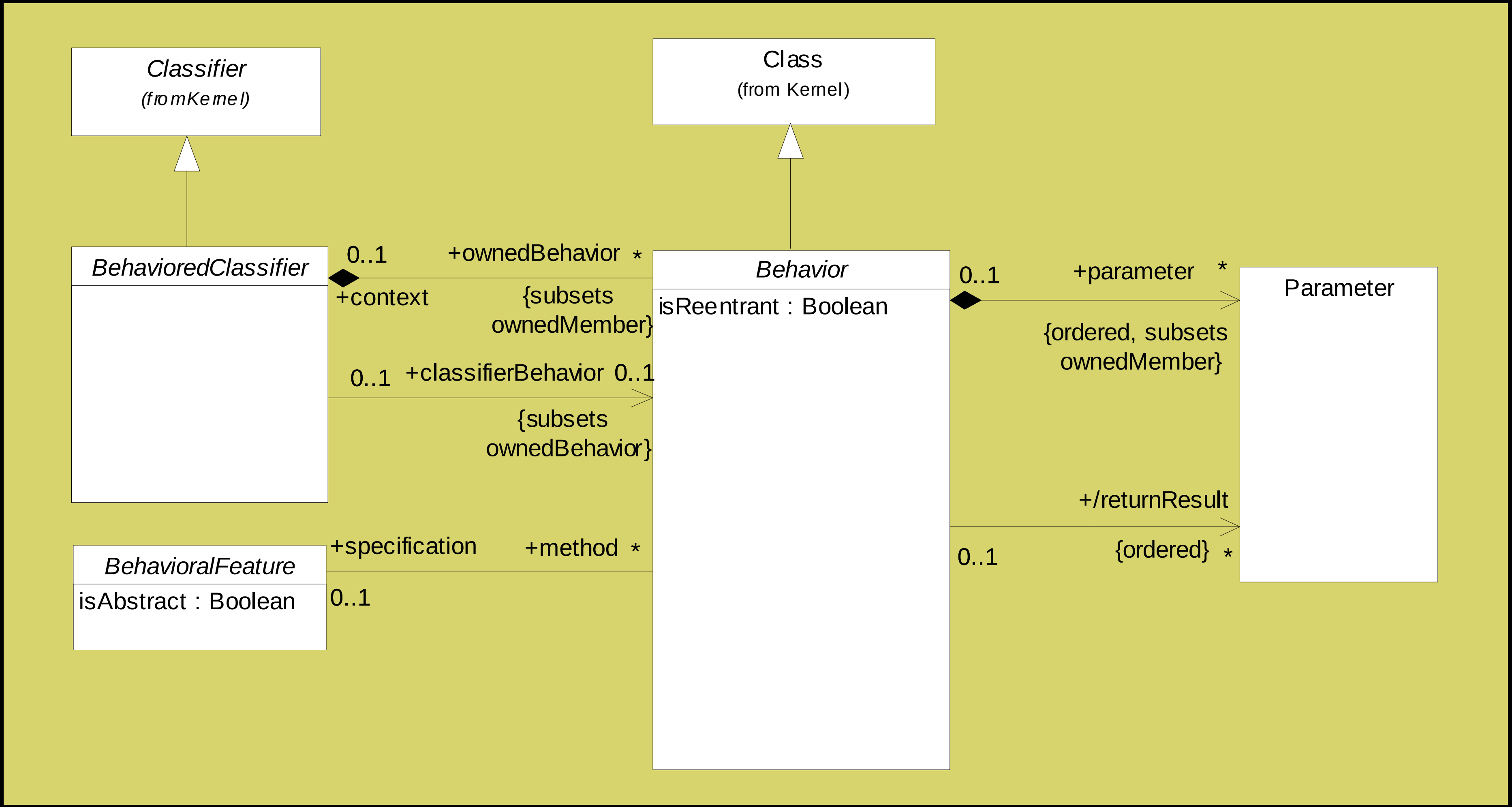
The points at which an active object responds to [messages received] from other objects is determined solely by the behavior specification of the active object...

Metamodel Structure



Common Behavior Metamodel

- The "classifier behavior" of a composite classifier is distinct from the behavior of its parts (i.e., it is NOT a resultant behavior)



UML 2.0: Kinds of Behavior

- Actions
  - Formally, defined in the context of an Activity
- Activities
- Interactions
- State machines
- Use cases

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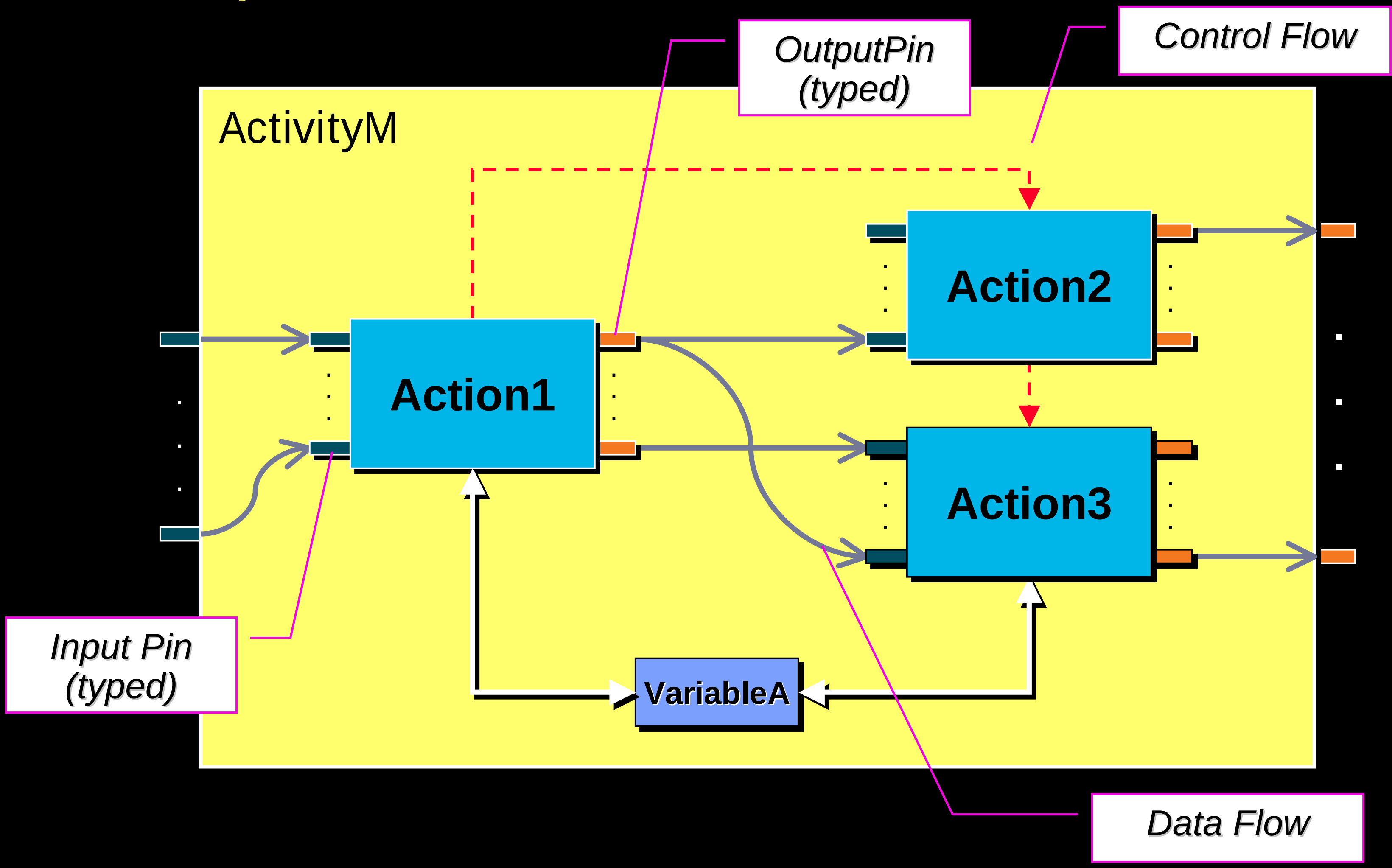
Actions in UML

- Action = fundamental unit of behavior
  - for modeling fine-grained behavior
  - Level of traditional programming languages
- UML defines:
  - A set of action types
  - A semantics for those actions
    - i.e. what happens when the actions are executed
    - Pre- and post-condition specifications (using OCL)
  - No concrete syntax for individual kinds of actions (notation)
    - Flexibility: can be realized using different concrete languages
- In UML 2, the metamodel of actions was consolidated
  - Shared semantics between actions and activities (Basic Actions)

Shared Action/Activity Semantics

- Data/control flow foundations for maximal implementation flexibility

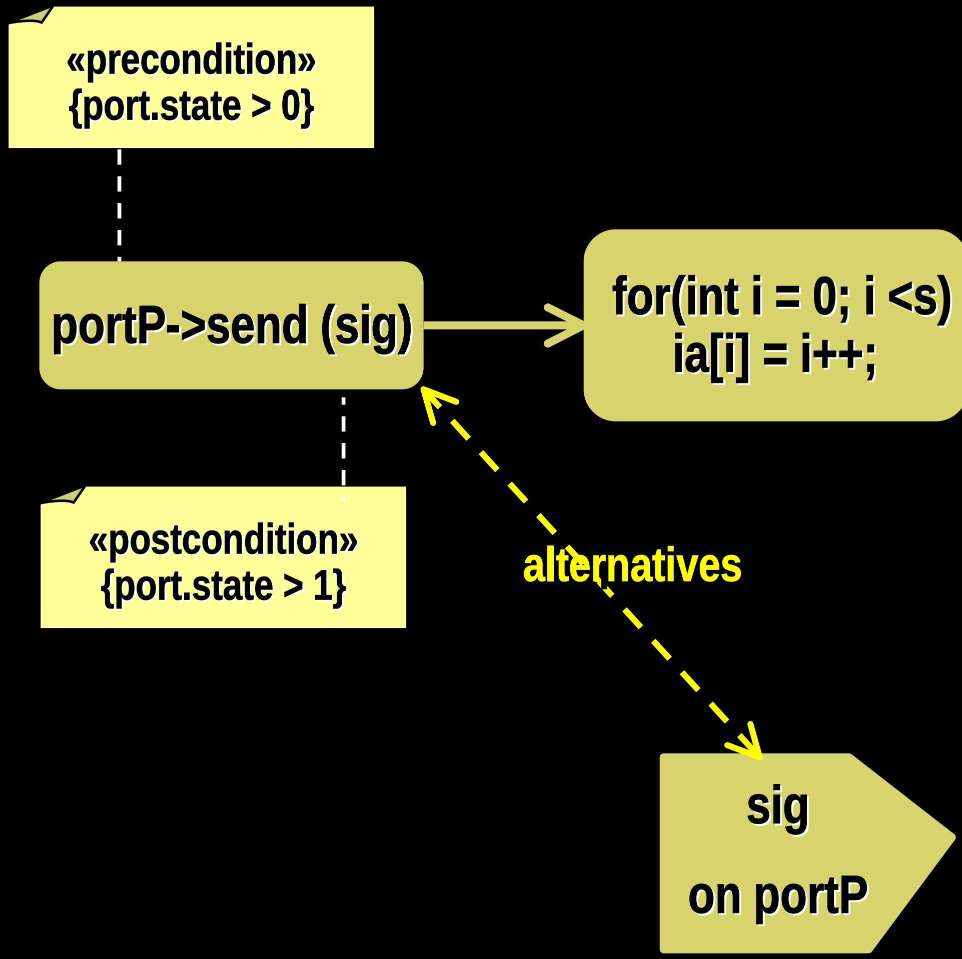


Categories of Actions

- Communication actions (send, call, receive,…)
- Primitive function action
- Object actions (create, destroy, reclassify,start,…)
- Structural feature actions (read, write, clear,…)
- Link actions (create, destroy, read, write,…)
- Variable actions (read, write, clear,…)
- Exception action (raise)

General Notation for Actions

- No specific symbols (some exceptions)



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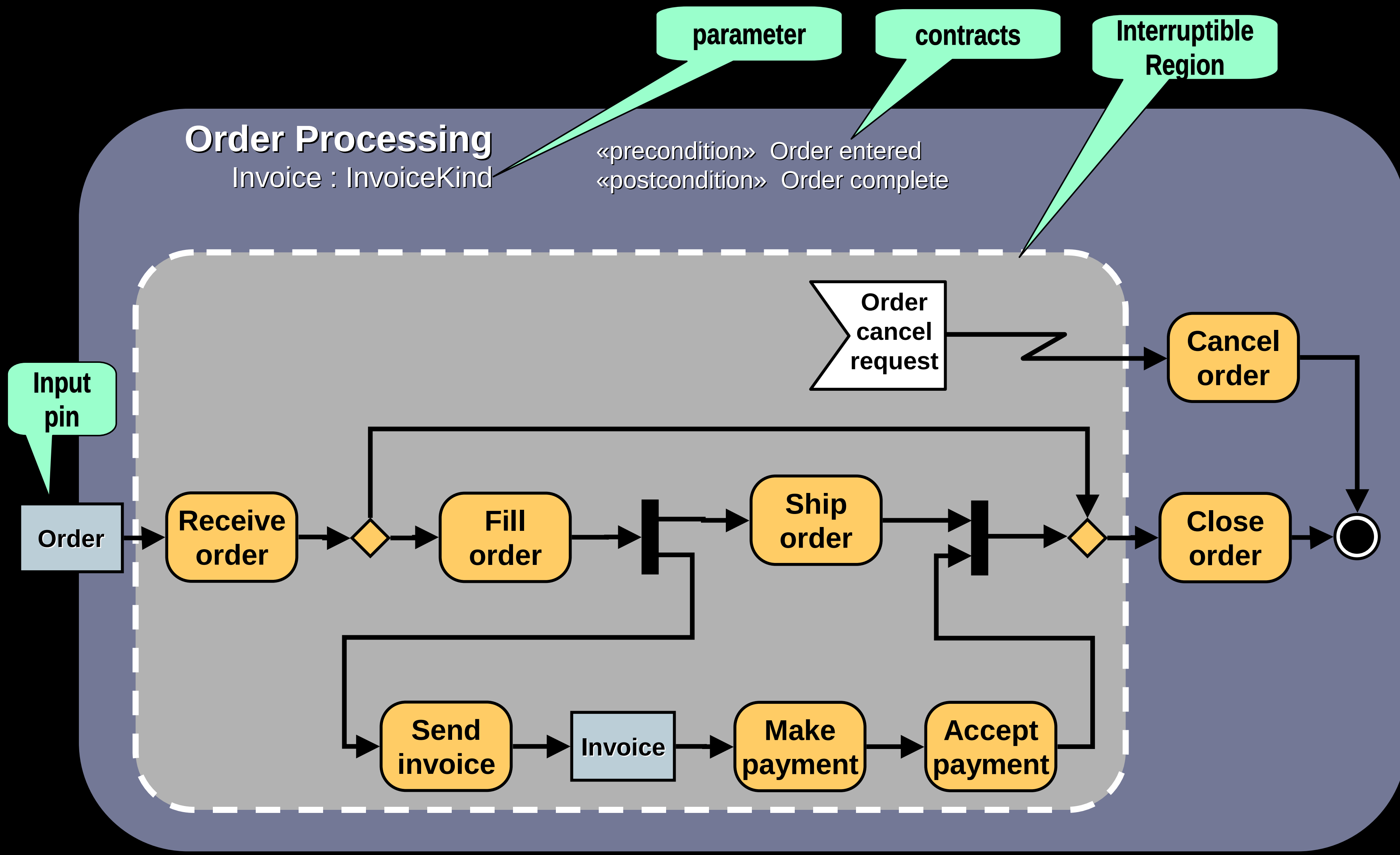
Activities

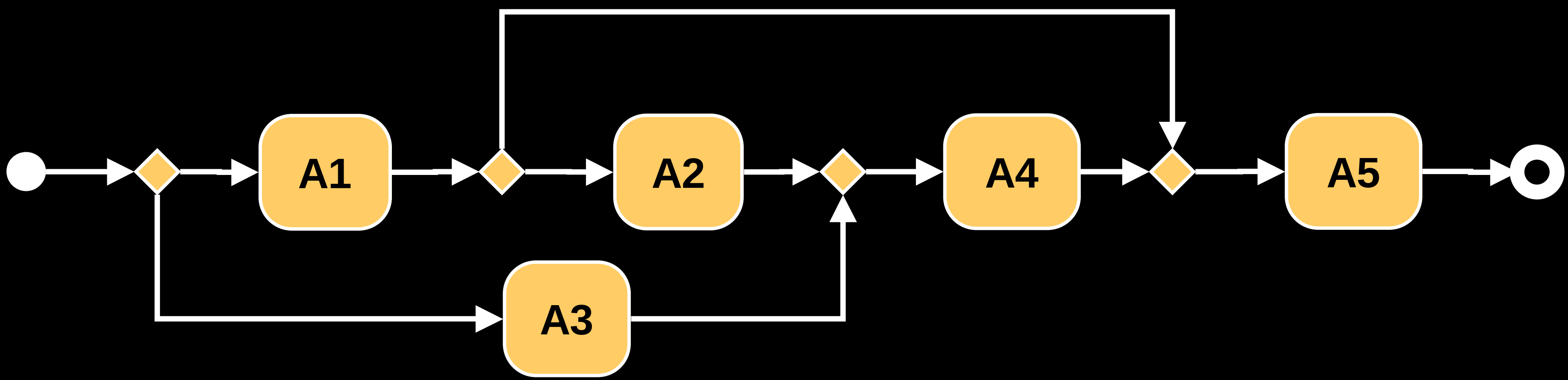
- Significantly enriched in UML 2.0 (relative to UML 1.x activities)
  - More flexible semantics for greater modeling power (e.g., rich concurrency model based on Petri Nets)
  - Many new features
- Major influences for UML 2.0 activity semantics
  - Business Process Execution Language for Web Services (BPEL4WS) – a de facto standard supported by key industry players (Microsoft, IBM, etc.)
  - Functional modeling from the systems engineering community (INCOSE)

Activity Graph Example

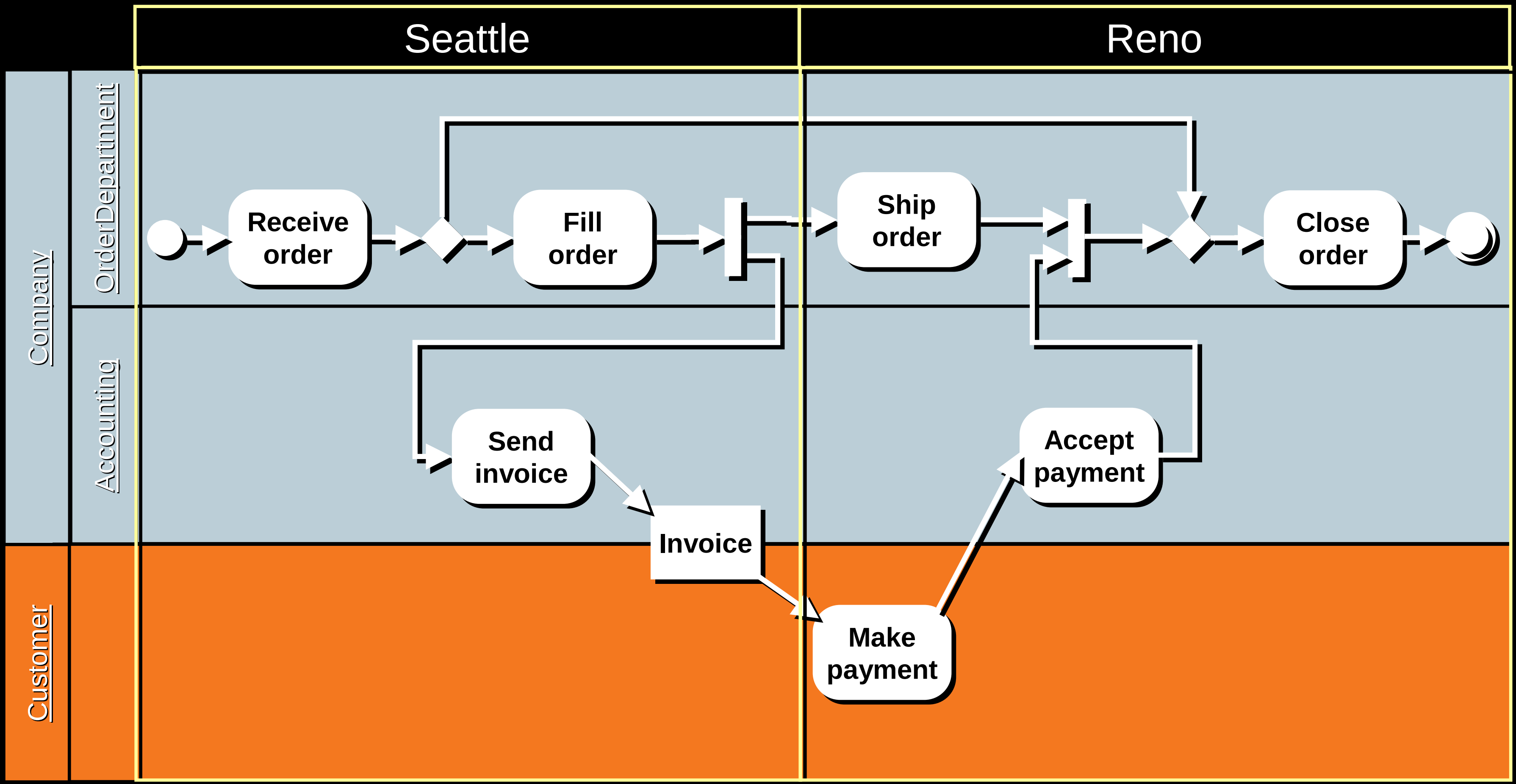


“Unstructured” Activity Graphs

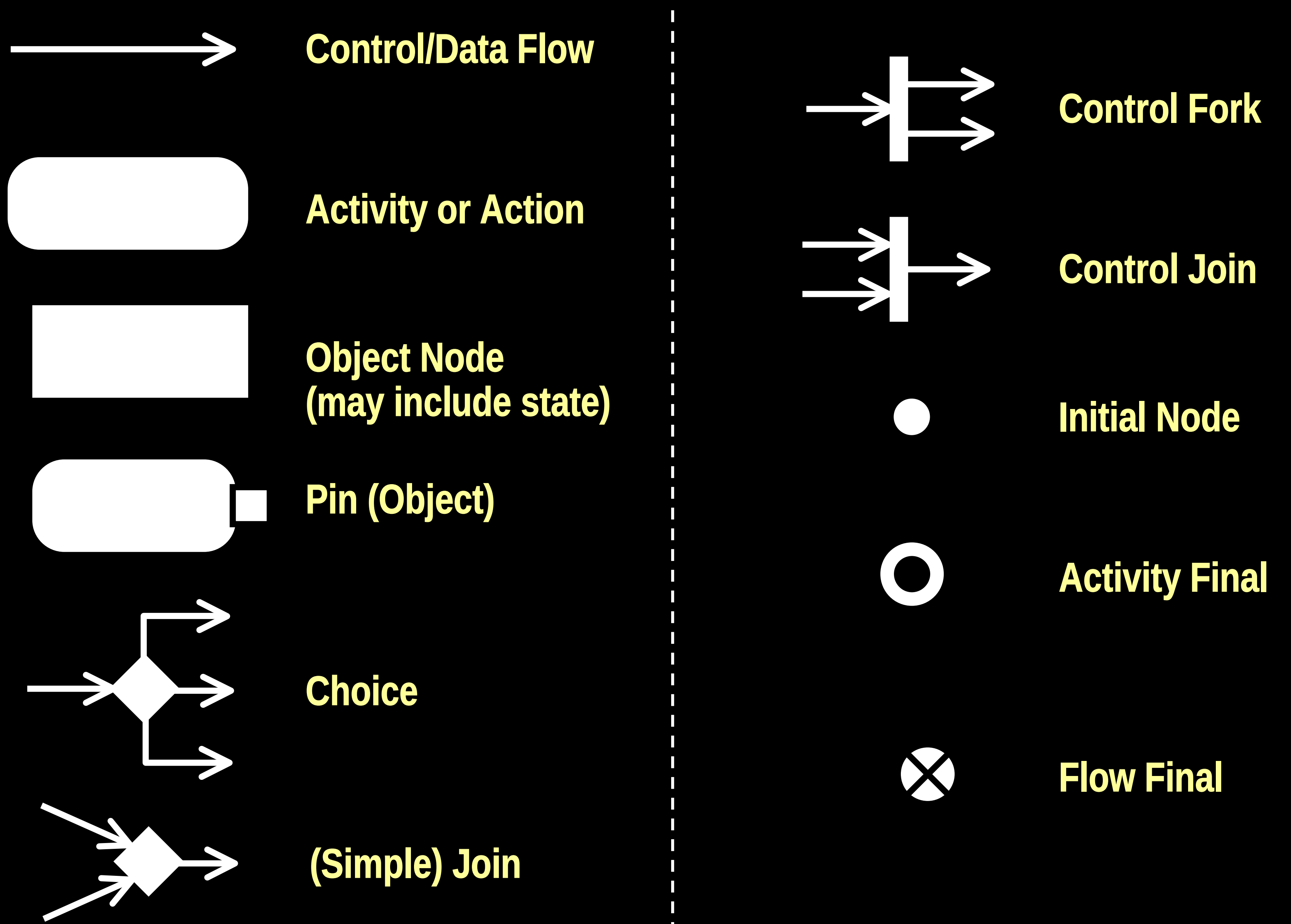
- Not possible in 1.x
  - But, business processes are not necessarily well structured



Partitioning capabilities

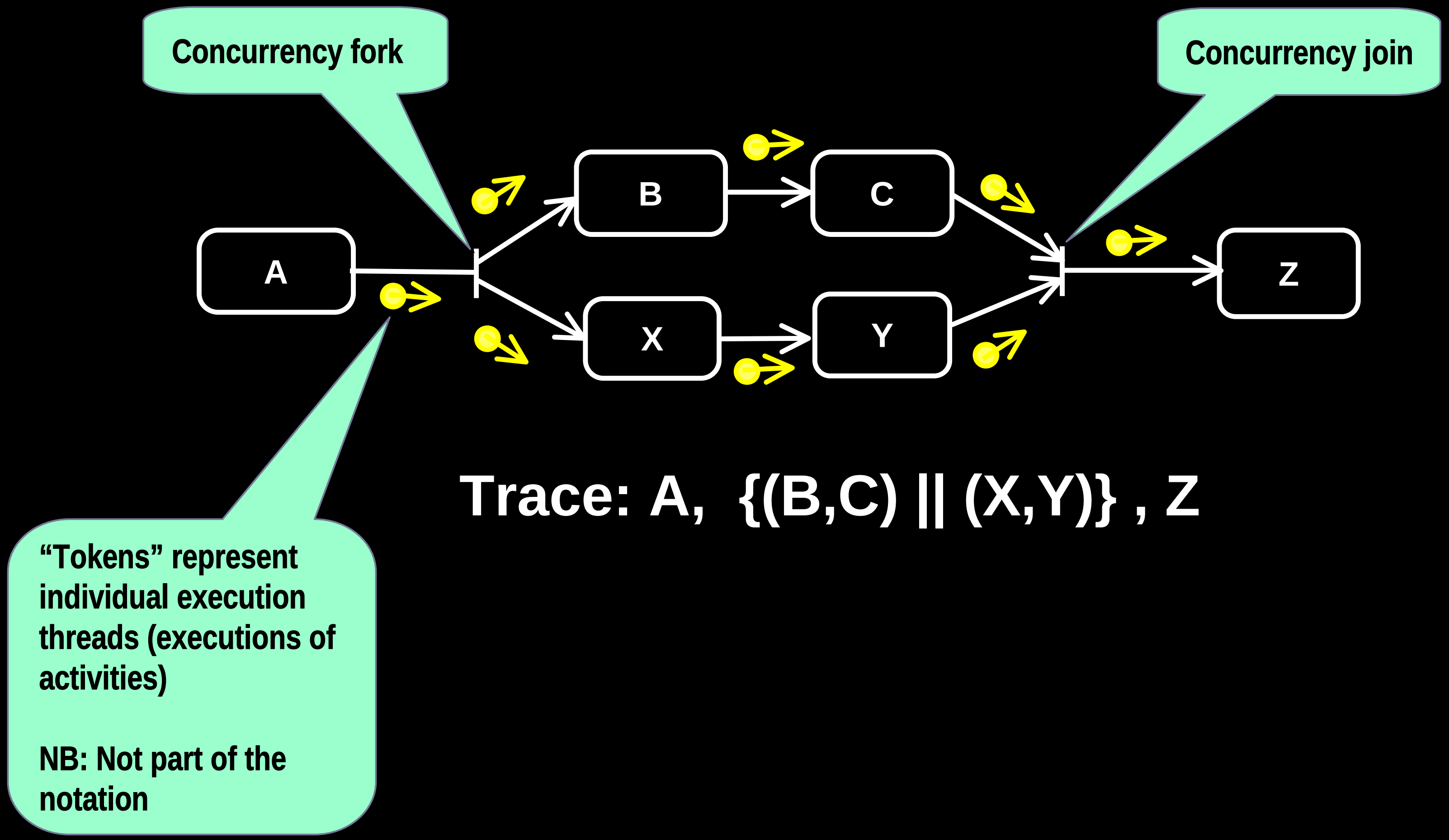


Activities: Basic Notational Elements



Extended Concurrency Model

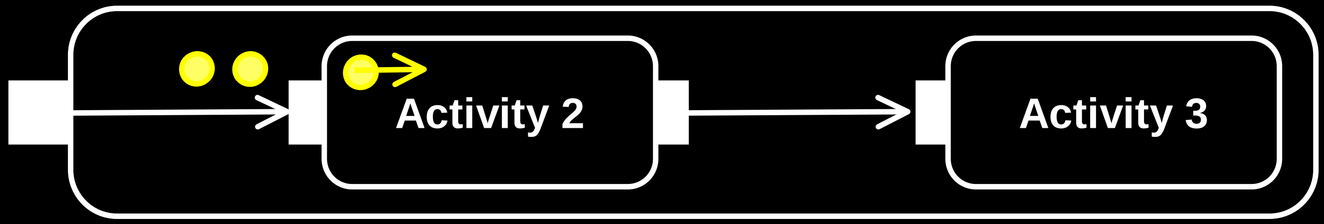
- Fully independent concurrent streams ("tokens")



Trace: A, {(B,C) || (X,Y)} , Z

Activities: Token Queuing Capabilities

- Tokens can
  - queue up in “in/out” pins.
  - backup in network.
  - prevent upstream behaviors from taking new inputs.



- …or, they can flow through continuously
  - taken as input while behavior is executing
  - given as output while behavior is executing
  - identified by a {stream} adornment on a pin or object node

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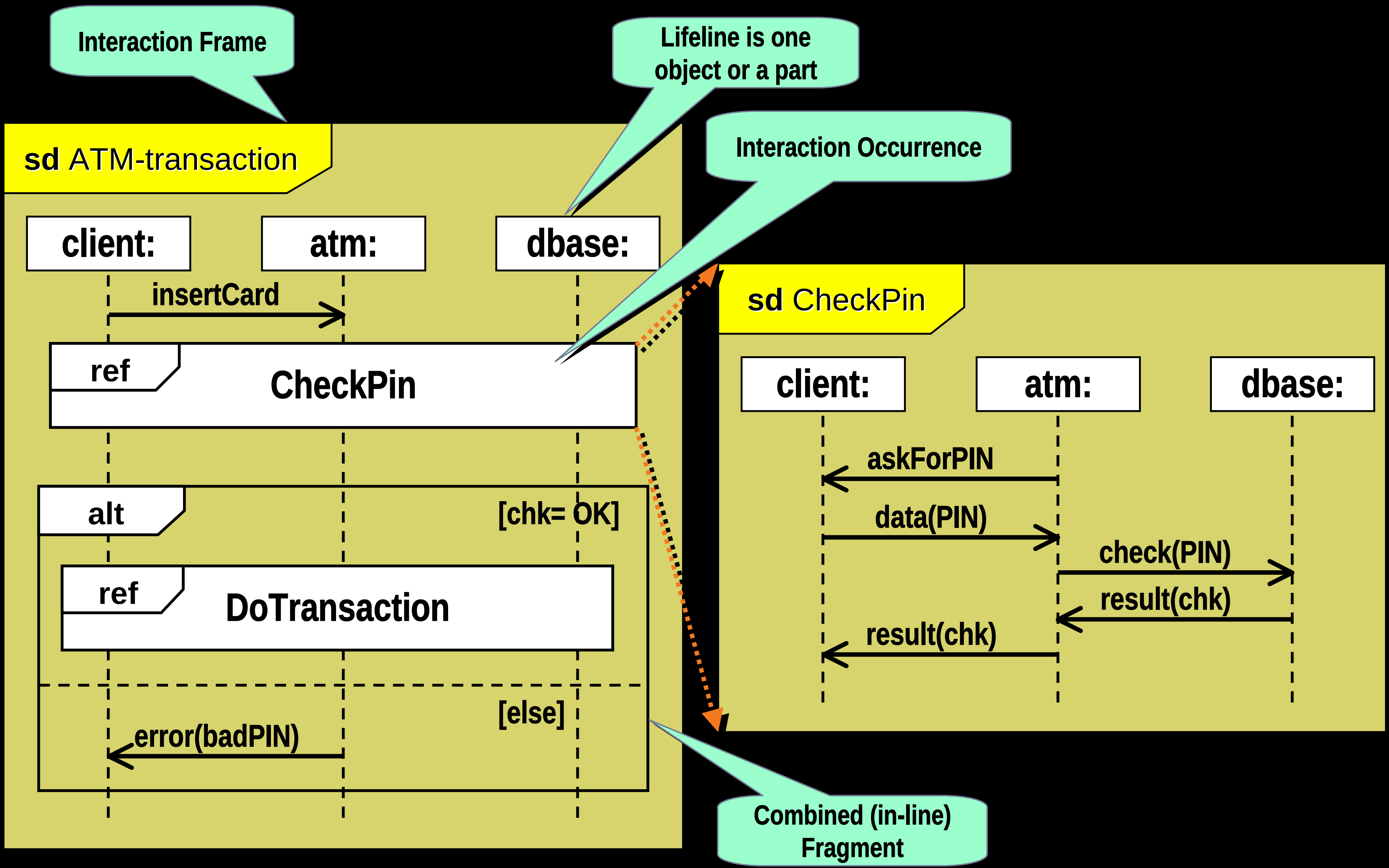
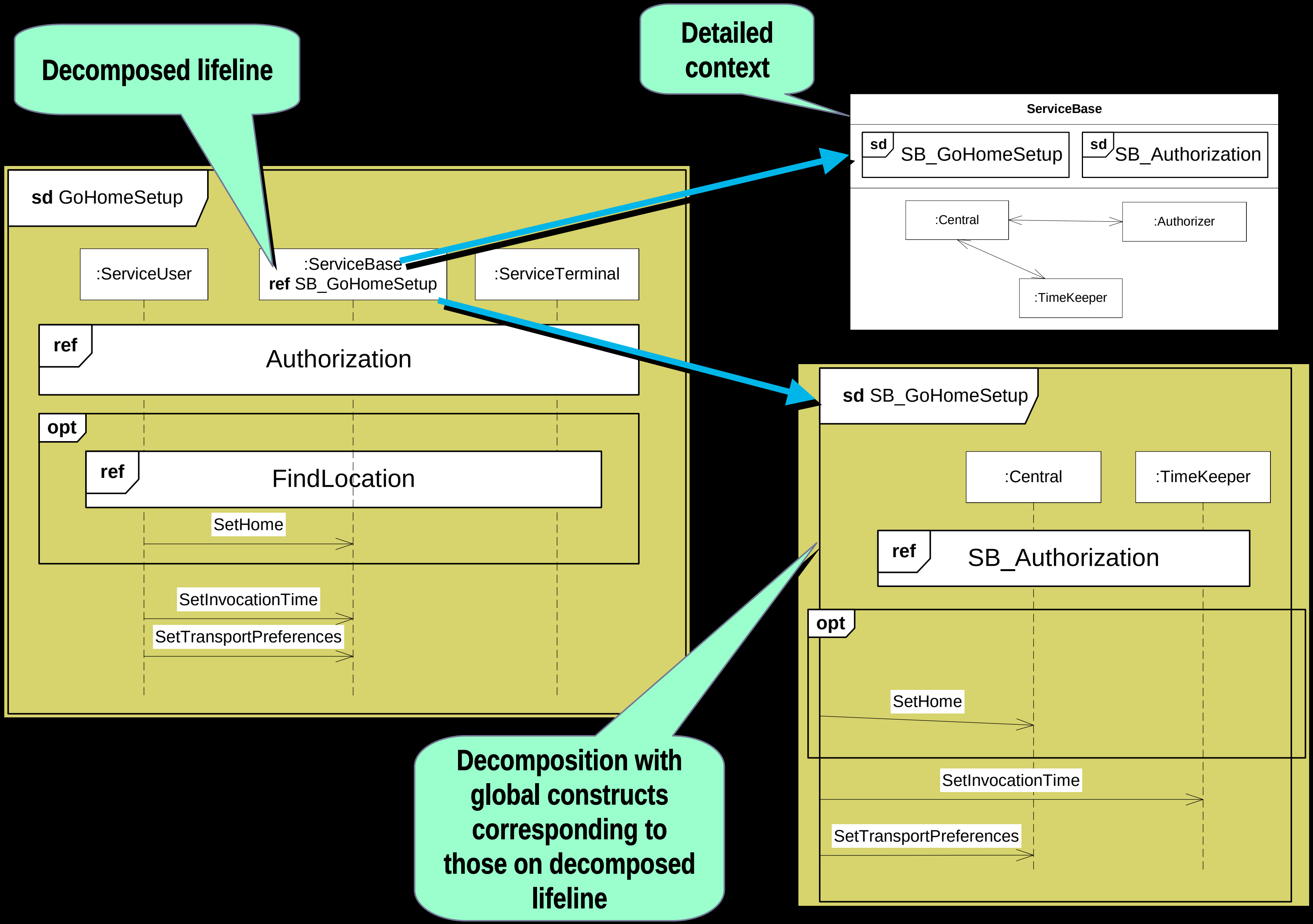
Overview of New Features

- Interactions focus on the communications between collaborating instances communicating via messages
  - Both synchronous (operation invocation) and asynchronous (signal sending) models supported
- Multiple concrete notational forms:
  - sequence diagram (based on ITU Standard Z.120 – MSC-2000)
  - communication diagram
  - interaction overview diagram
  - timing diagram
  - interaction table

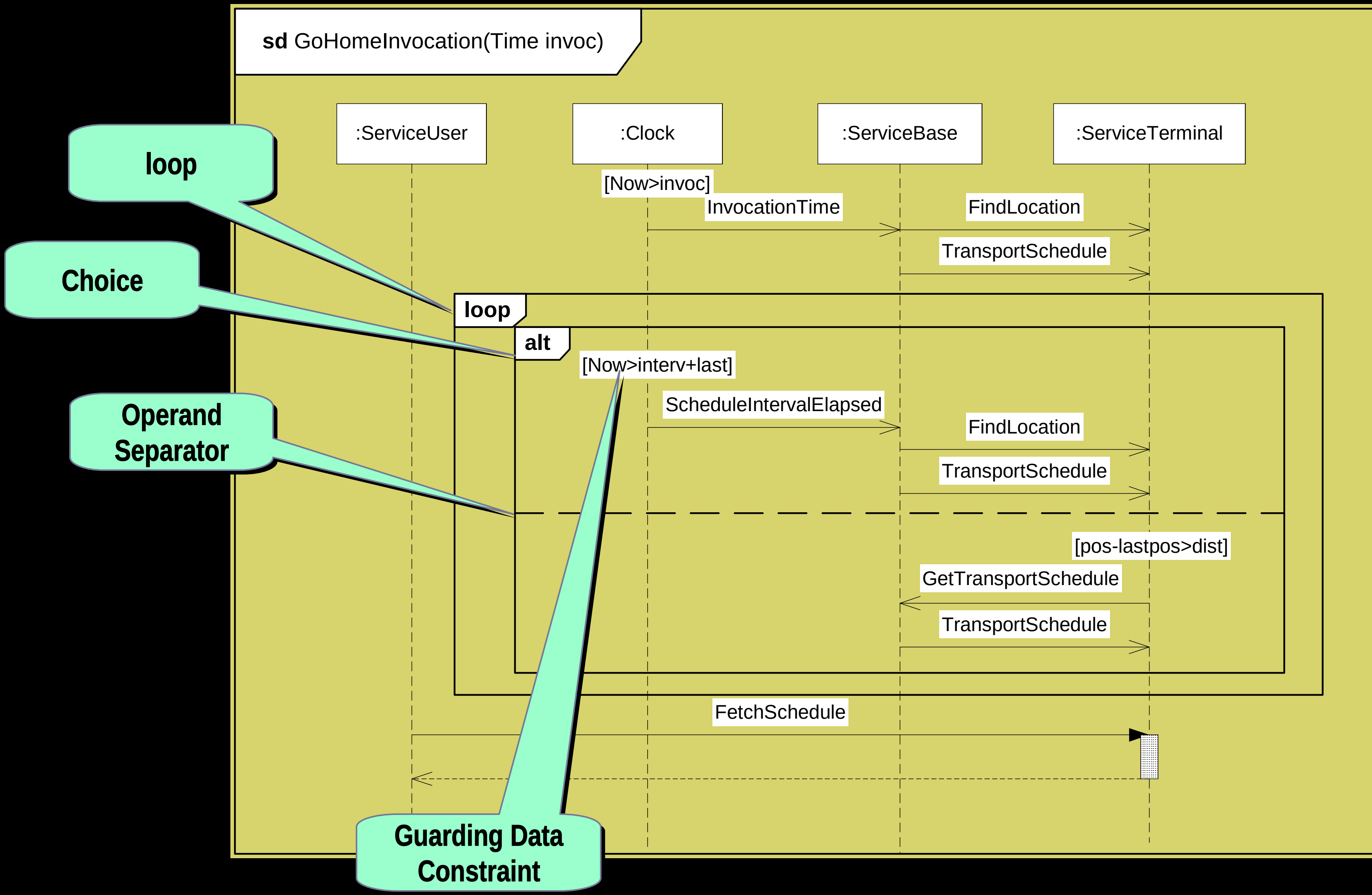
Interaction Diagrams



Structural Decomposition in Sequence Diagrams



Combined Fragments and Data



Combined Fragment Types (1 of 2)

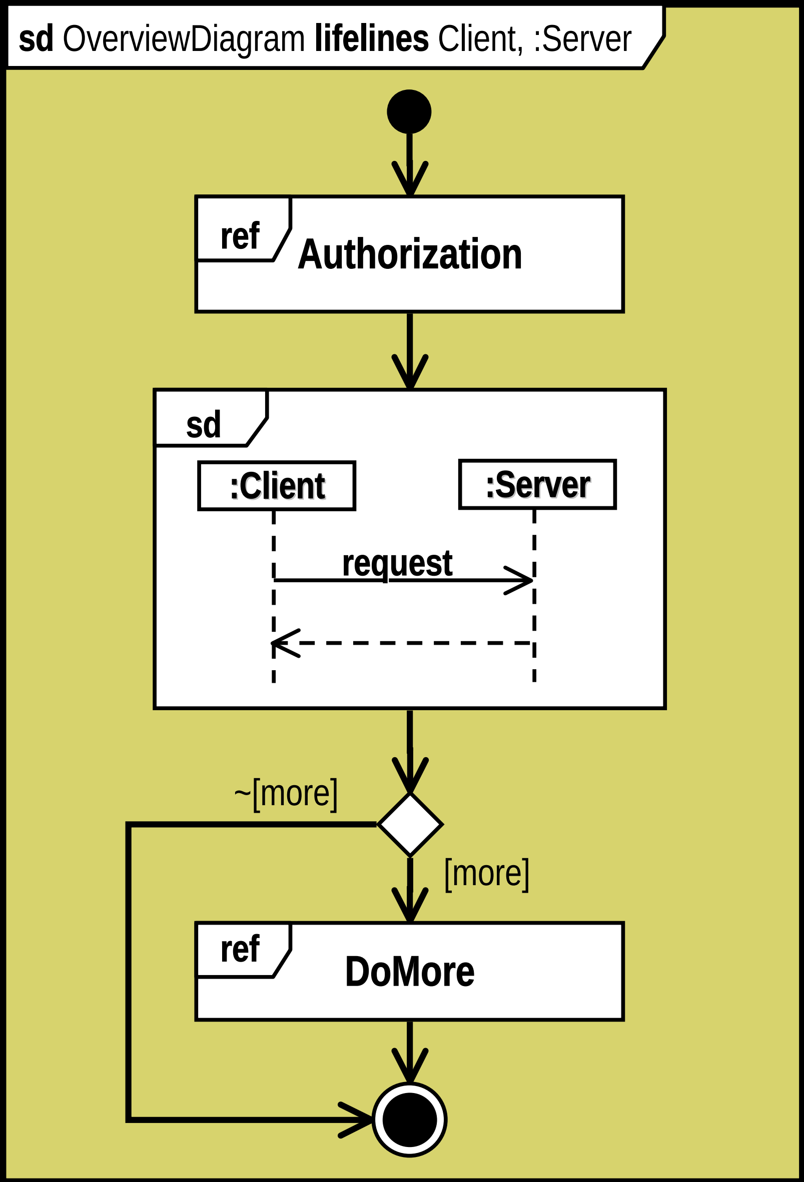
- Alternatives (**alt**)
  - choice of behaviors – at most one will execute
  - depends on the value of the guard ("else" guard supported)
- Option (**opt**)
  - Special case of alternative
- Break (**break**)
  - Represents an alternative that is executed instead of the remainder of the fragment (like a break in a loop)
- Parallel (**par**)
  - Concurrent (interleaved) sub-scenarios
- Negative (**neg**)
  - Identifies sequences that must not occur

Combined Fragment Types (2 of 2)

- Critical Region (**region**)
  - Traces cannot be interleaved with events on any of the participating lifelines
- Assertion (**assert**)
  - Only valid continuation
- Loop (**loop**)
  - Optional guard: [<min>, <max>, <Boolean-expression>]
  - No guard means no specified limit

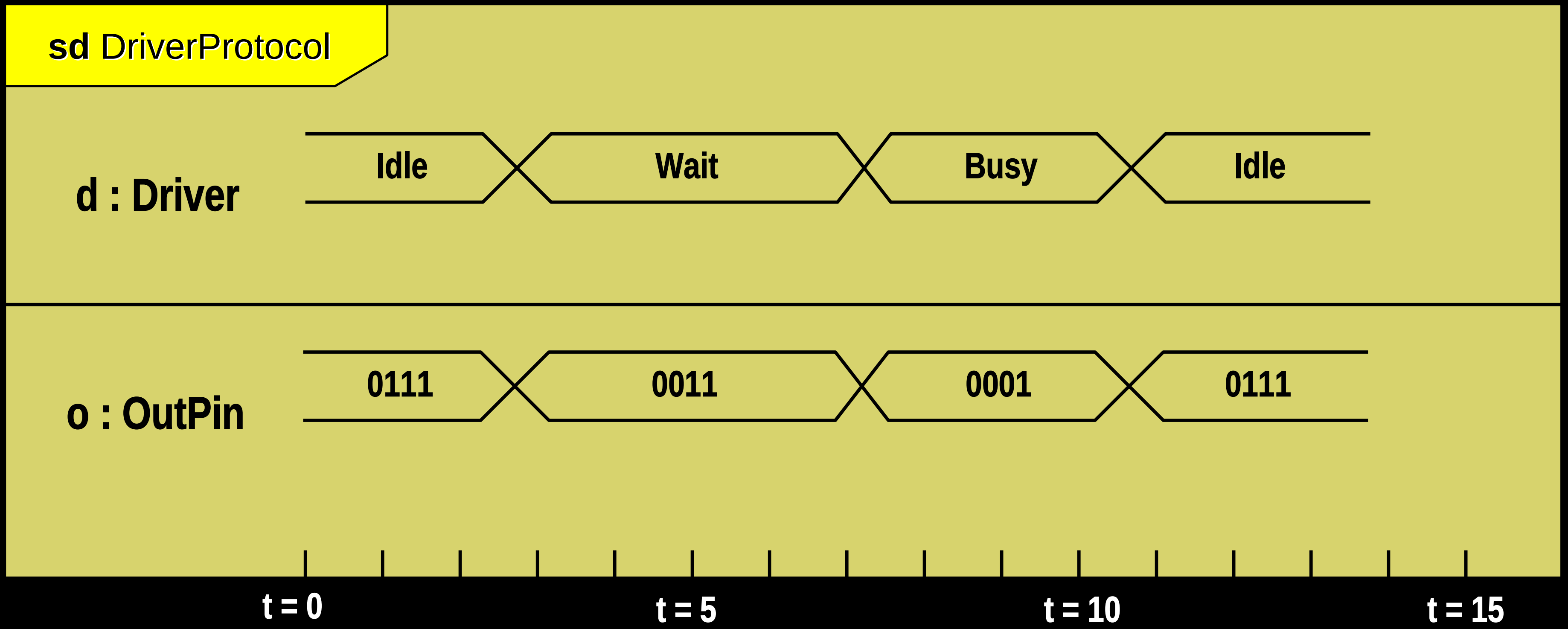
Interaction Overview Diagram

- Like flow charts
  - using activity graph notation for control constructs

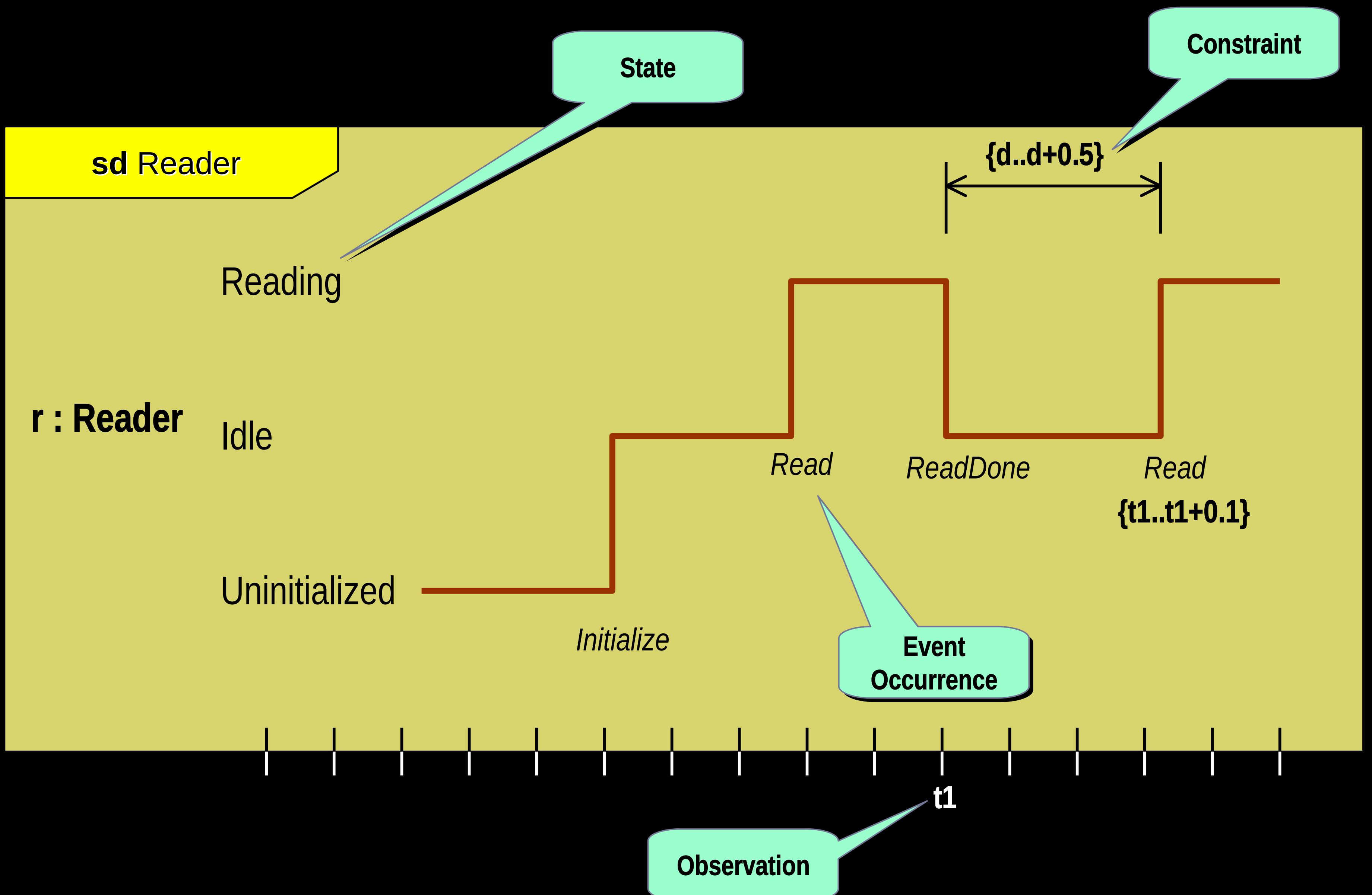


Timing Diagrams

- Can be used to specify time-dependent interactions
  - Based on a simplified model of time (use standard “real-time” profile for more complex models of time)

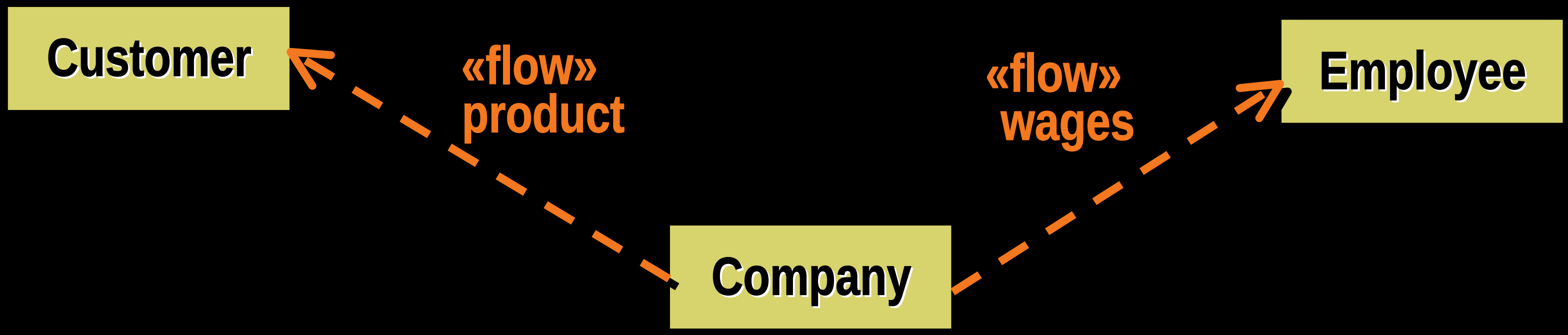


Timing Diagrams (cont.)



Sidebar: Information Flows

- For specifying kinds of information that are exchanged between elements of the system – *at a very abstract level*
  - Do not specify details of the information (e.g., type)
  - Do not specify how the information is relayed
  - Do not specify the relative ordering of information flows



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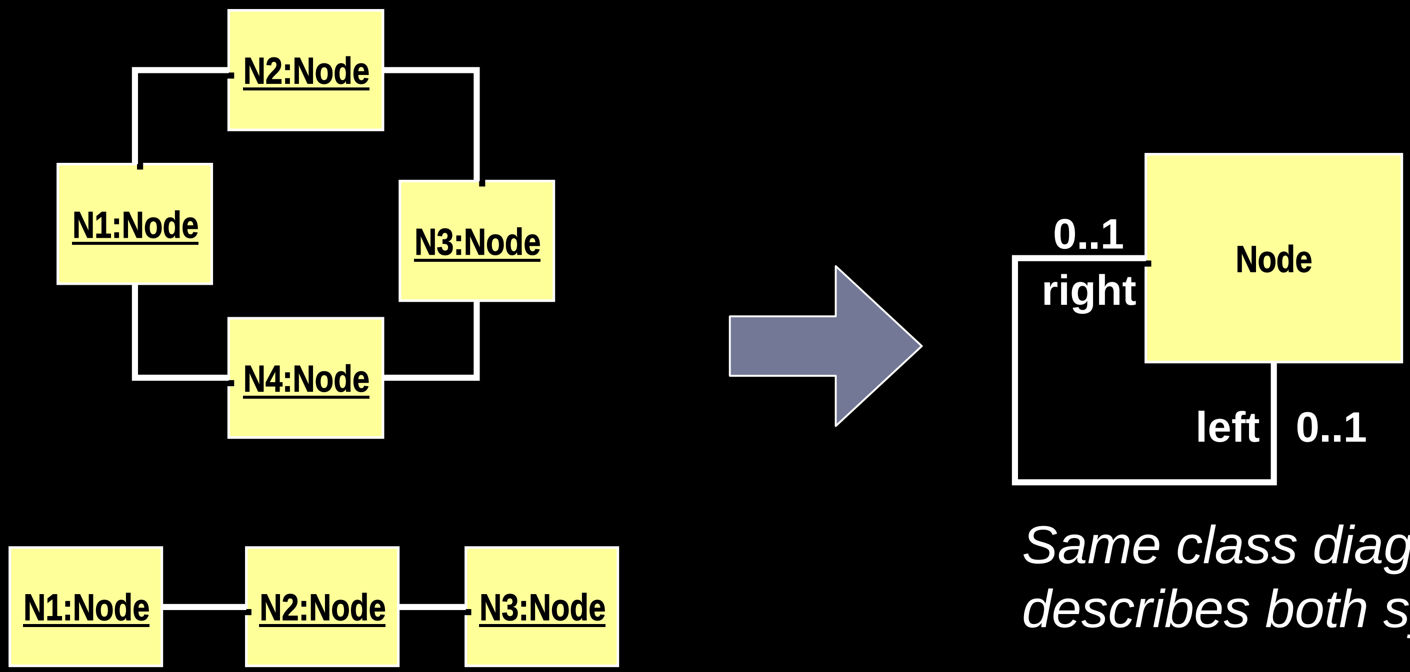
Aren't Class Diagrams Sufficient?

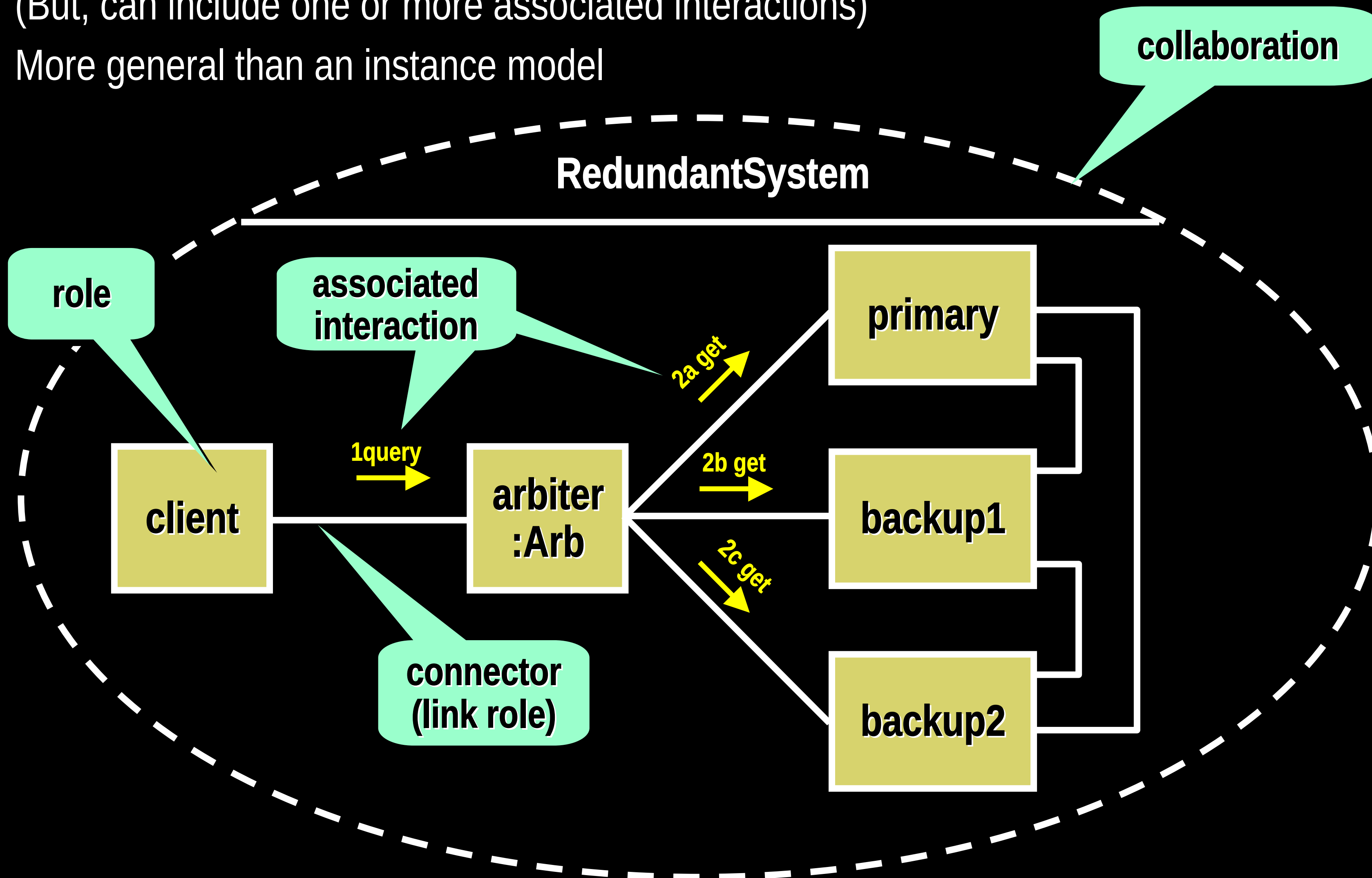
- No!
  - Because they abstract out certain specifics, class diagrams are not suitable for performance analysis
- Need to model structure at the instance level



Same class diagram describes both systems!

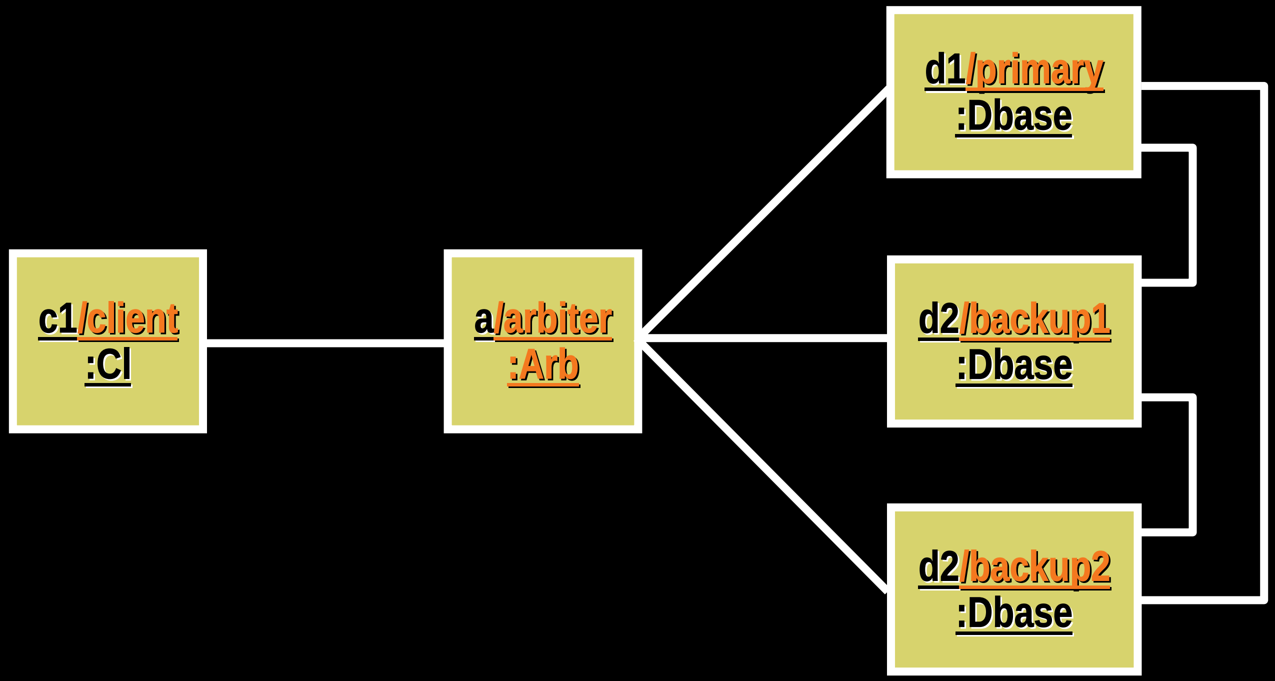
Collaborations

- In UML 2.0 a collaboration is a *purely structural concept*
  - (But, can include one or more associated interactions)
  - More general than an instance model

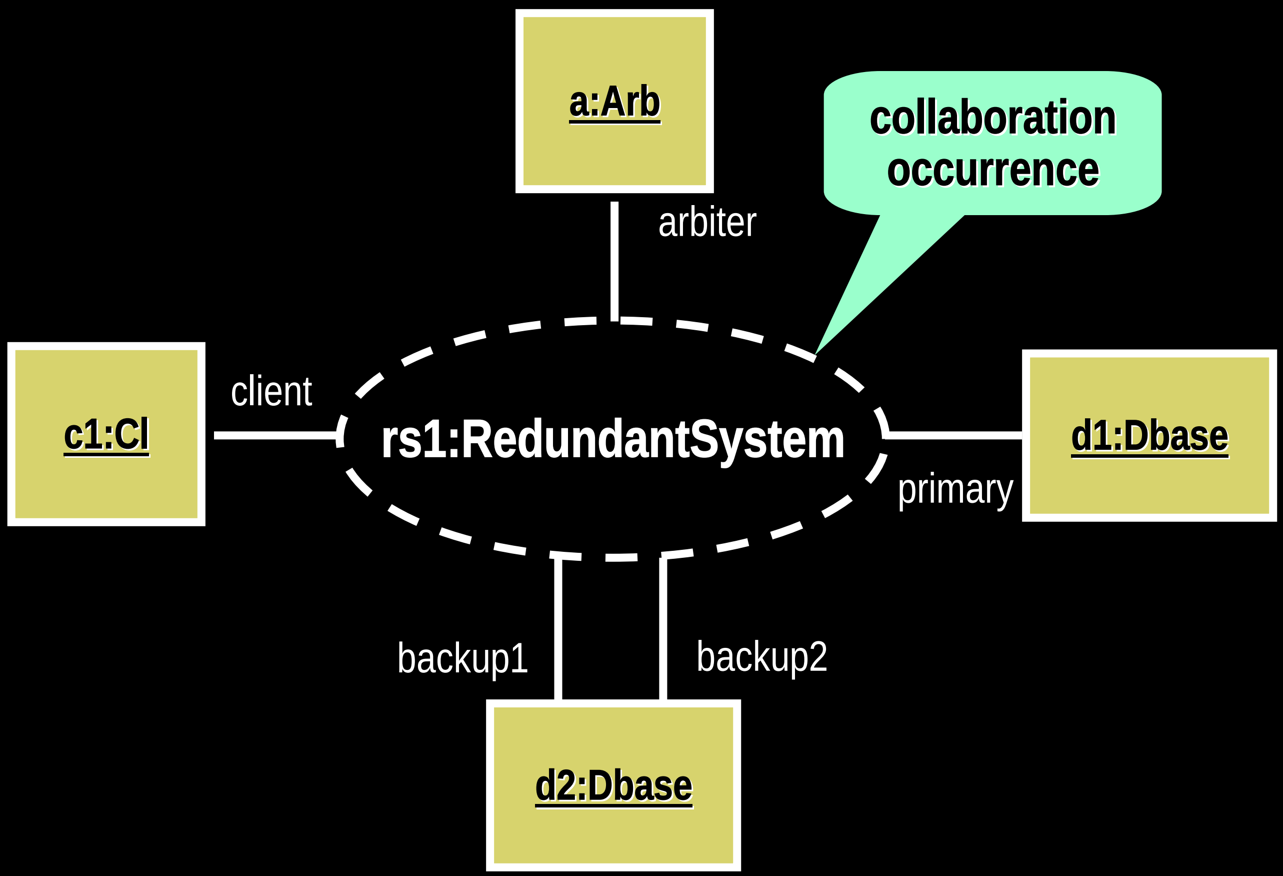


Roles and Instances

- Specific object instances playing specific the roles in a collaboration

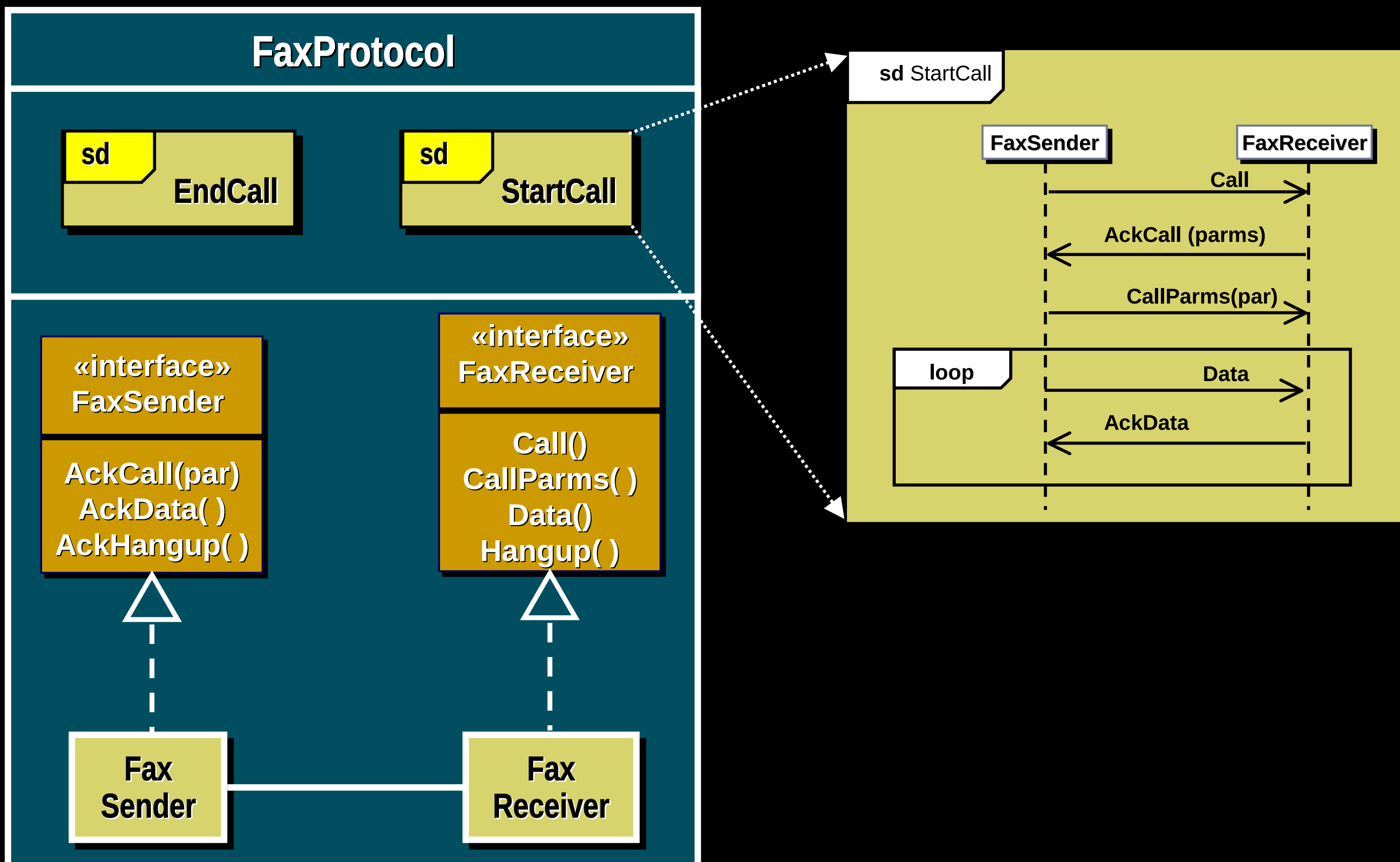


Alternative Notation



Collaboration Protocols

- For dynamic relationships between interfaces

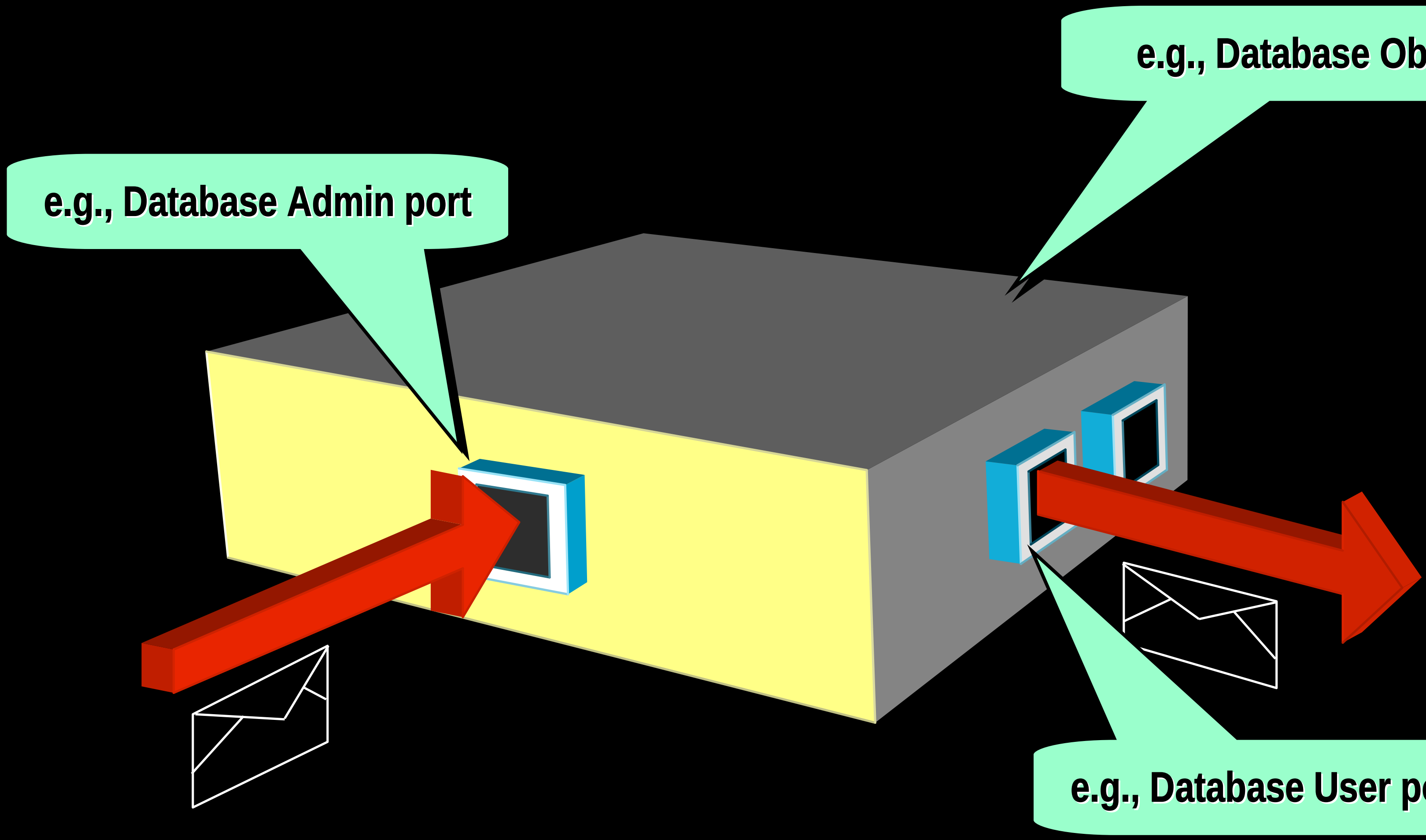


Structured Classes

- Classes with
  - Internal (collaboration) structure
  - Ports (optional)
- Primarily intended for architectural modeling
- Heritage: architectural description languages (ADLs)
  - UML-RT profile: Selic and Rumbaugh (1998)
  - ACME: Garlan et al.
  - SDL (ITU-T standard Z.100)

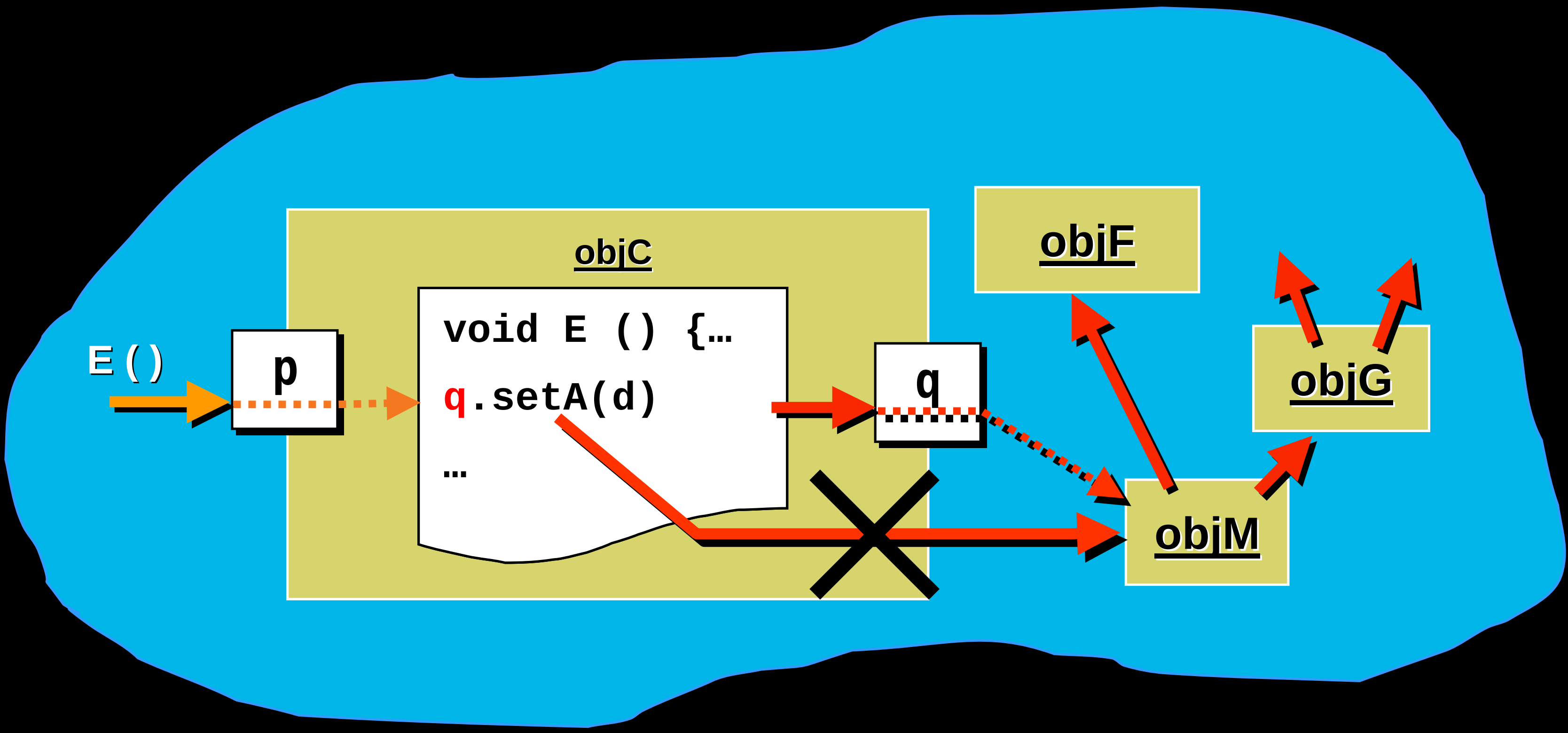
Structured Objects: Ports

- Multiple points of interaction
  - Each dedicated to a particular purpose



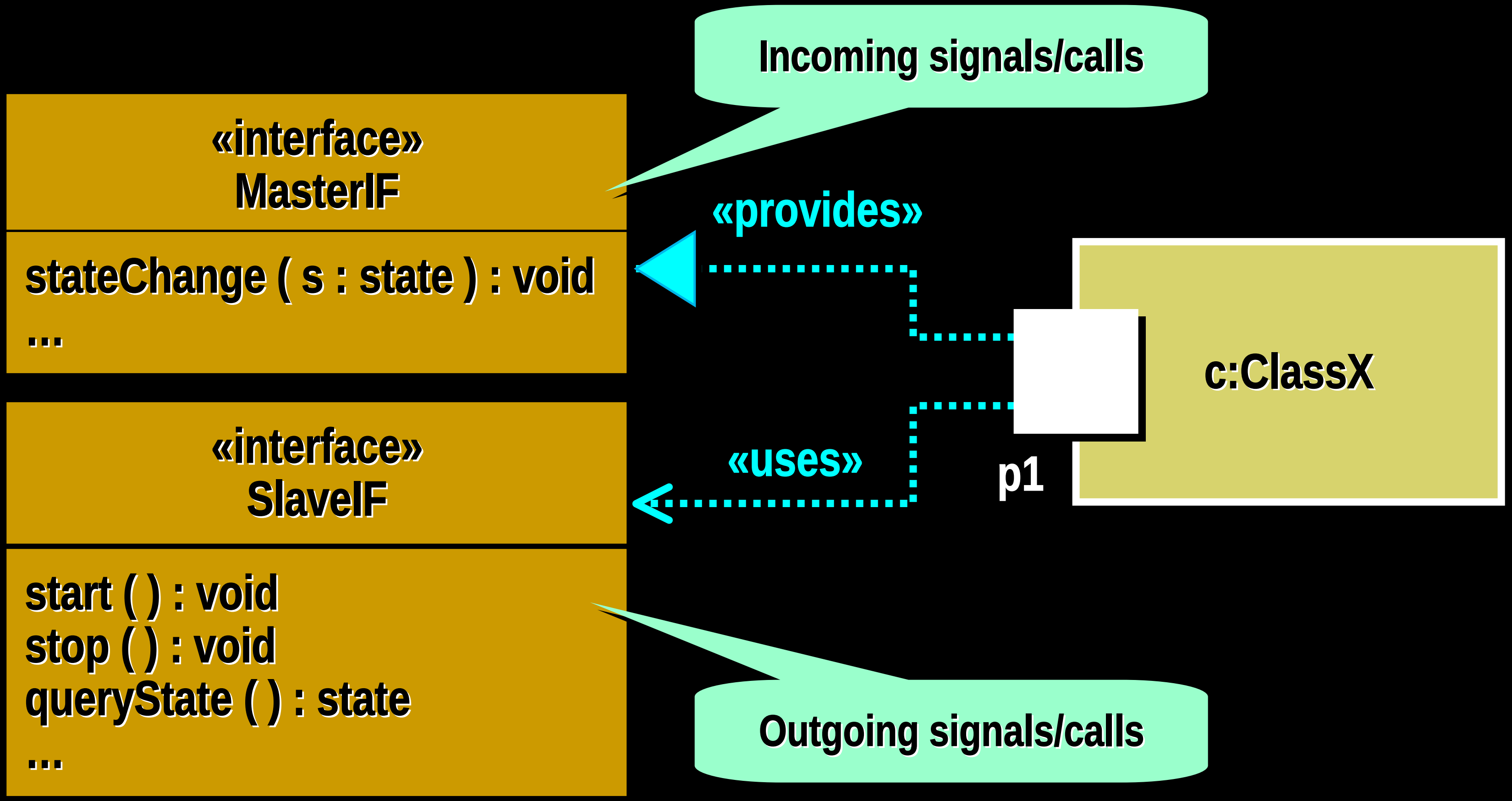
New Feature: Ports

- Used to distinguish between multiple collaborators
  - Based on port through which interaction is occurring
- Fully isolate an object's internals from its environment



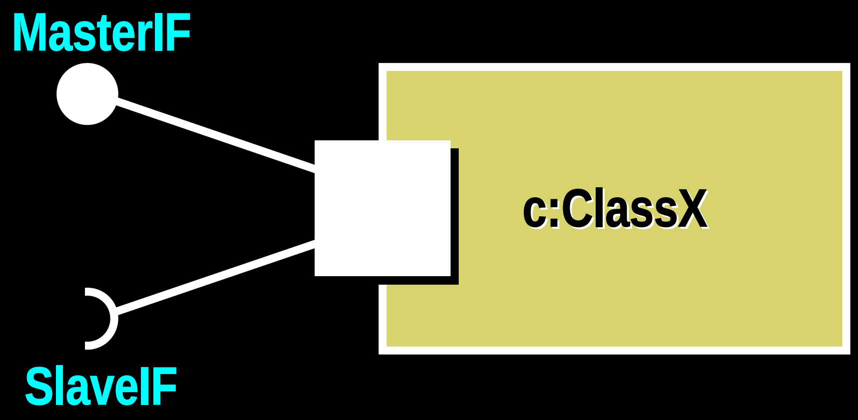
Port Semantics

- A port can support multiple interface specifications
  - Provided interfaces (what the object can do)
  - Required interfaces (what the object needs to do its job)



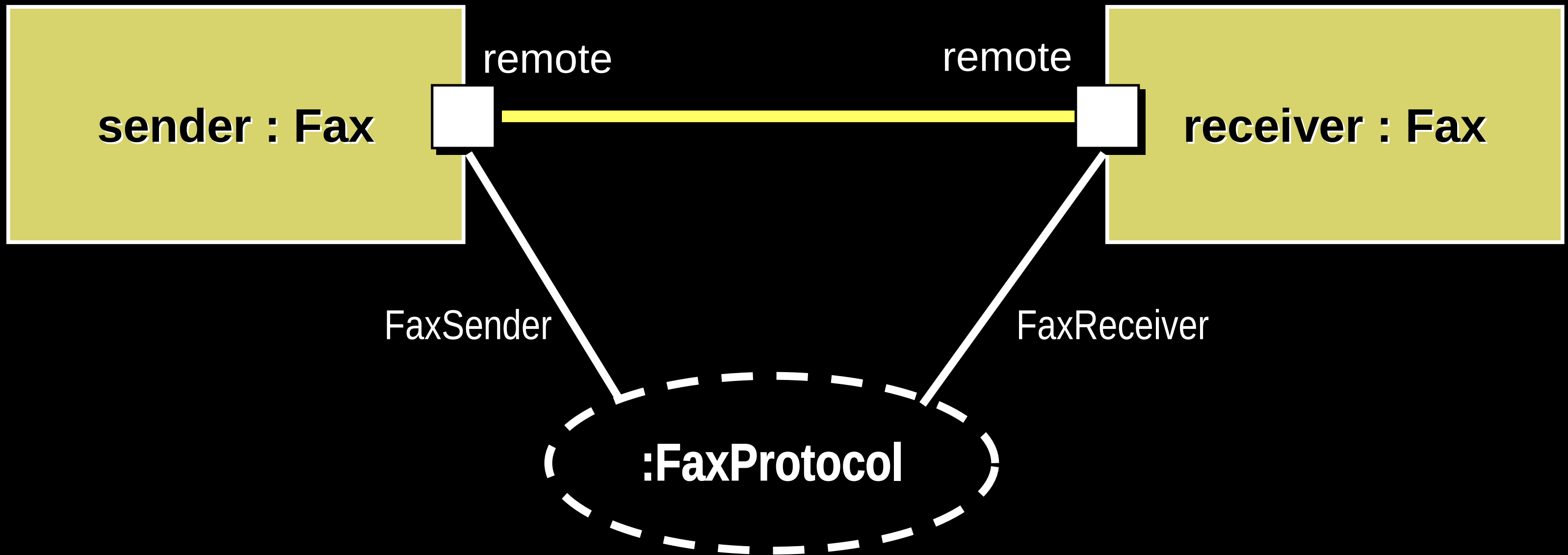
Ports: Alternative Notation

- Shorthand "lollipop" notation with 1.x backward compatibility



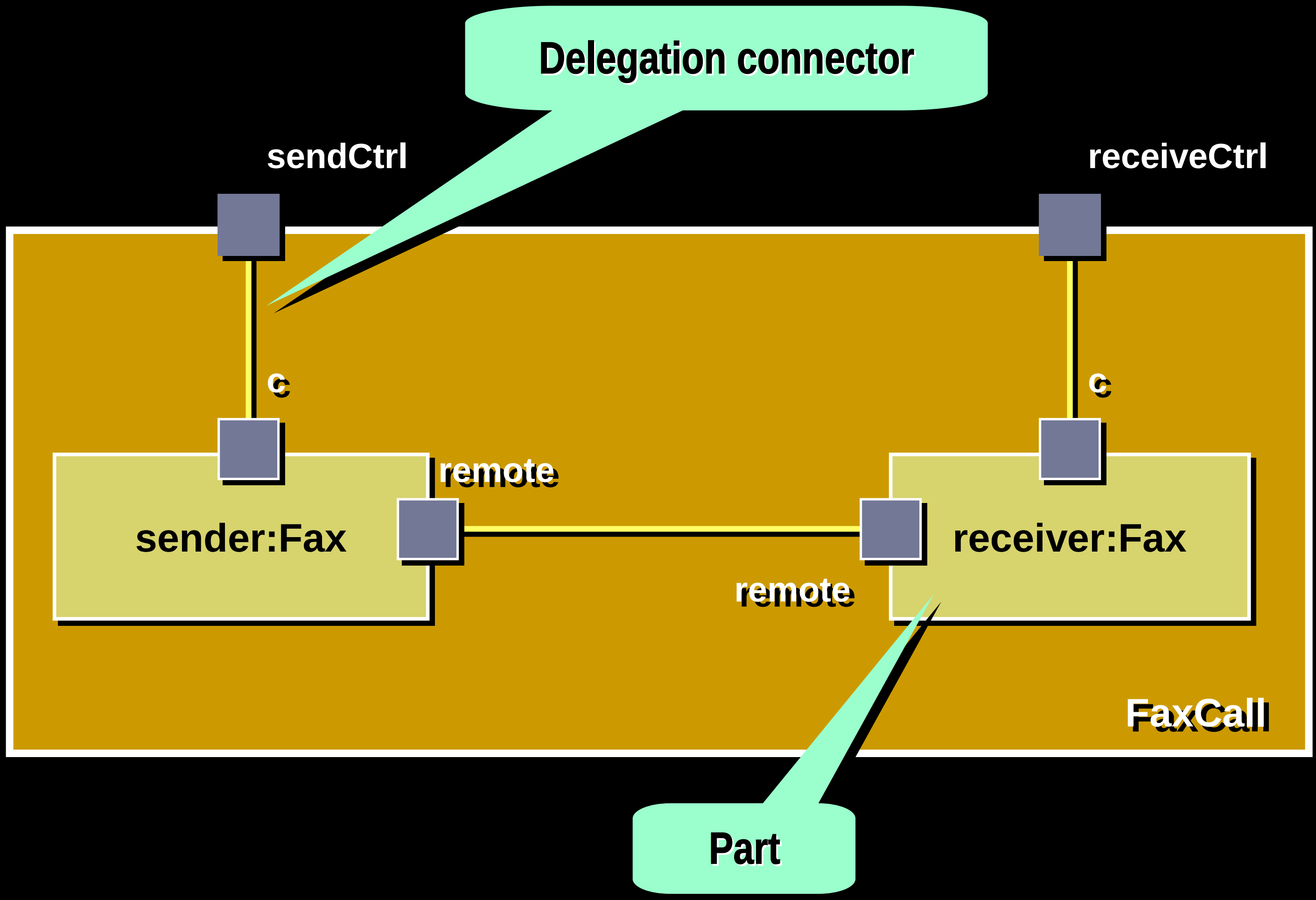
Assembling Structured Objects

- Ports can be joined by connectors
- These connections can be constrained to a protocol
  - Static checks for dynamic type violations are possible
  - Eliminates "integration" (architectural) errors



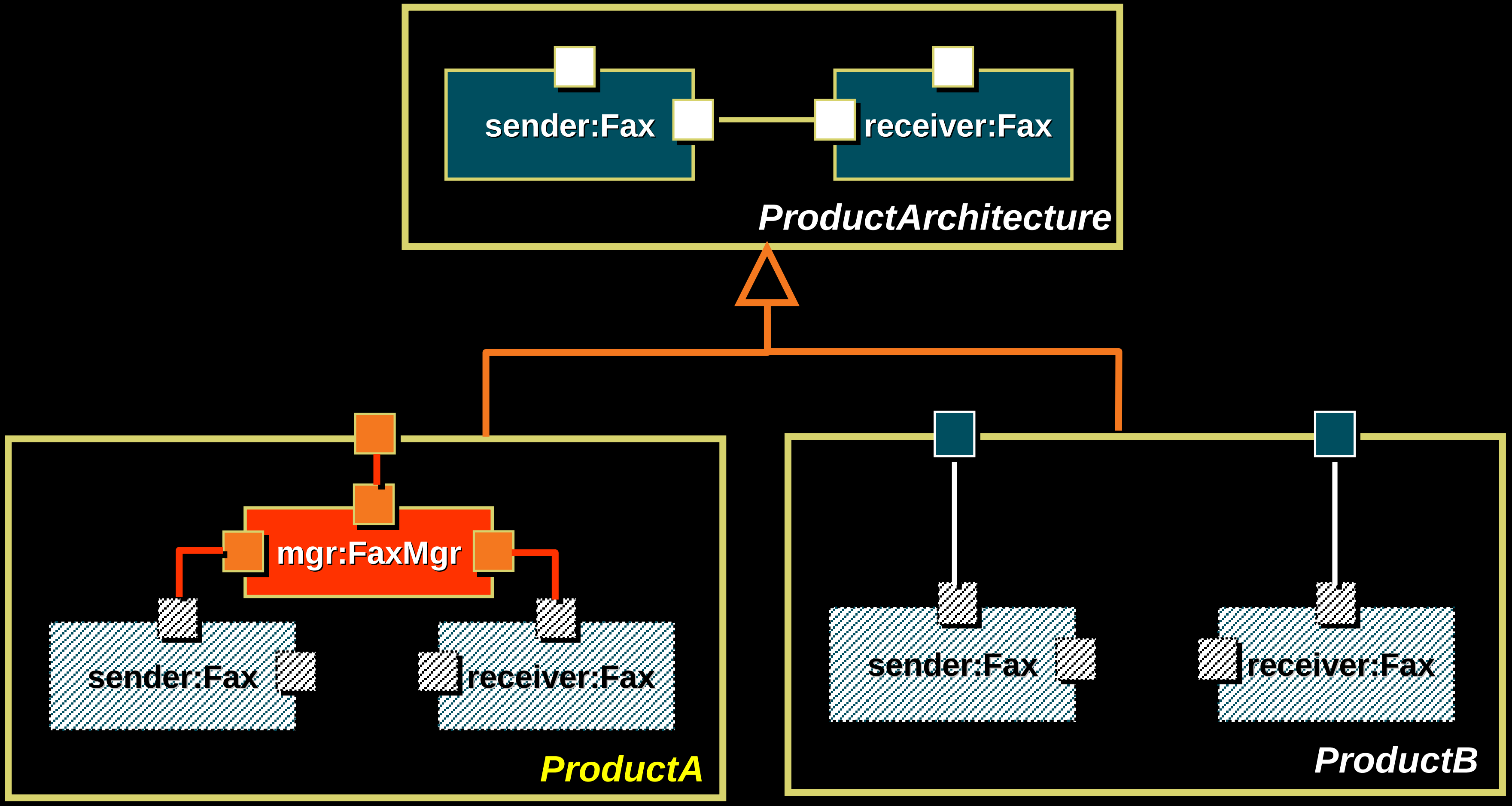
Structured Classes: Internal Structure

- Structured classes may have an internal structure of (structured class) parts and connectors



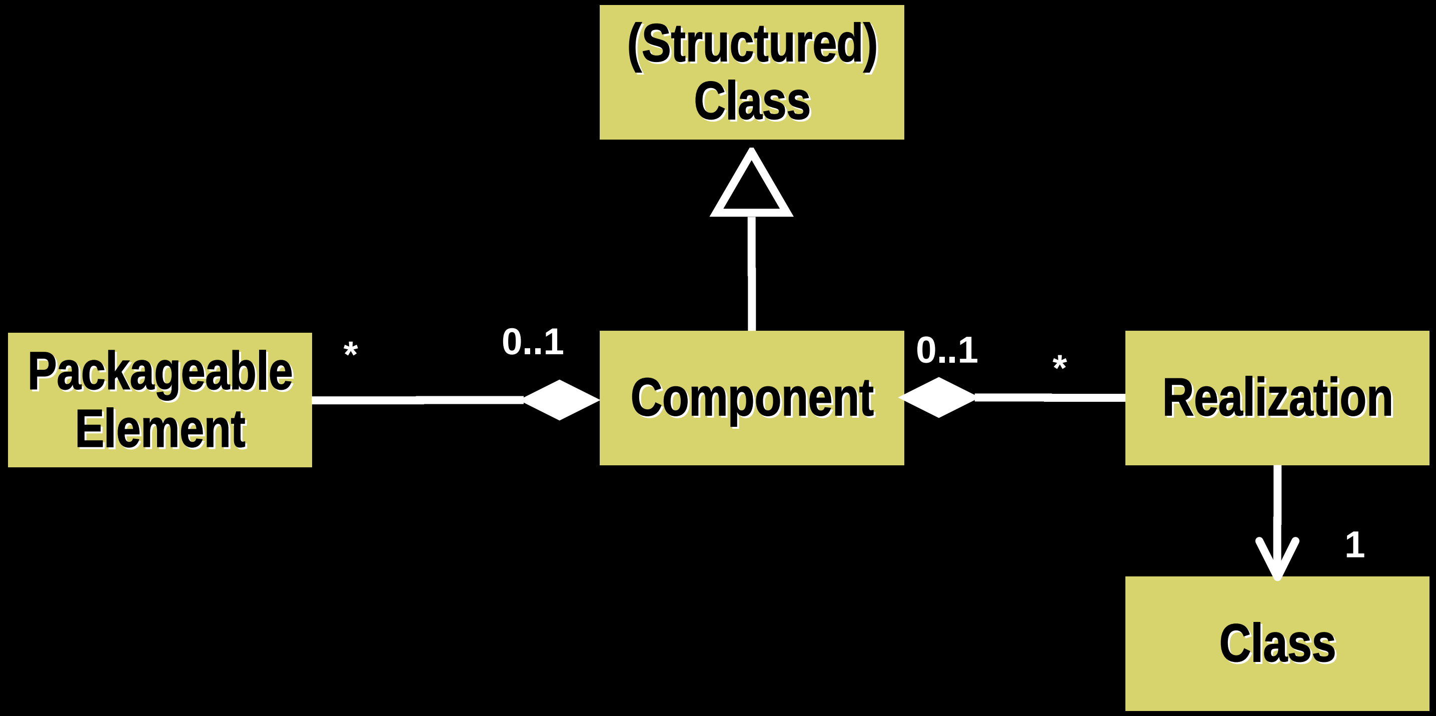
Structure Refinement Through Inheritance

- Using standard inheritance mechanism (design by difference)



Components

- A kind of structured class whose specification
  - May be realized by one or more implementation classes
  - May include any other kind of packageable element (e.g., various kinds of classifiers, constraints, packages, etc.)



Subsystems

- A system stereotype of Component («subsystem») such that it may have explicit and distinct specification («specification») and realization («realization») elements
  - Ambiguity of being a subclass of Classifier and Package has been removed (was intended to be mutually exclusive kind of inheritance)
  - Component (specifications) can contain any packageable element and, hence, act like packages

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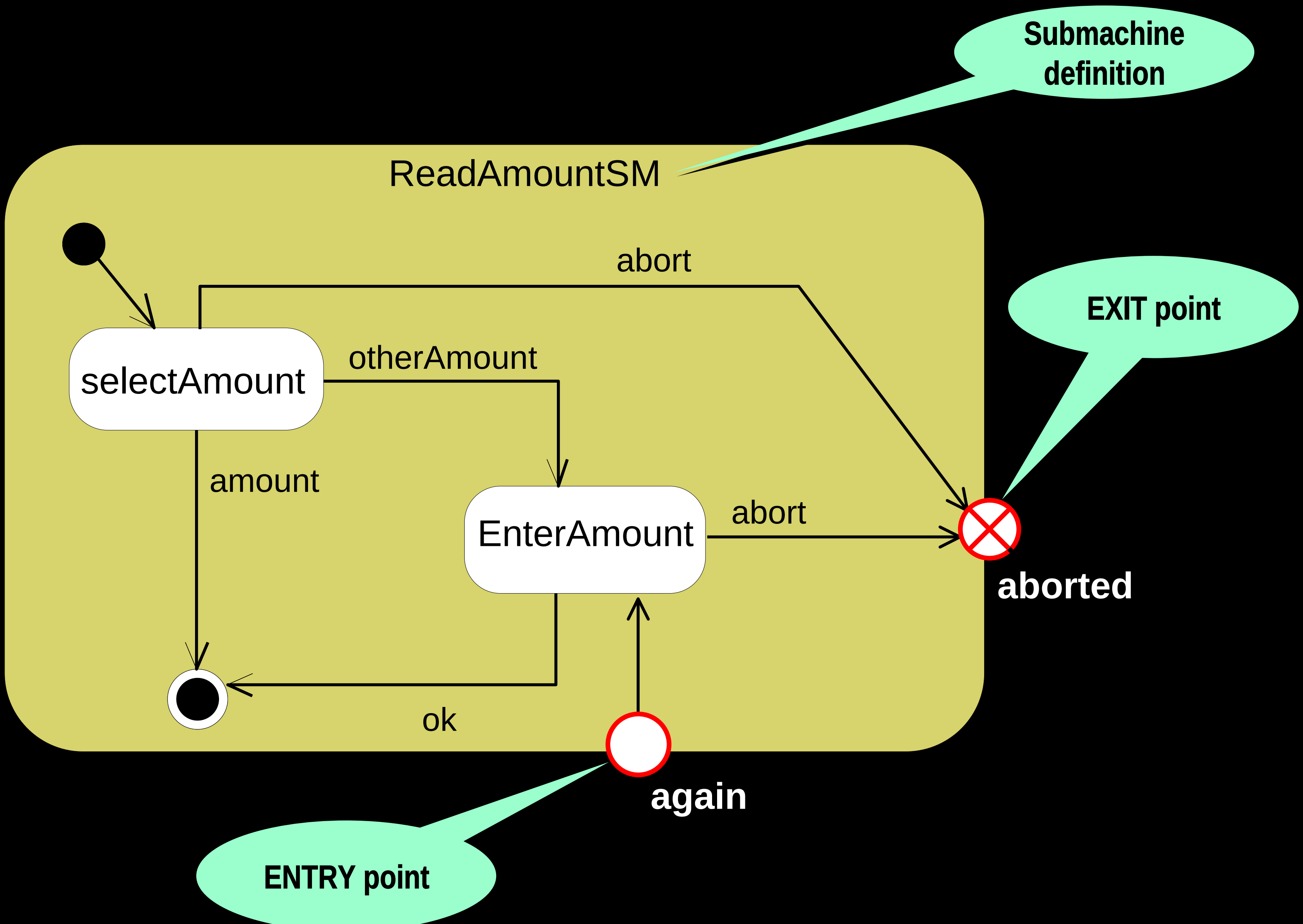
- Templates
- Summary

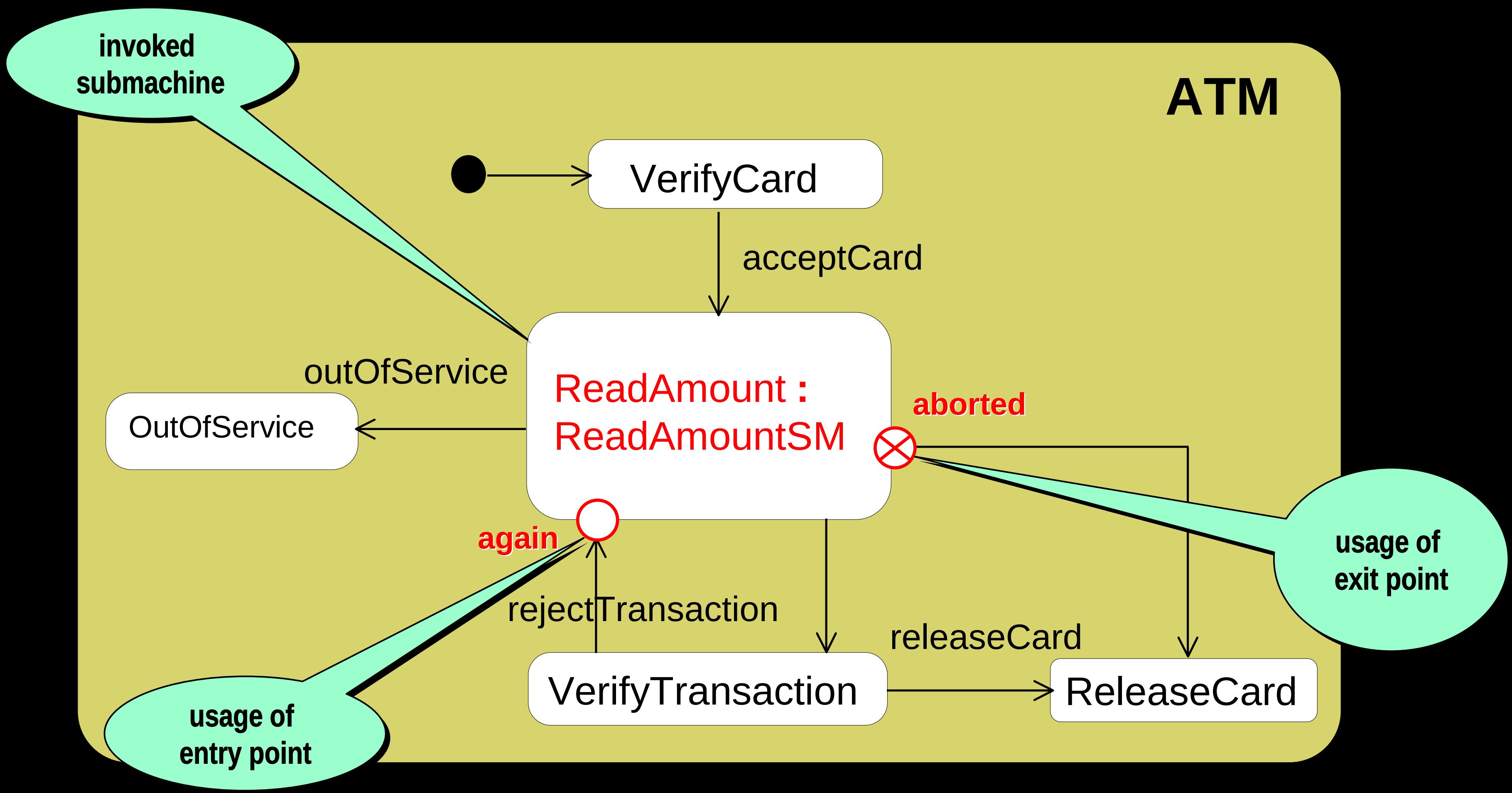
State Machine Improvements

- New modeling constructs:
  - Modularized submachines
  - State machine specialization/redefinition
  - State machine termination
  - “Protocol” state machines
    - transitions pre/post conditions
    - protocol conformance
- Notational enhancements
  - action blocks
  - state lists

Modular Submachines: Definition

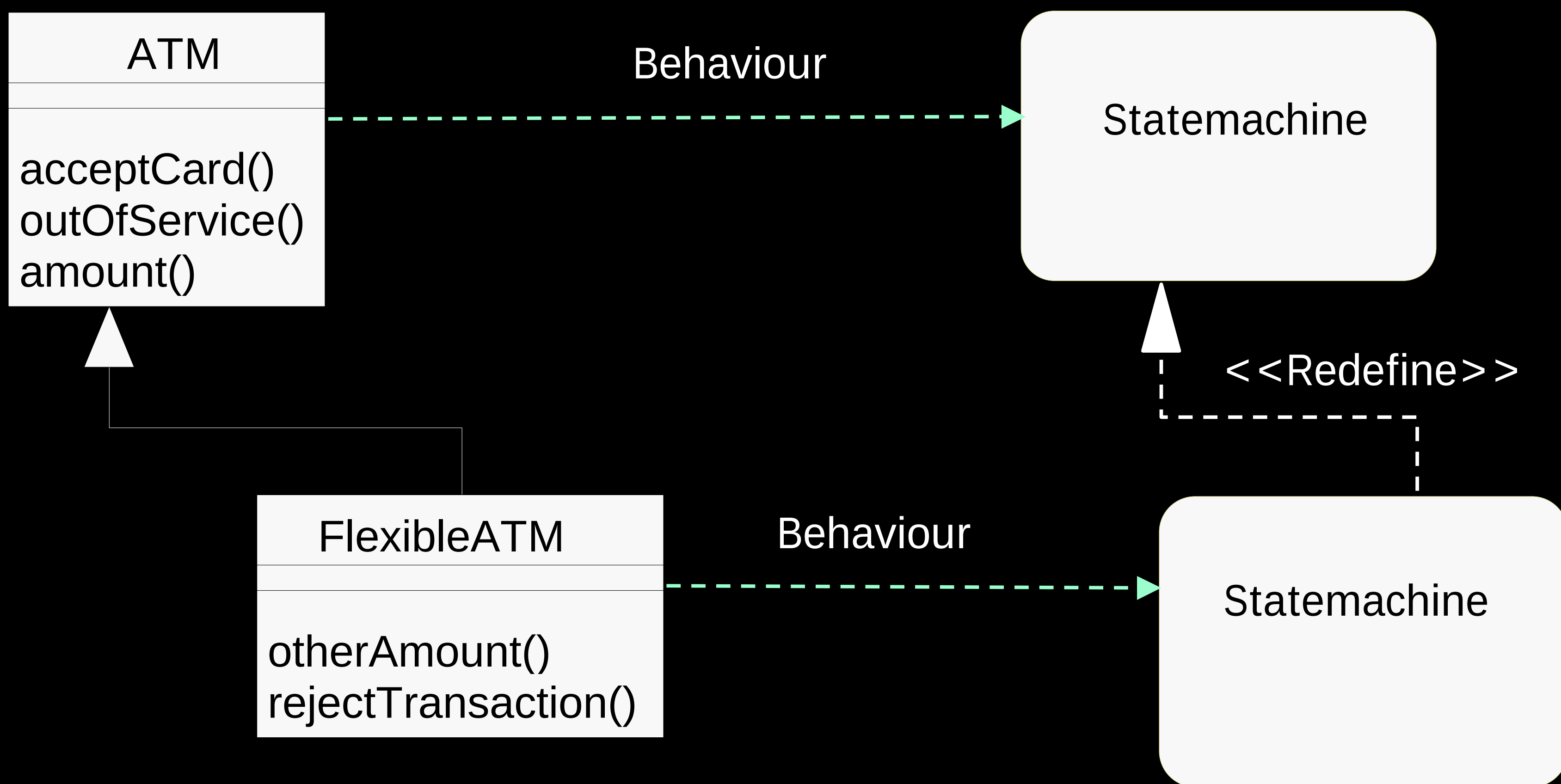


Modular Submachines: Usage



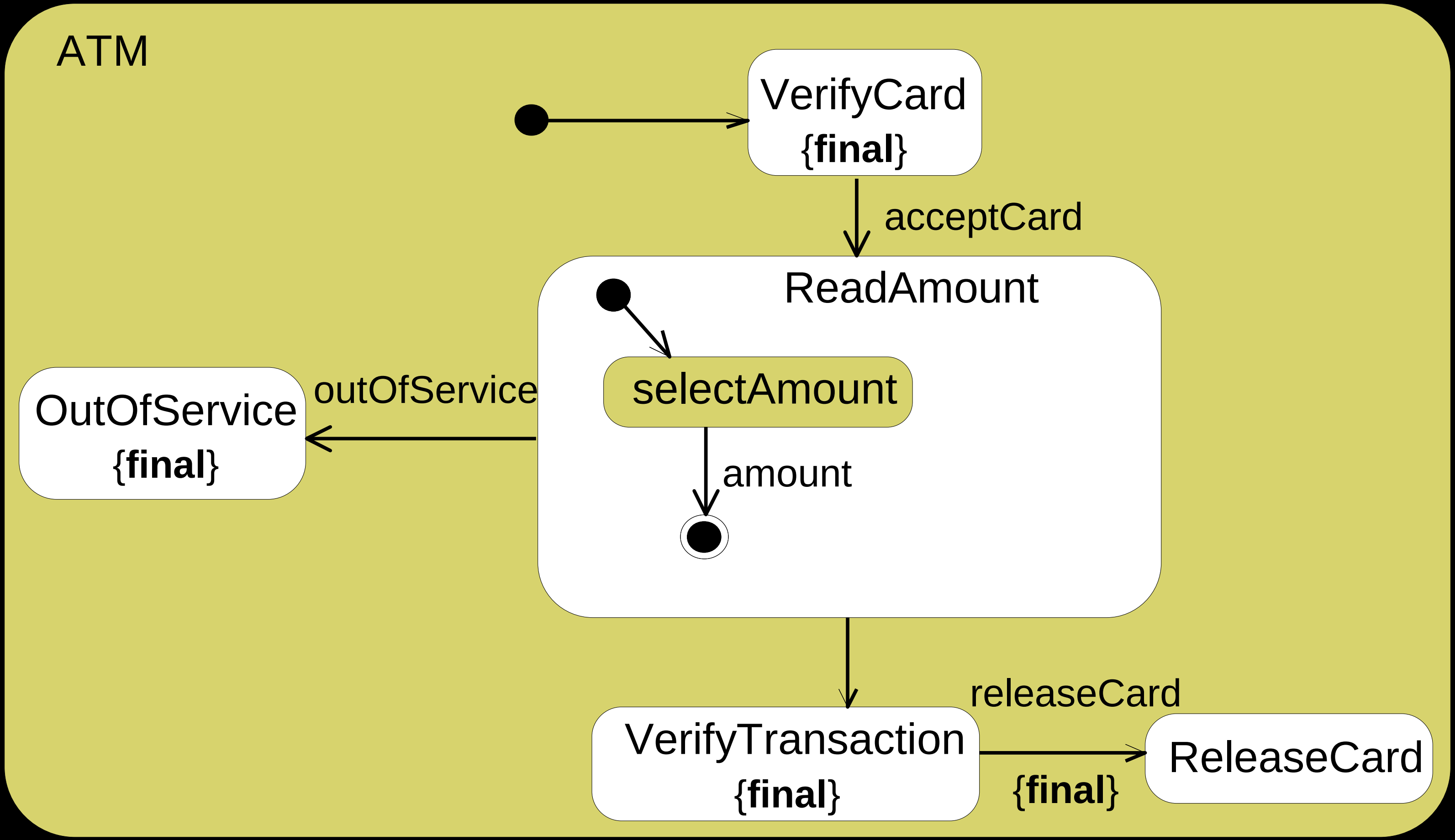
Specialization

- Redefinition as part of standard class specialization

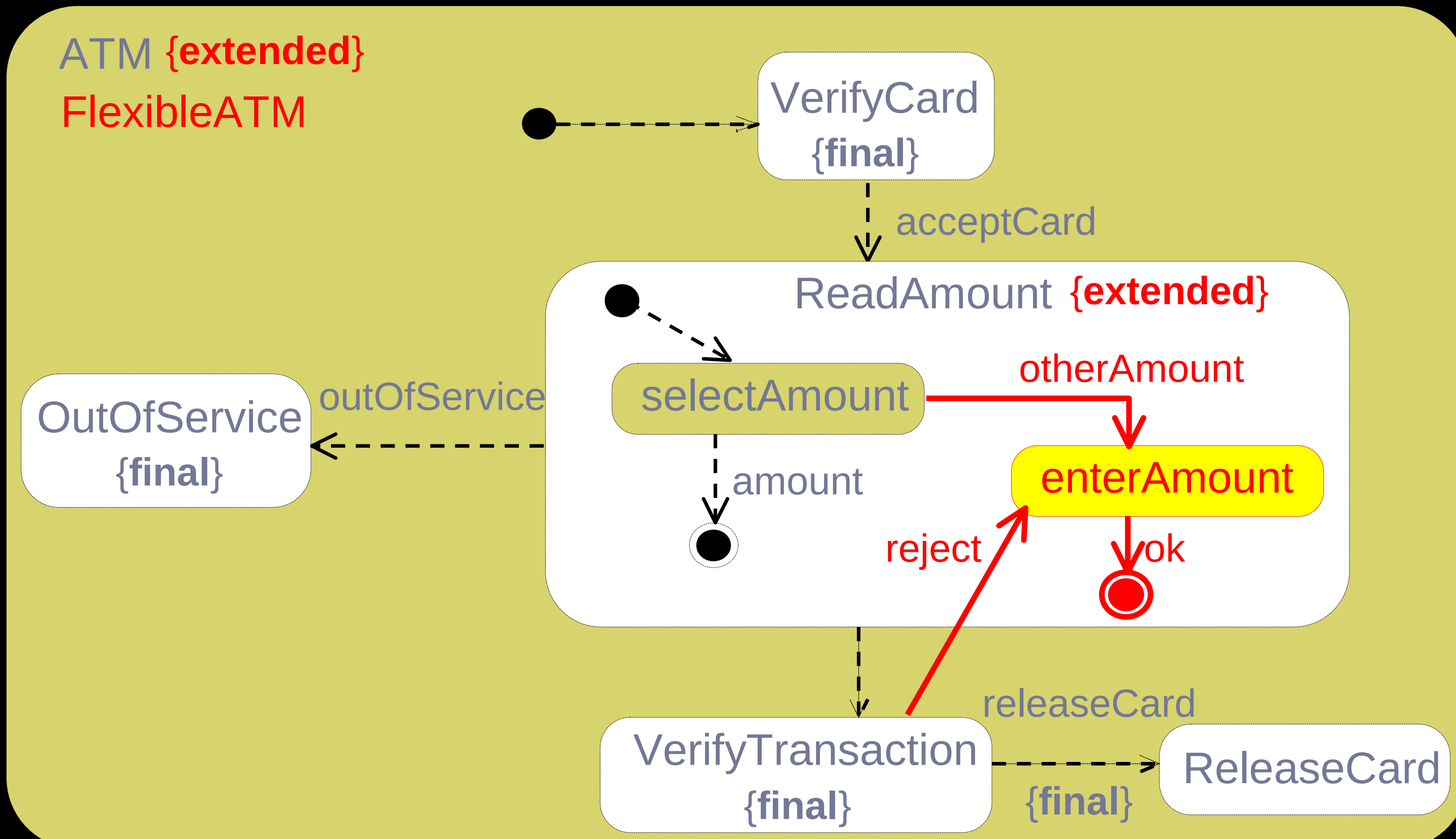


Example: State Machine Redefinition

- State machine of ATM to be redefined

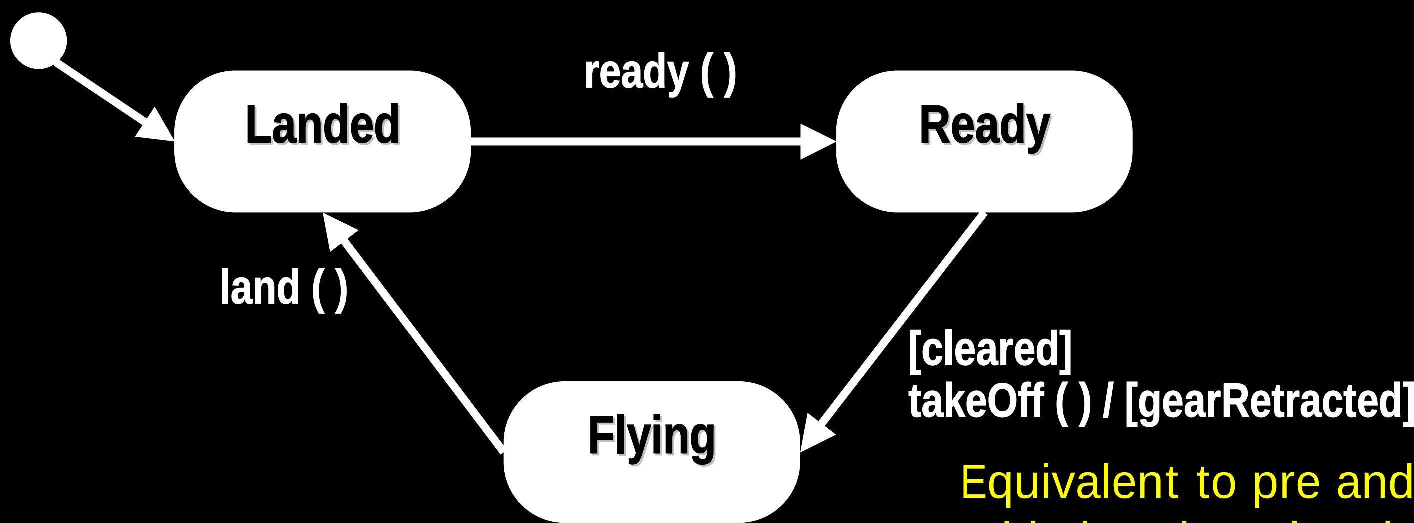


State Machine Redefinition



Protocol State Machines

- Impose sequencing constraints on interfaces
  - (should not be confused with multi-party protocols)



Equivalent to pre and post conditions added to the related operations:

takeOff()

Pre

-in state ”Ready"

-cleared for take off

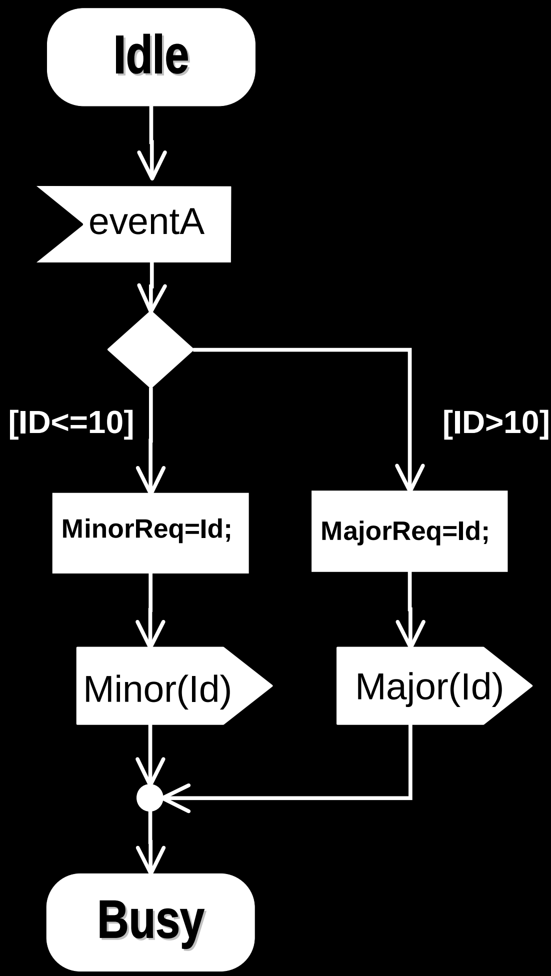
Post

-landing gear is retracted

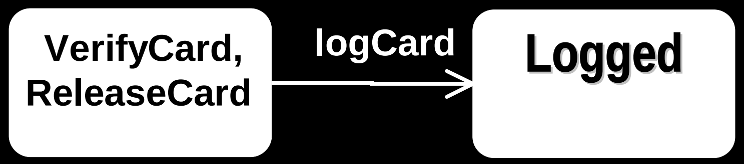
-in state ”Flying"

Notational Enhancements

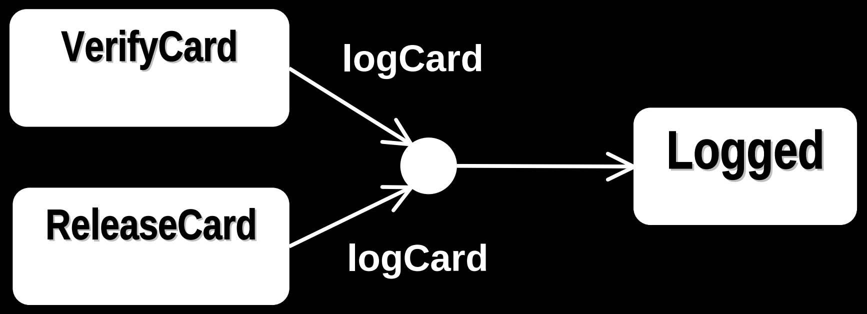
- Alternative transition notation



- State lists



Is a notational shorthand for



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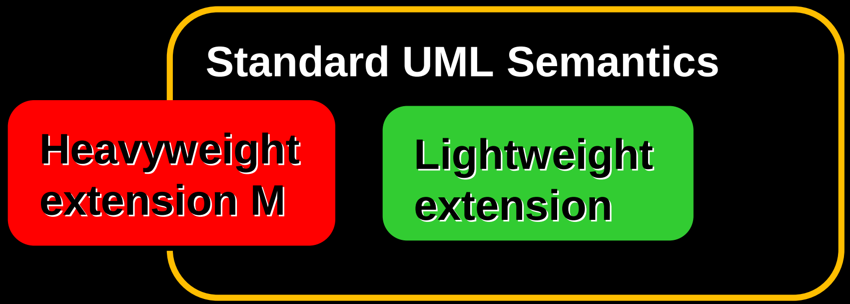
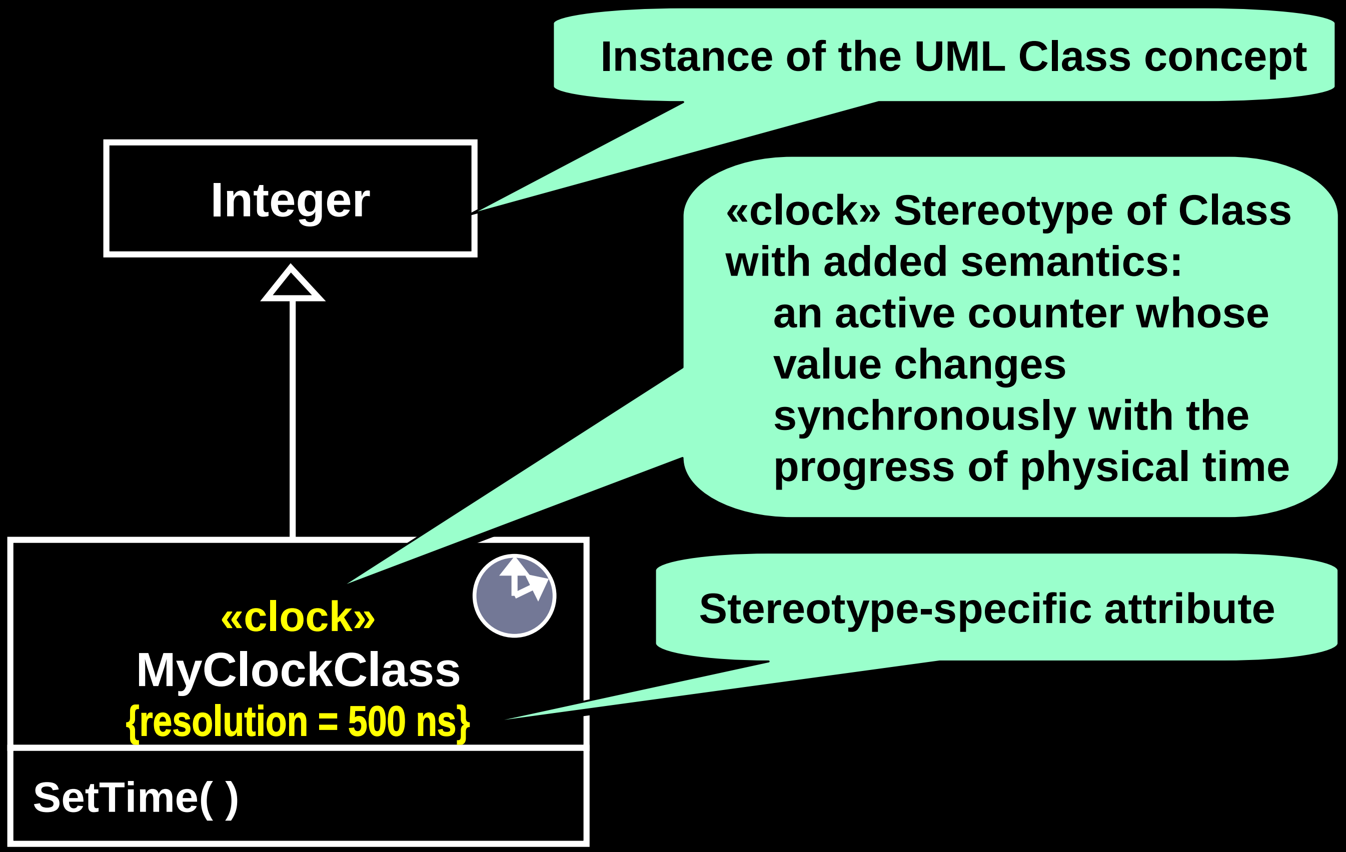
Specializing UML

- *Lightweight extensions*
  - Extend semantics of existing UML concepts by specialization
  - Conform to standard UML (tool compatibility)
  - Profiles, stereotypes
- *Heavyweight (MOF) extensions*
  - Add new non-conformant concepts or
  - Incompatible change to existing UML semantics/concepts



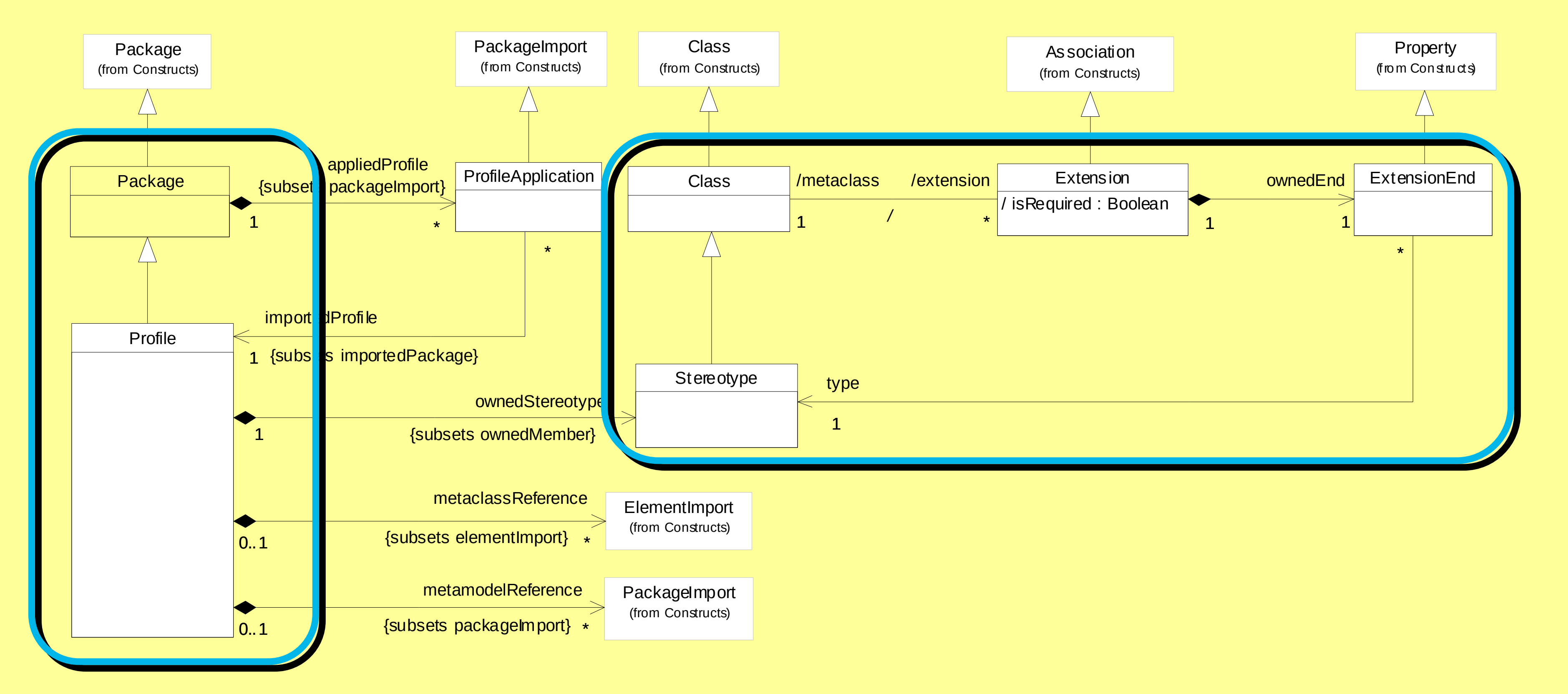
Stereotyping versus Inheritance

- For semantics not expressible through standard UML mechanisms
- Stereotypes can be standardized (application independent)



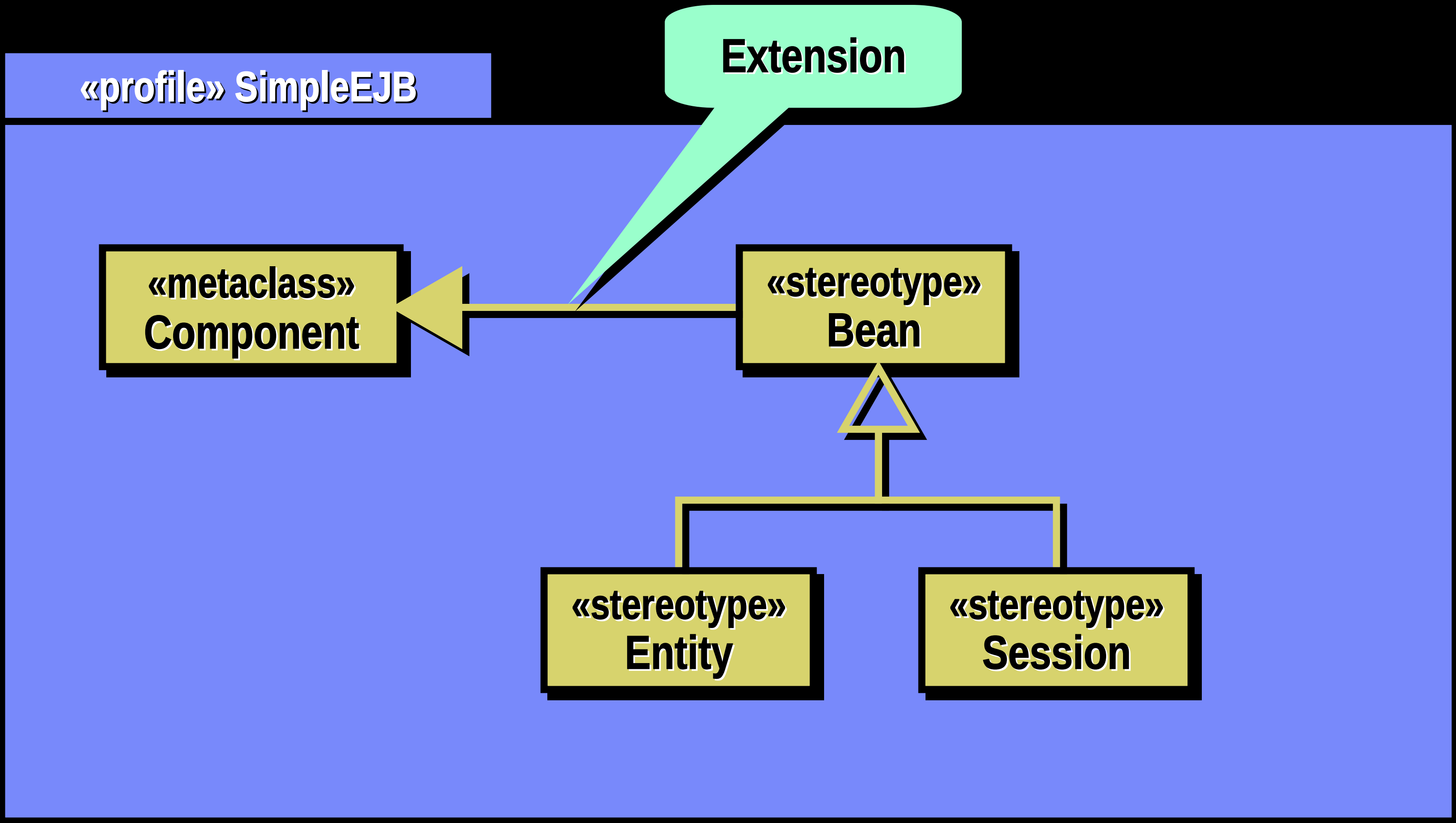
Profiles: Metamodel

- Semantically equivalent to 1.x from a user's perspective
  - But, new notation introduced
  - Extension concept: a form of "specialization" of metaclasses



Profiles: Notation

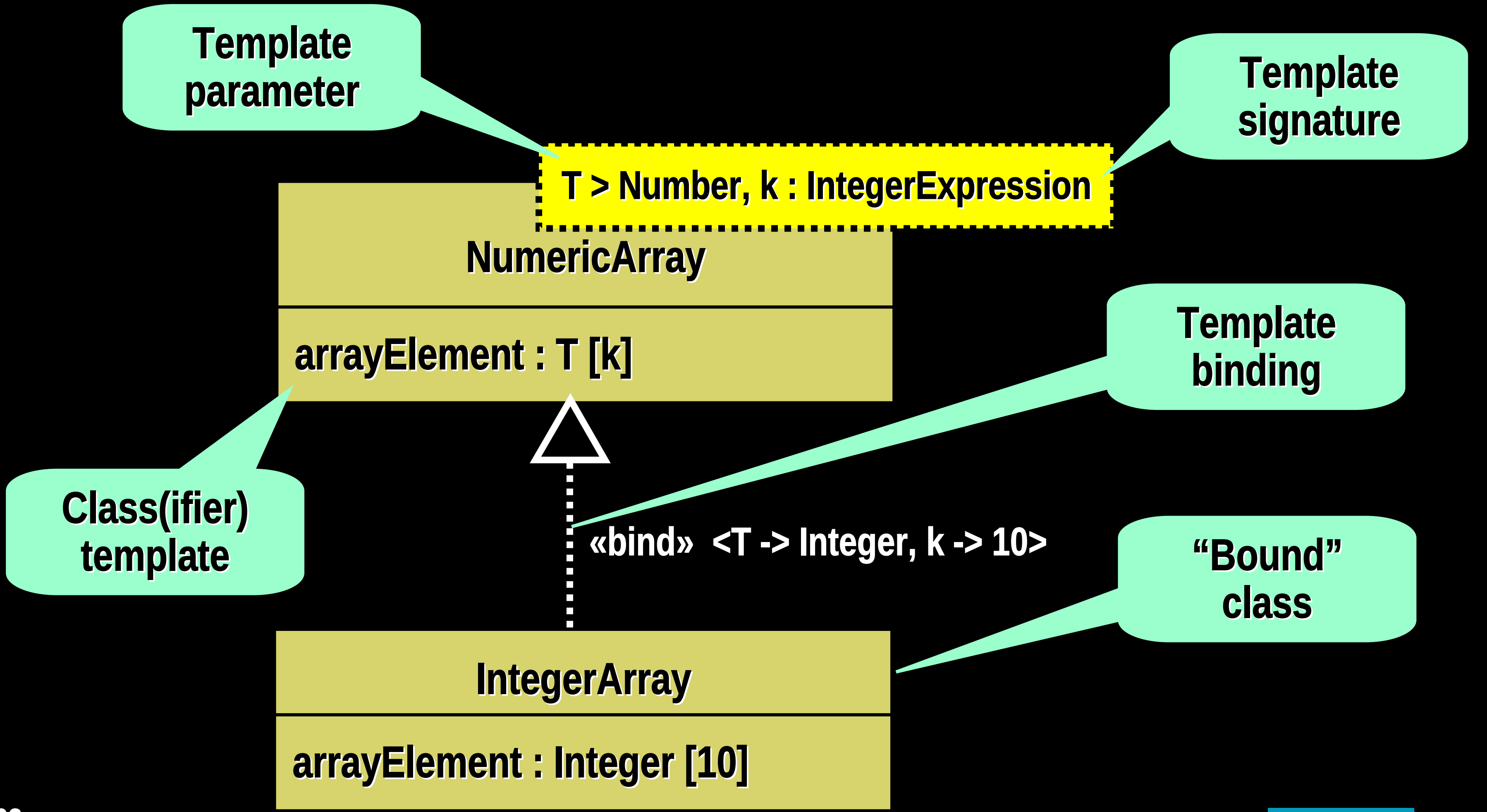
- E.g., specializing the standard Component concept



Contents

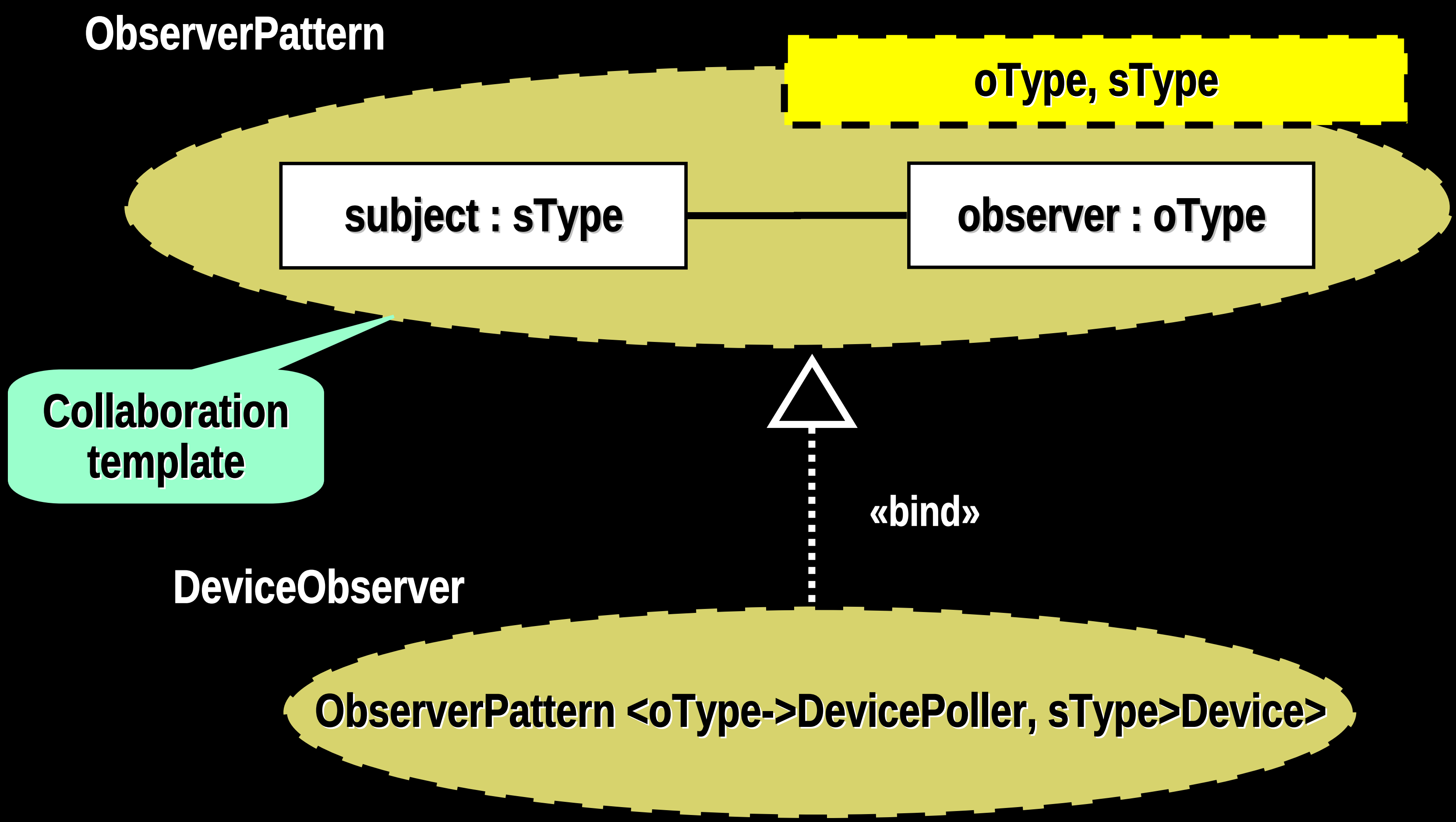
Templates

- More precise model than UML 1.x
- Limited to Classifiers, Packages, and Operations



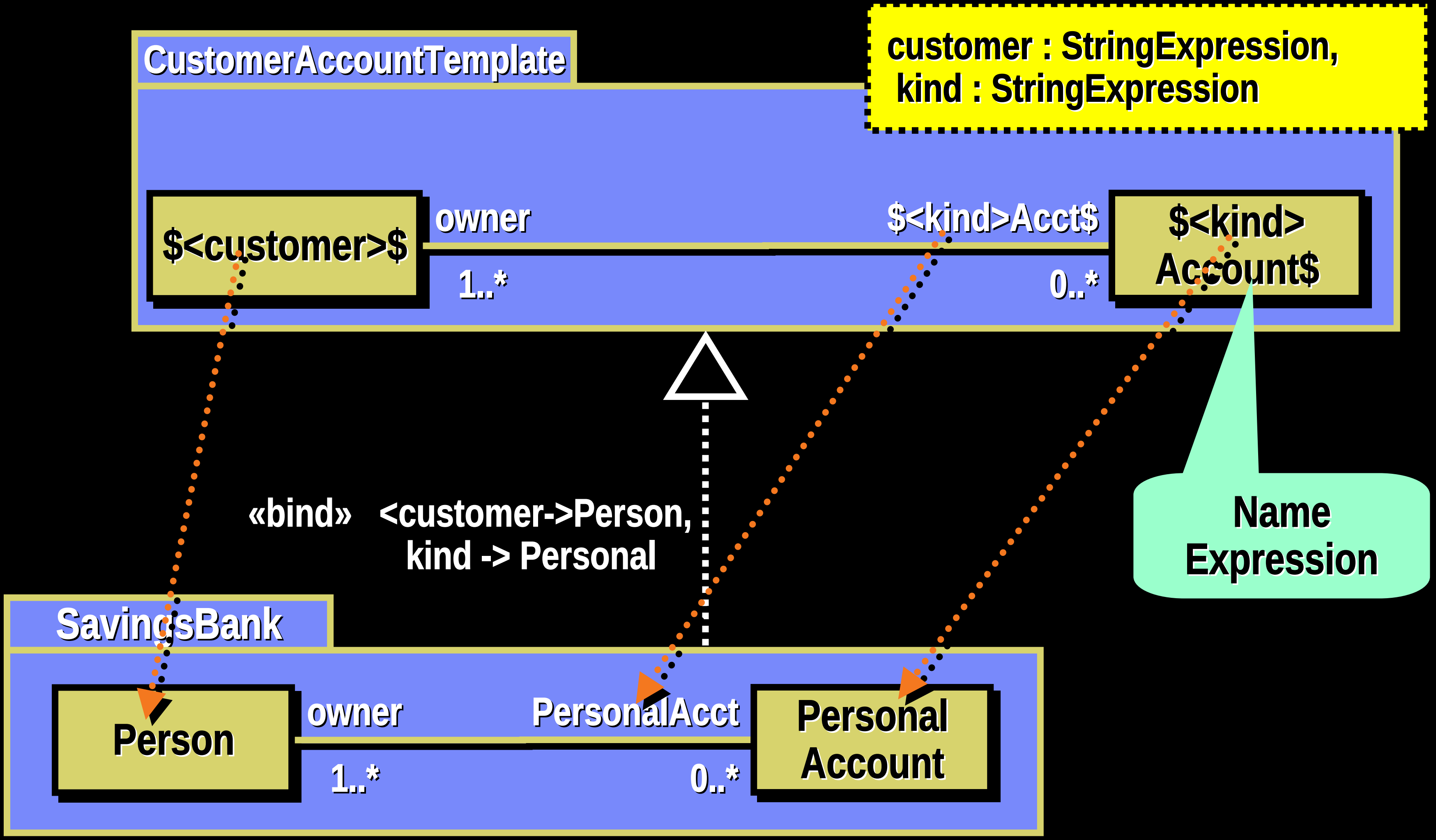
Collaboration Templates

- Useful for capturing design patterns



Package Templates

- Based on simple string substitution



Contents

Summary: UML 2.0

- First major revision of UML
- Original standard had to be adjusted to deal with
  - MDD requirements (precision, code generation, executability)
- UML 2.0 characterized by
  - Small number of new features + consolidation of existing ones
  - Scaleable to large software systems (architectural modeling capabilities)
  - Modular structure for easier adoption (core + optional specialized sub-languages)
  - Increased semantic precision and conceptual clarity
  - Suitable foundation for MDA (executable models, full code generation)

QUESTIONS?

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