# 3. Modelling Dynamic Behavior with Petri Nets

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1) Basics
   1) Elementary Nets
   2) Colored Petri Nets
2) Patterns in Petri Nets
3) Refactorings
4) Composability of Colored Petri Nets
5) Parallel Composition with CPN
6) Application to modelling

# Obligatory Readings

- Balzert 2.17
- Or Ghezzi Chap 5
- or (not enough in Pfleeger):
- W.M.P. van der Aalst and A.H.M. ter Hofstede. Verification of workflow task structures: A petri-net-based approach. Information Systems, 25(1): 43-69, 2000.
- Kurt Jensen, Lars Michael Kristensen and Lisa Wells. Coloured Petri Nets and CPN Tools for Modelling and Validation of Concurrent Systems. Software Tools for Technology Transfer (STTT). Vol. 9, Number 3-4, pp. 213-254, 2007.
- J. B. Jörgensen. Colored Petri Nets in UML-based Software Development – Designing Middleware for Pervasive Healthcare. www.pervasive.dk/publications/files/CPN02.pdf
- Web portal “Petri Net World” http://www.informatik.uni-hamburg.de/TGI/PetriNets/

# Literature

- K. Jensen: Colored Petri Nets. Lecture Slides http://www.daimi.aau.de/~kjensen Many other links and informations, too
  - www.daimi.aau.dk/CPnets the home page of CPN. Contains lots of example specifications. Very recommended
- K. Jensen, Colored Petri Nets. Vol. I-III. Springer, 1992-96. Landmark book series on CPN.
- T. Murata. Petri Nets: properties, analysis, applications. IEEE volume 77, No 4, 1989.
- W. Reisig. Elements of Distributed Algorithms – Modelling and Analysis with Petri Nets. Springer. 1998.
- W. Reisig, G. Rozenberg: Lectures on Petri Nets I+II, Lecture Notes in Computer Science, 1491+1492, Springer.
- J. Peterson. Petri Nets. ACM Computing Surveys, Vol 9, No 3, Sept 1977
- http://www.daimi.au.dk/CPnets/intro/example_indu.html

# Relationship of PN and other Behavioral Models

- P.D. Bruza, Th. P. van der Weide. The Semantics of Data-Flow Diagrams. Int. Conf. on the Management of Data. 1989
  - http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.40.9398
- Other courses at TU Dresden:
  - Entwurf und Analyse mit Petri-Netzen
  - Lehrstuhl Alg. u. log. Grundlagen d. Informatik
  - Dr. rer. nat. W. Nauber
  - http://wwwtcs.inf.tu-dresden.de/~nauber/eapn10add.html

# Goals

- Understand untyped and Colored Petri nets (CPN)
- Understand that CPN are a verifiable and automated technology for safety-critical systems

# The Initial Problem

- You work for PowerPlant Inc. Your boss comes in and says:

Our government wants a new EPR reactor, similarly, in the way Finland has it. How can we produce a verified control software? We need a good modelling language. Assembler would be too bad...

UML does not work...

How do we produce software for safety-critical systems?

# Interesting Projects with Safety-Critical, Parallel Embedded Software

- Arial
  - The WITAS UAV unmanned autonomously flying helicopter from Linköping http://www.ida.liu.se/~marwz/papers/ICAPS06_System_Demo.pdf
- Automotive
  - Prometheus: driving in car queues on the motorway
    - http://www.springerlink.com/content/j06n312r36805683/
- Trains
  - www.railcab.de Autonomous rail cabs
  - www.cargocab.de Autonomous cargo metro
    - http://www.cargocap.de/files/cargocap_presse/2005/2005_01_12%20kruse.pdf
  - http://www.rubin-nuernberg.de/ Autonomous mixed metro

# Application Areas of Petri Nets

- Model introduced by C.A. Petri in 1962.
  - Ph.D. Thesis: "Communication with Automata".
  - Over many years developed within GMD (now Fraunhofer, FhG)
  - PNs describe explicitly and graphically: Conflict/non-deterministic choice, concurrency
- Reliable software (quality-aware software)
  - PetriNets can be checked on deadlocks, liveness, fairness, bounded resources
- Safety-critical software that require proofs
  - Control software in embedded systems or power plants
- User interface software
  - Users and system can be modeled as separate components
- Hardware synthesis
  - Software/Hardware co-design

# Application Area I: Behavior Specifications in UML

- Instead of describing the behavior of a class with a statechart, a CPN can be used
- CPN have several advantages:
  - They model parallel systems naturally
  - They are compact and modular, can be reducible
  - They lend themselves to aspect-oriented composition, in particular of parallel protocols
  - They can be used to generate code, also for complete applications
  - UML statecharts, data flow diagrams, and activity diagrams are special instances of CPN
- Informal: for CPN, the following features can be proven
  - Liveness: All parts of the net do never get into a dead lock, i.e., can always proceed
  - Fairness: all parts of the net are equally “loaded” with activity
  - K-boundedness: the data that flows through the net is bound by a threshold
  - Deadlock-freeness: the net does not stop (deadlock)

# Application Area II: Contract checking (Protocol Checking) for Components

- Petri Nets describe behavior of components (dynamic semantics)
  - They can be used to check whether components fit to each other
- Problem: General fit of components is undecidable
  - The protocol of a component must be described with a decidable language
  - Due to complexity, context-free or -sensitive protocol languages are required
- Algorithm:
  - Describe the behavior of two components with two CPN
  - Link their ports
  - Check on *liveness* of the unified CPN
  - If the unified net is not live, components will not fit to each other…
- Liveness and fairness are very important criteria in safety-critical systems

# 3.1 Basics of PN

Petri Net Classes

Predicate/Transition Nets: simple tokens, no hierarchy.

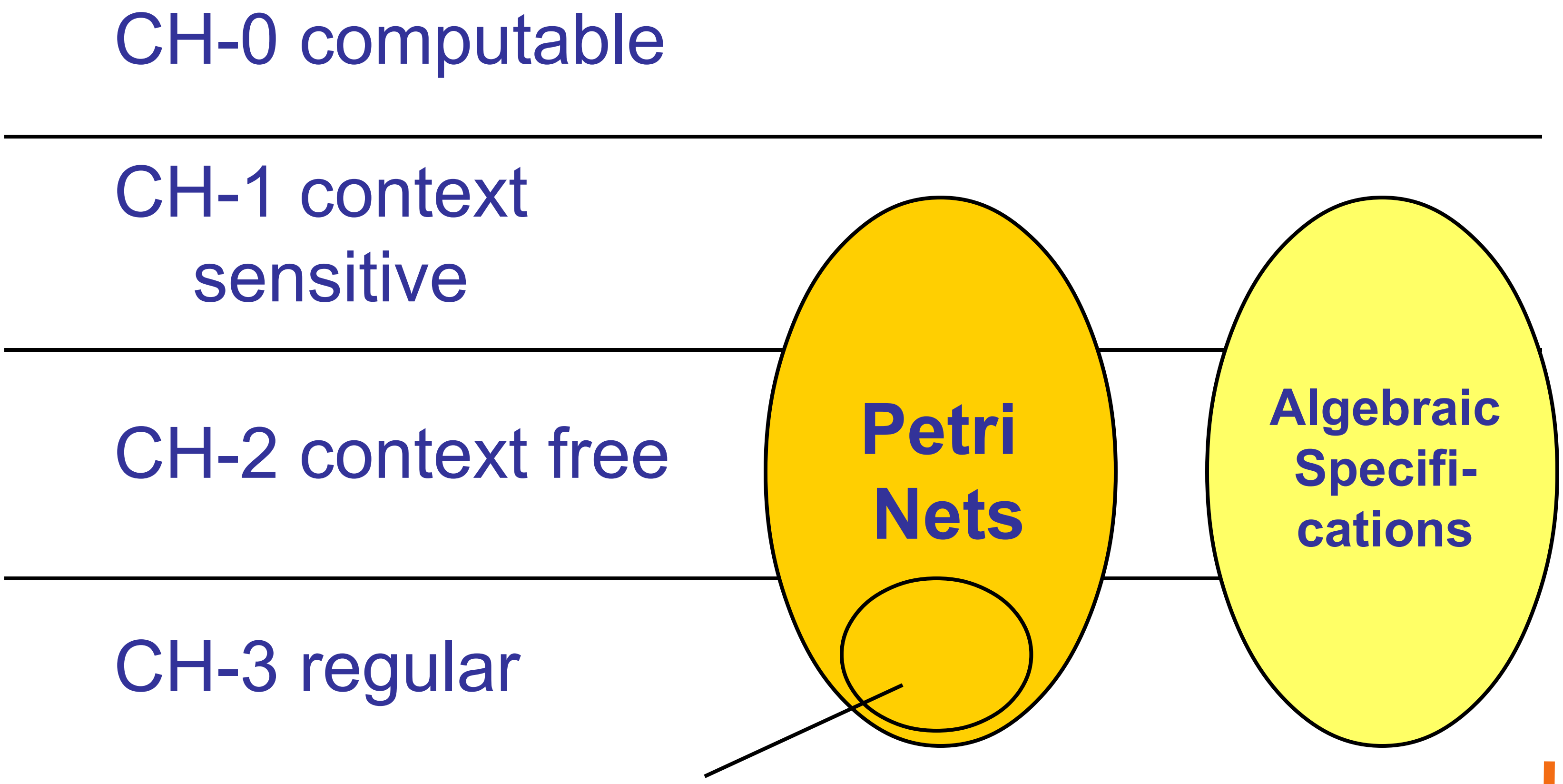
Place-Transition Nets: multiple tokens

High Level Nets: structured tokens, hierarchy

There are many other variants, e.g., with timing constraints

# Language Levels

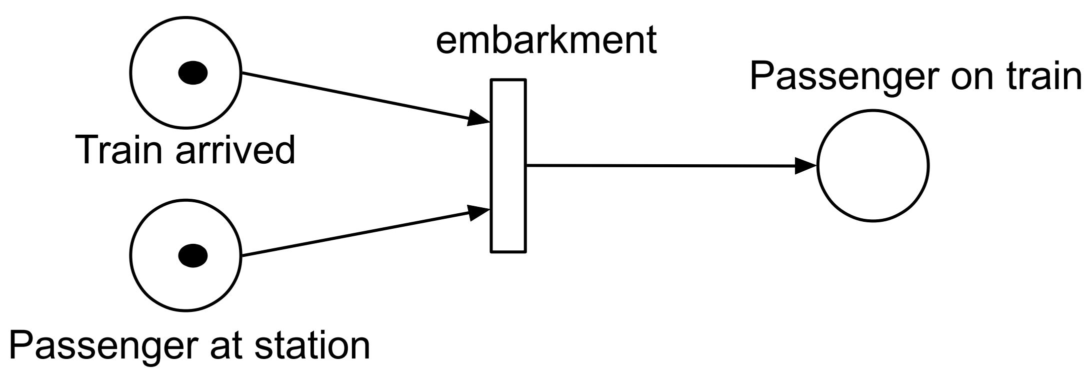
- PN extend finite automata with indeterminism
  - Asynchronous execution model (partial ordering)




**Finite state machines are PN with finite reachability graph**

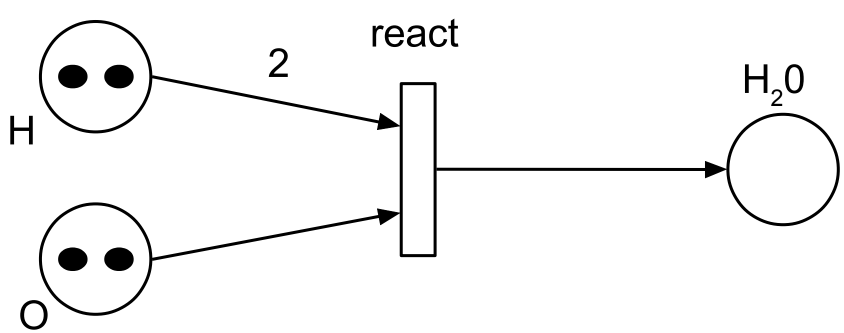
# Elementary Nets: Predicate/Transition Nets

- A **Petri Net (PN)** is a directed, bipartite graph over two kinds of *nodes,* namely *places* (circles) and *transitions* (bars or boxes)
- An *elementary PN* is  with boolean tokens, i.e., one token per place (bound of place = 1)
  - aka basic, predicate/transition nets (PTN), condition/Event nets
  - The presence of a token in a place means that the condition or predicate is true
  - The *firing* of a transition means that from the input predicates the output predicates are concluded
  - Thus elementary PN can model simple forms of logic



# Integer Place/Transitions-Nets

- An *integer PN* is a directed, weighted, bipartite graph over places and transitions with *integer* tokens, i.e., places may contain several tokens, and a *capacity* (*bound* = k)
  - *k* tokens in a place indicate that *k* data items are available
  - *M(p)* is the number of tokens in place *p*
- A *marking* assigns to each place a nonnegative integer
  - A marking is denoted by *M*, an m-vector where m is the number of places.
  - A PN has a *initial marking*, $M_0$.
- Arcs have *cardinalities (weights)* to show how many tokens they transfer

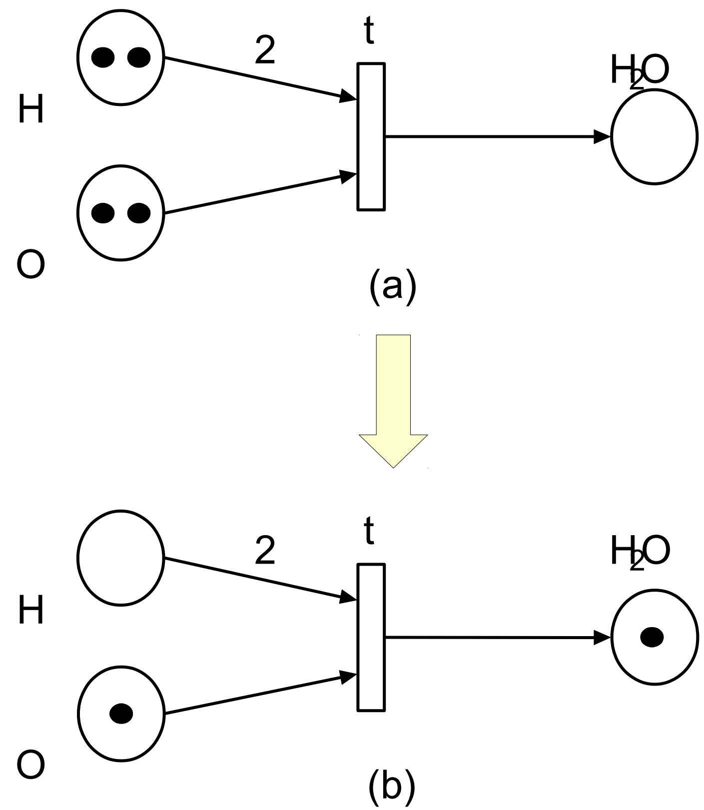



Here: initial marking $M_0(2,2,0)$

# Formal Transition Enabling and Firing

In a PN a state is changed according to the following *transitions firing rule*:

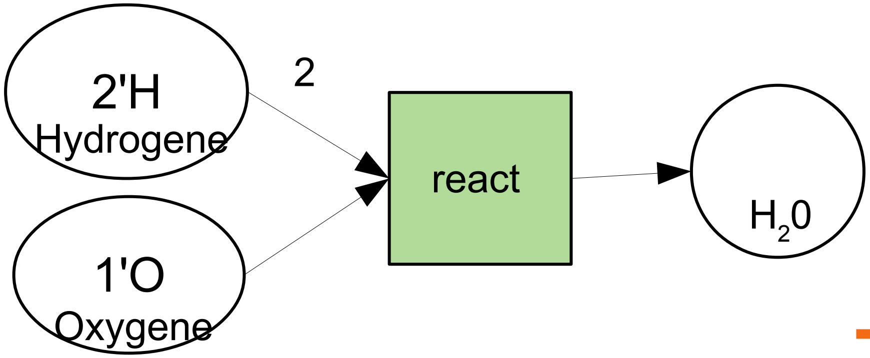
- A transition t is *enabled* if
  - each input place *p* of *t* is marked with at least *w(p,t)* tokens, where *w(p,t)* is the weight of the arc from *p* to *t*
  - The output place can be filled
- An enabled transition may or may not fire.
- A *firing* of an enabled transition removes *w(p,t)* tokens from each input place *p* to *t*, and adds *w(t,p)* tokens to each output place *p* of *t*, where *w(t,p)* is the weight of the arc from *t* to *p*.



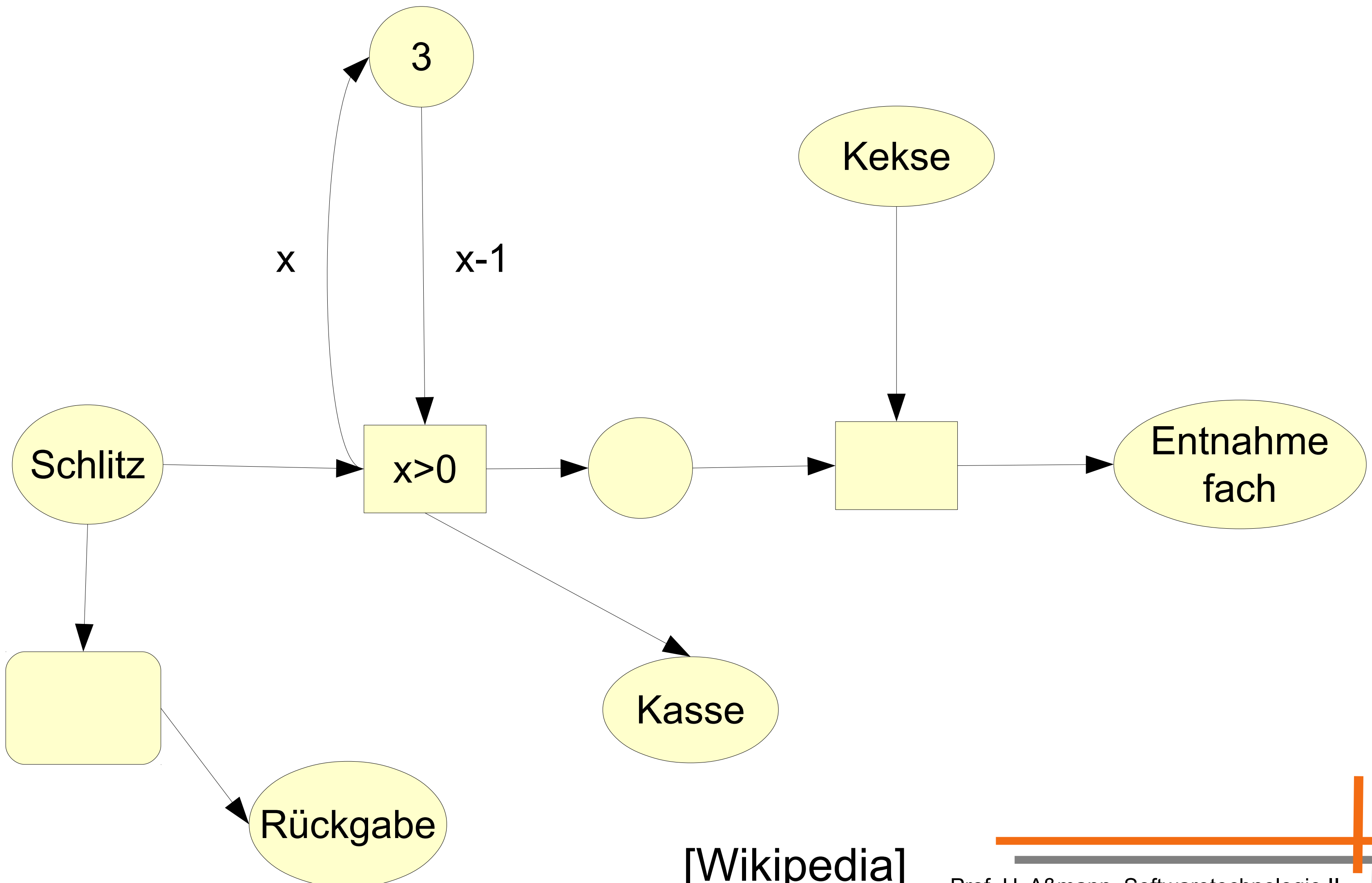

*(a)* *t* is enabled.
*(b)* *t* has been fired.

# High-Level Nets

- A *high-level PN (colored PN)* allows for *typed* places and arcs
  - For types, any DDL can be used (e.g., UML-CD)
- High-level nets are modular
  - Places and transitions can be refined
  - A Colored Petri Net is a reducible graph
- The upper layers of a reducible CPN are called *channel agency nets*
  - Places are interpreted as channels between components



# Cookie Automaton with Counter




[Wikipedia]

# 3.1.1 Elementary Nets (Predicate/Transition Nets)

# Meaning of Places and Transitions in Elementary Nets

- Predicate/Transition (Condition/Event-, State/Transition) Nets:
  - Places represent conditions, states, or predicates
  - Transitions represent the firing of events:
    - if a transition has one input place, the event fires immediately if a token arrives in that place
    - If a transition has several input places, the event fires when all input places have tokens
- A transition has *input* and *output* places (pre- and postconditions)
  - The presence of a token in a place is interpreted as the condition is true

# Formal Definition of a Place/Transition Net

- A PN is a 5-tuple, P = (P, T, F, W, $M_0$) with

$P = \{p_1, p_2, \ldots, p_m\}$ is a finite set of places,

$T = \{t_1, t_2, \ldots, t_m\}$ is a finite set of transitions,

$F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs (flow relation),

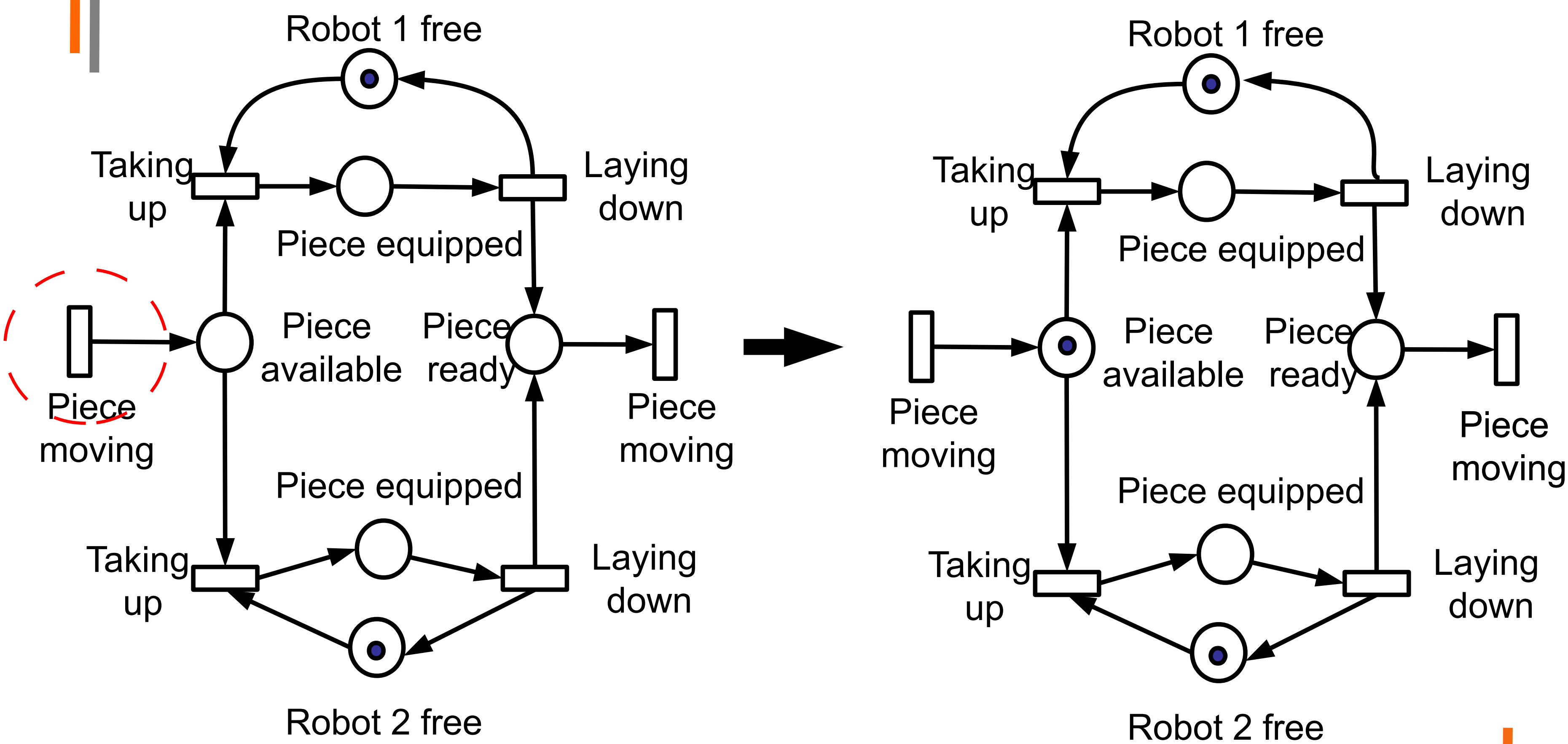
$W : F \rightarrow \{1, 2, 3, \ldots\}$ is a weight function,

$M_0 : P \rightarrow \{0, 1, 2, 3, \ldots\}$ is the initial marking, (if img(P) = {0,1}, we have a elementary net, otherwise an integer net)

$P \cap T = \emptyset, P \cup T \neq \emptyset$

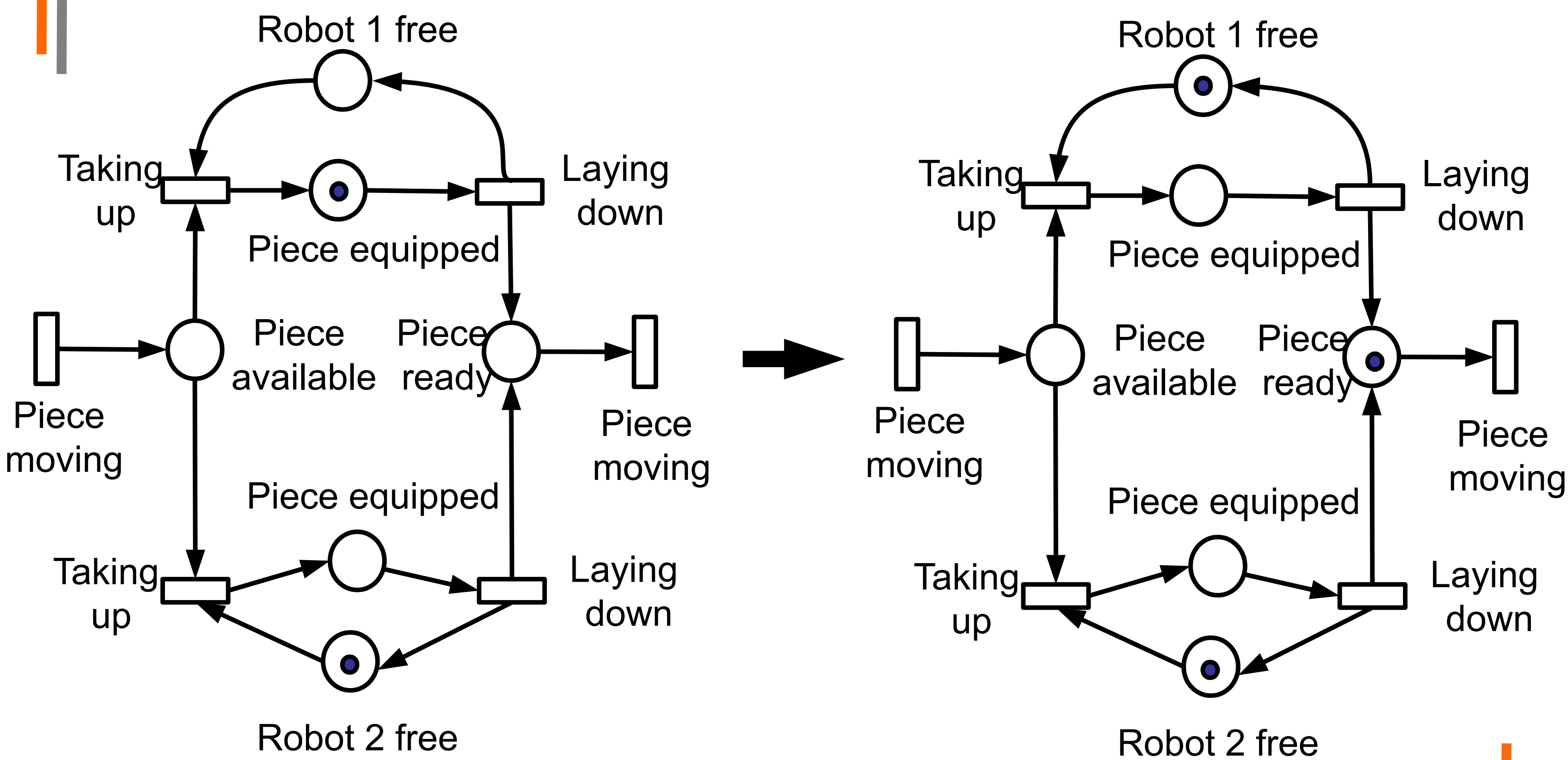
A PN structure N = (P, T, W) without any specific initial marking is denoted N
A PN with the given initial marking is denoted by (N, $M_0$)

# Example of 2 Robots as Predicate/Transition Net



# Example of 2 Robots as Predicate/Transition Net

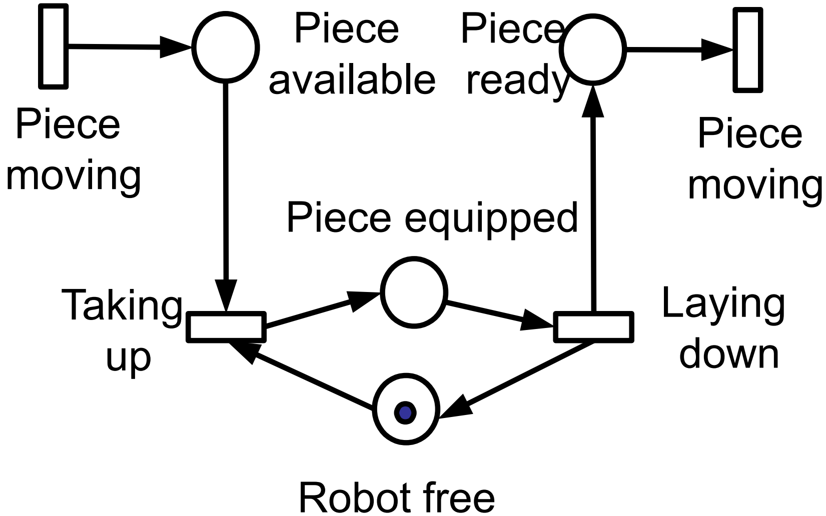
- Places represent predicates; tokens show validity



# 3.1.2 Special Nets

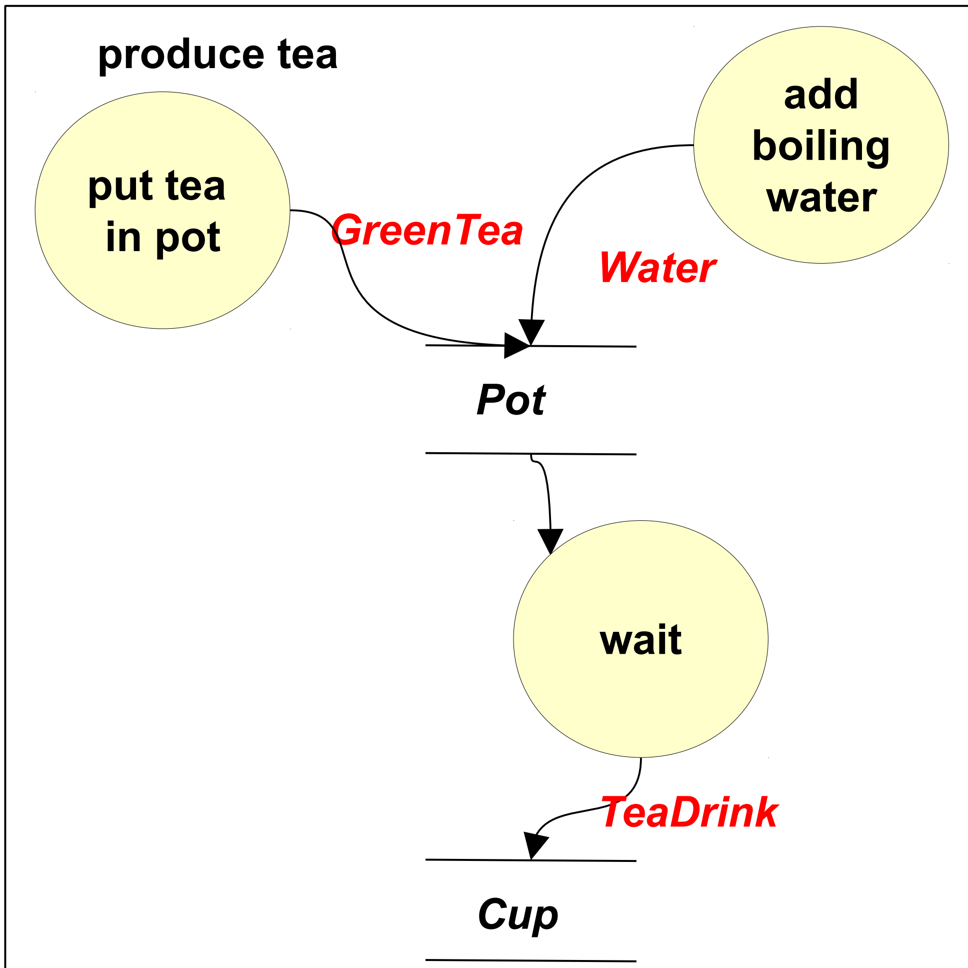
# Marked Graphs (MG, Data-Flow Graphs, Data-Flow Diagrams, DFD)

- A *Marked Graph (MG)* is an elementary PN such each place is the input to only one transition and the output of only one transition
  - Marked Graphs are Data-flow graphs (Data flow diagrams, DFD)
  - Transitions correspond to processes in DFD, places to stores
  - States can be *merged* with the ingoing and outcoming arcs → DFD
- All theory for CPN holds for DFD, too [BrozaWeide]
- Bsp. Robot is a DFD (but not the assembly line):



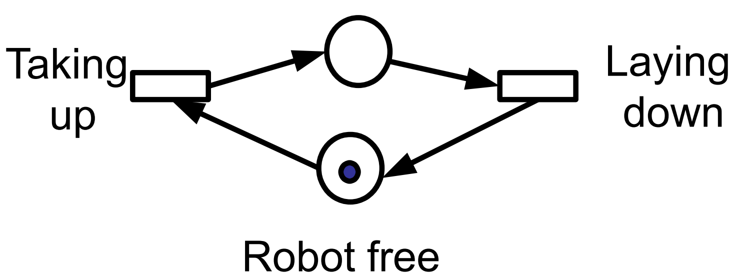
# For DFD, Many Notations Exist

- Notation from Structured Analysis [Balzert]



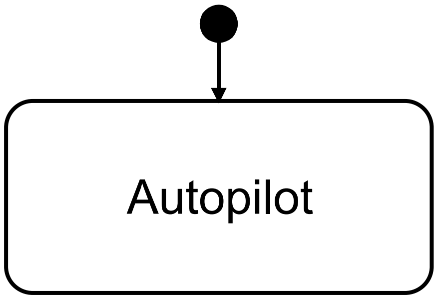
# State Machines are PN with Cardinality Restrictions

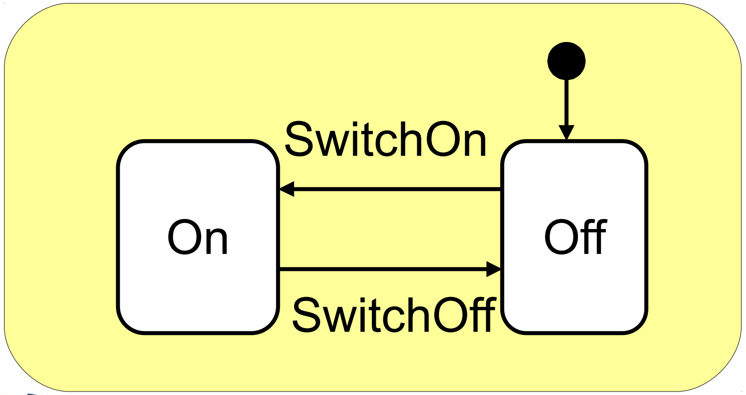
- A *Finite State Machine* PN is an elementary PN such that each transition has only one input and one output place
  - Then, it is equivalent to a finite automaton or a *statechart*
  - From every class-statechart that specifies the behavior of a class, a State Machine can be produced easily
    - Flattening the nested states
  - Transitions correspond to transitions in statecharts, states to states
  - Transitions can be *merged* with the ingoing and outcoming arcs
  - In a FSM there is only one token
- All theory for CPN holds for Statecharts, too
- Ex. Robot is an FSM (but not with incoming data flow):

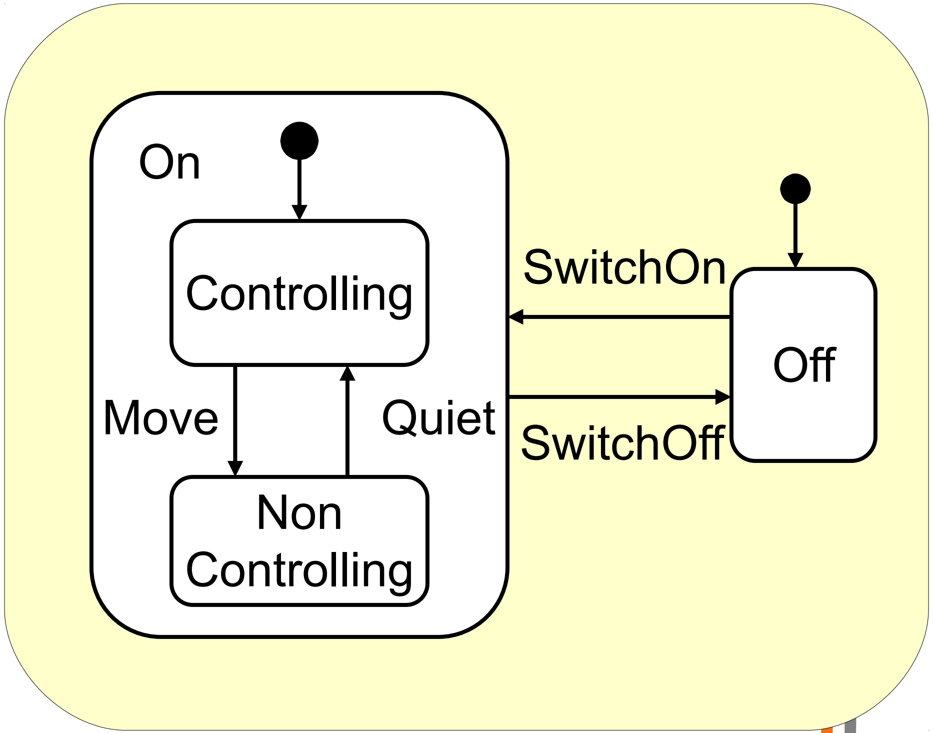


# Hierarchical StateCharts from UML

- States can be nested in StateCharts



# 3.1.2 Colored Petri Nets as Example of High Level Nets

Modularity, Refinement, Reuse

Preparing “reducible graphs”

# Colored Petri Nets, CPN

- Colored (Typed) Petri Nets (CPN) refine Petri nets:
  - Tokens are typed (colored)
  - Types are described by data structure language, such as Java, ML, UML class diagrams
  - but may also be data dictionaries, grammars
  - Concept of time can be added
- Full tool support
  - Fully automated code generation in Java and ML  (in contrast to UML), e.g., DesignCPN of Aarhus University http://www.daimi.aau.dk
  - Prover proofs features about the PN
  - Net simulator allows for debugging
- Much better for safety-critical systems than UML, because proofs can be done

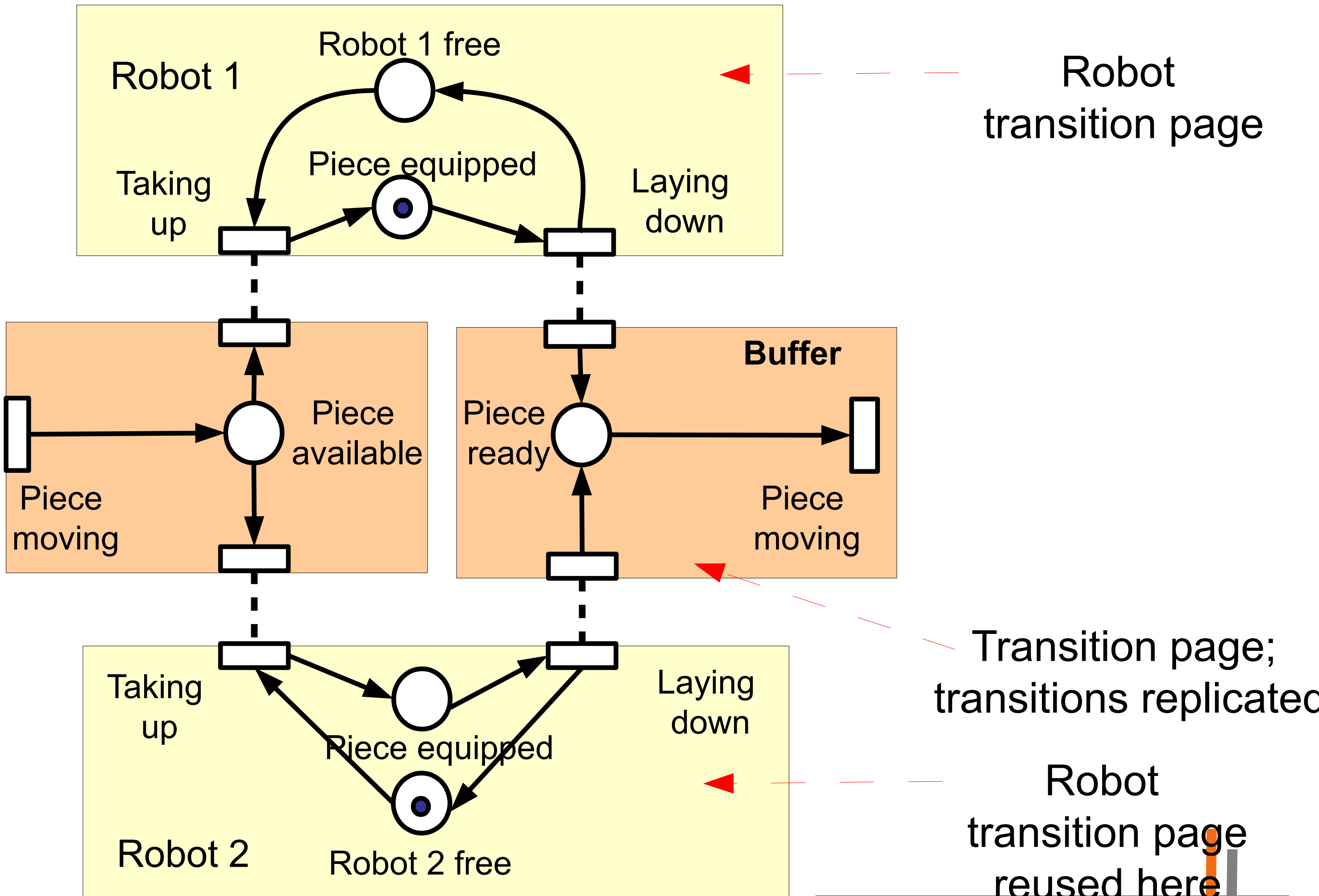
# Annotations in CPN

- Places are annotated by
  - Token types
    - `(STRING x STRING)`
  - Markings of objects and the cardinality in which they occur:
    - `2'("Uwe","Assmann")`
- Edges are annotated by
  - Type variables which are unified by unification against the token objects
    - `(X,Y)`
  - Guards
    - `[ X == 10]`
  - if-then-else statements
    - `if X < 20 then Y := 4 else Y := 7`
  - switch statements
  - boolean functions that test conditions

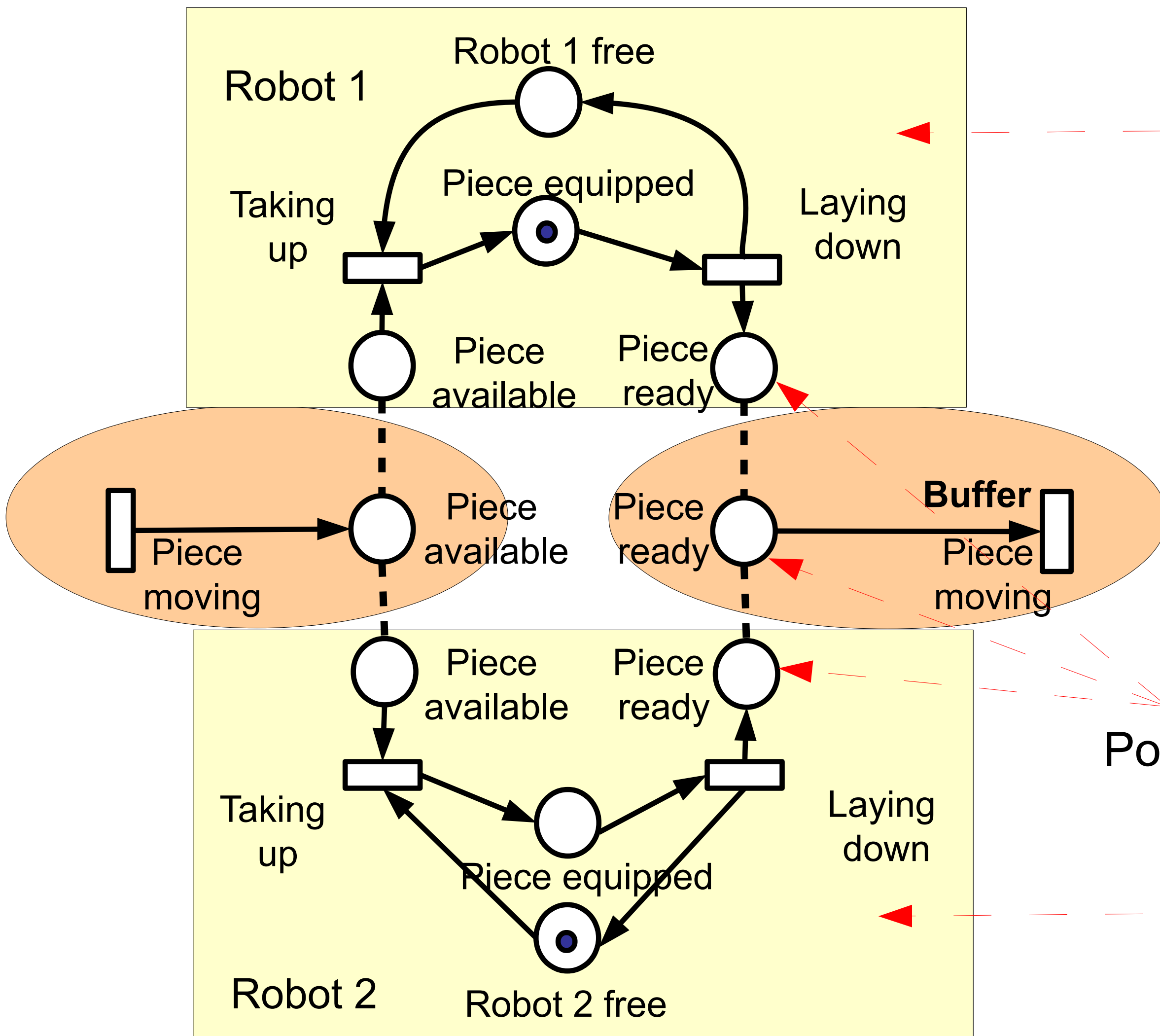
# CPN are Modular

- A subnet is called a *page (module)*
  - Every page has ports which mark in- and out-going transitions (into a place) or in- and outgoing places (into a transition)
- *Transition page*: interface contains transitions (transition ports)
- *Place page (state page)*: interface contains place (place ports)
- *Net class*: a named page that is a kind of ”template” or ”class”
  - It can be instantiated to a net ”object”
- Reuse of pages and templates possible
  - Libraries of CPN ”procedures” possible

# Robots with Transition Pages, Coupled by Transition Ports



# Robots with Place (State) Pages, Coupled by Replicated State Ports




Robot as state page

Port states replicated

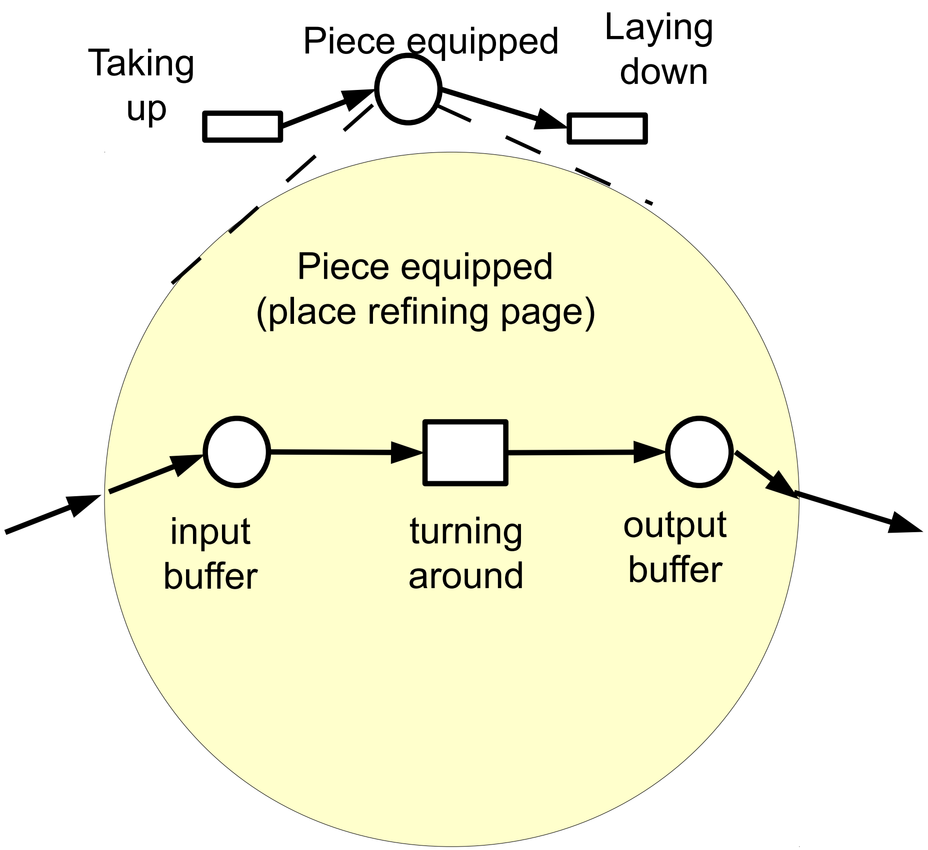
Robot state page reused here

# CPN are Hierarchical

- Places and transitions may be hierarchically **refined**
  - Two pointwise refinement operations:
    - Replace a transition with a transition page
    - Replace a state with a state page
  - Refinment condition: Retain the embedding (embedding edges)
- CPN can be arranged as hierarchical graphs (reducible graphs, see later)
  - Large specifications possible, overview is still good
  - Subnet stemming from refinements are also place or transition pages

# Point-wise Refinement Example

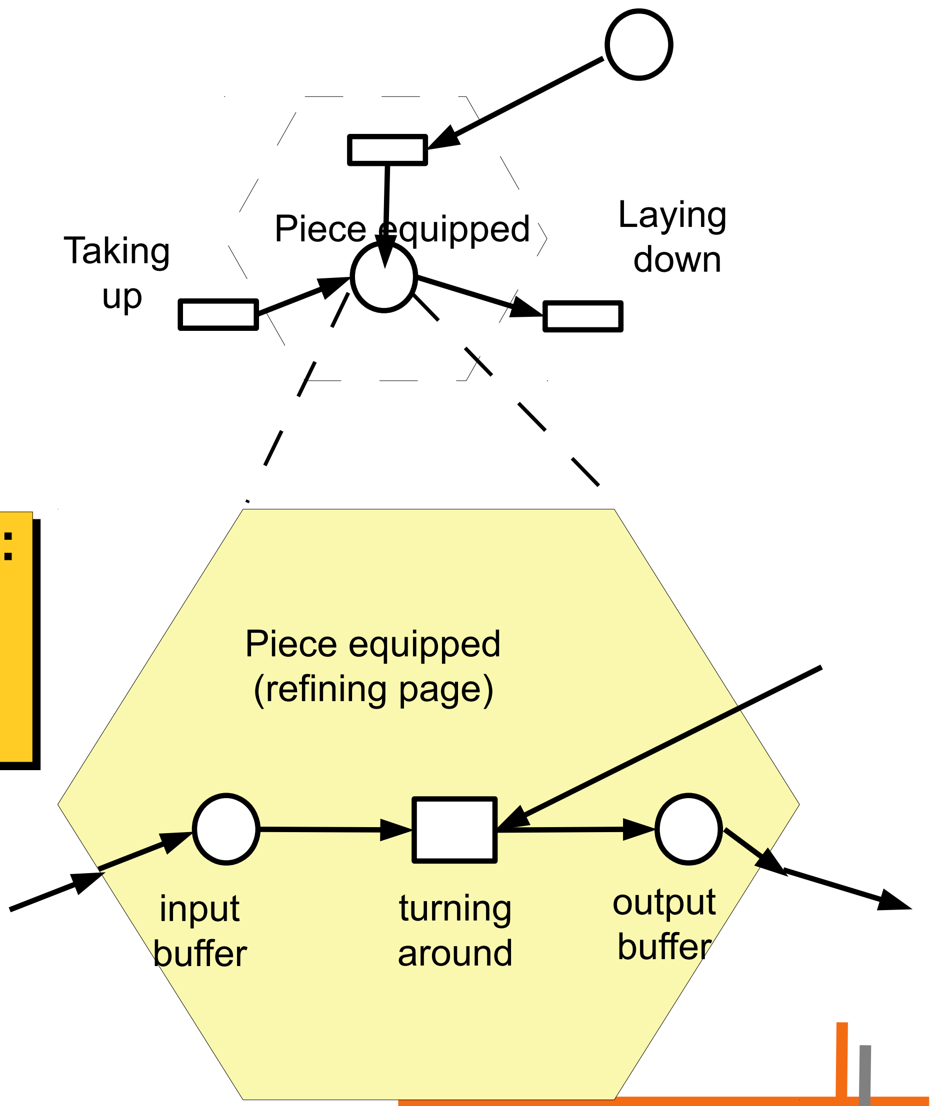
- Pointwise refinement:
  - *Transition refining page*: refines a transition, transition ports
  - *Place refining page (state refining page)*: refines a place, place ports




**Law of syntactic refinement:** The graph interface (attached edges) of a refined node must be retained by the refining page.

# Region (Hyperedge) Refinement Example

- Hyperedges and regions in PN can be refined




**Law of syntactic region refinement:** The graph interface (attached edges) of a refined region must be retained by the refining region.

# Industrial Applications of CPN

- Large systems are constructed as reducible specifications
- ..have 10-100 pages, up to 1000 transitions, 100 token types
- Example: ISDN Protocol specification
  - Some page templates have more than 100 uses
  - Corresponds to millions of places and transitions in the expanded, non-hierarchical net
  - Can be done in several person weeks

# 3.2 Patterns in Petri Nets

Analyzability:

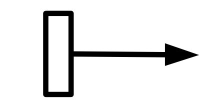
Petri Nets can be analyzed for patterns (by pattern matching)

# Modelling of Parallelism and Synchronization

Petri Nets have a real advantage when parallel processes and synchronization must be modelled

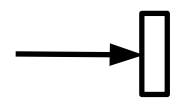
Many concepts can be expressed as *PN patterns*

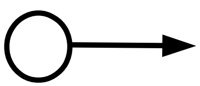
# Simple PN Buffering Patterns



Permanently live transition
generating objects
(object source)

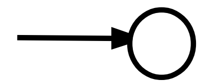
Permanently live transition
deleting/consuming objects
(object sink)

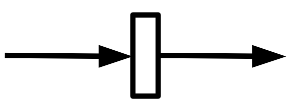




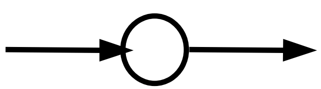
Reservoir Place
(does not generate
objects)

Archive of objects



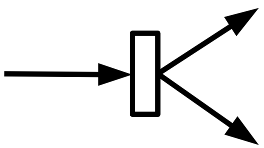


Process; sequentialization; action



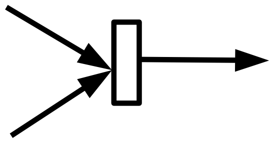
Intermediate archive (buffer)

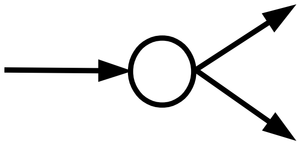
# Parallelism Patterns



Replication and distribution of objects; forking off parallelism

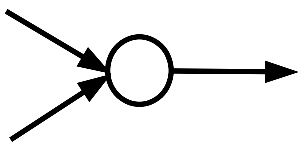
Joining parallelism synchronization barrier





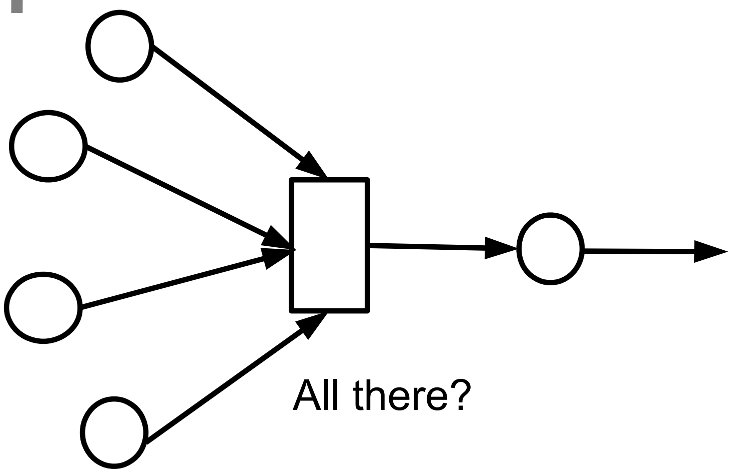
Forking off parallelism

Collecting objects from parallel processes (join)

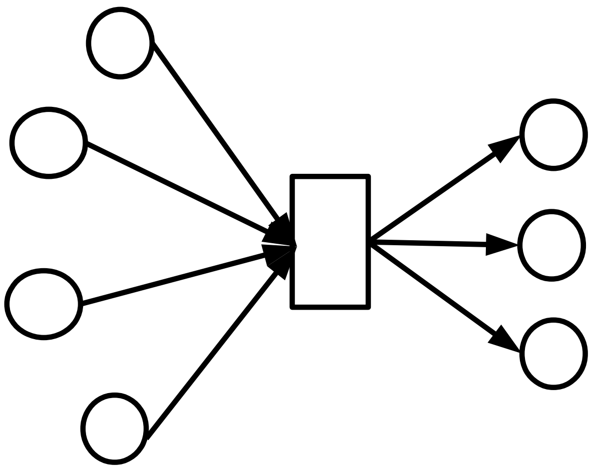


# Examples for Building Blocks

Synchronization barrier

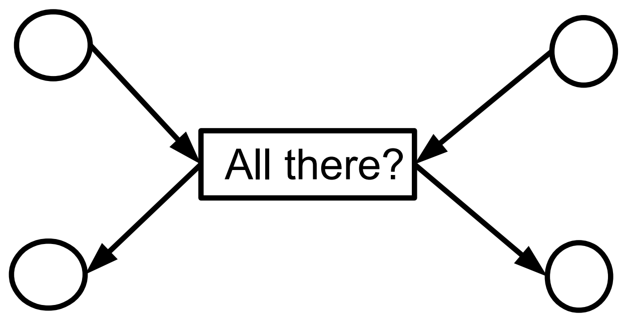



Bridges: Transitions between phases

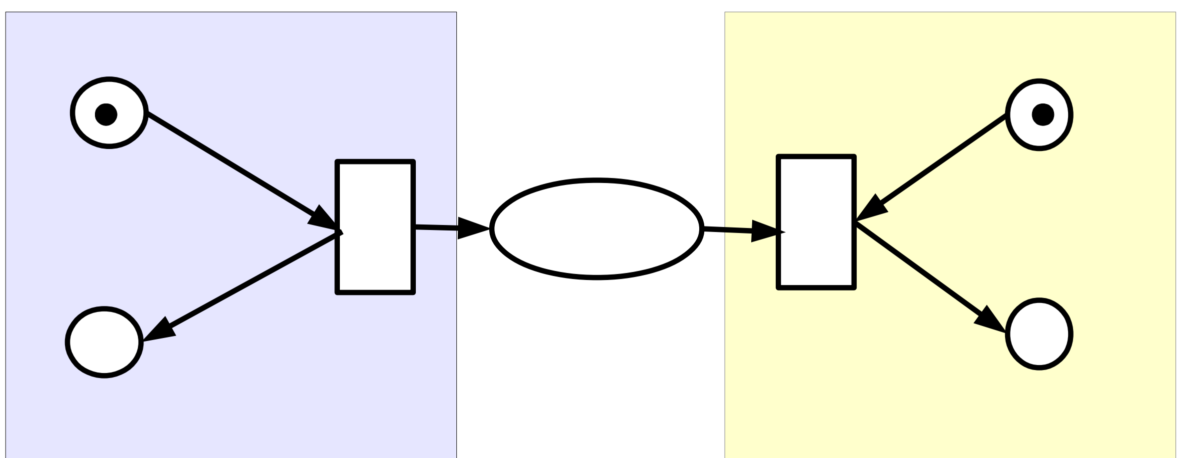


# Patterns for Parallelism

Coupling processes with parallel continuation

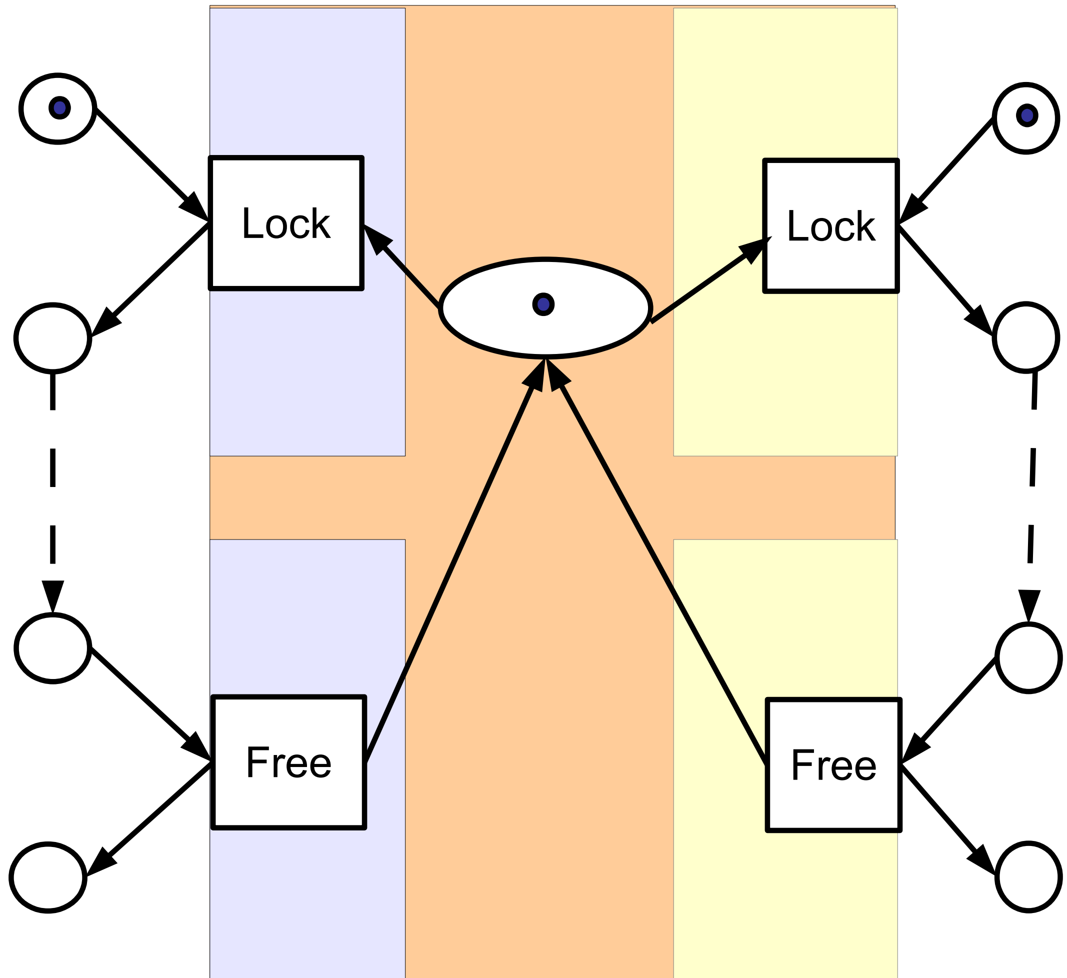



Producer/Consumer with buffer (CSP channel)

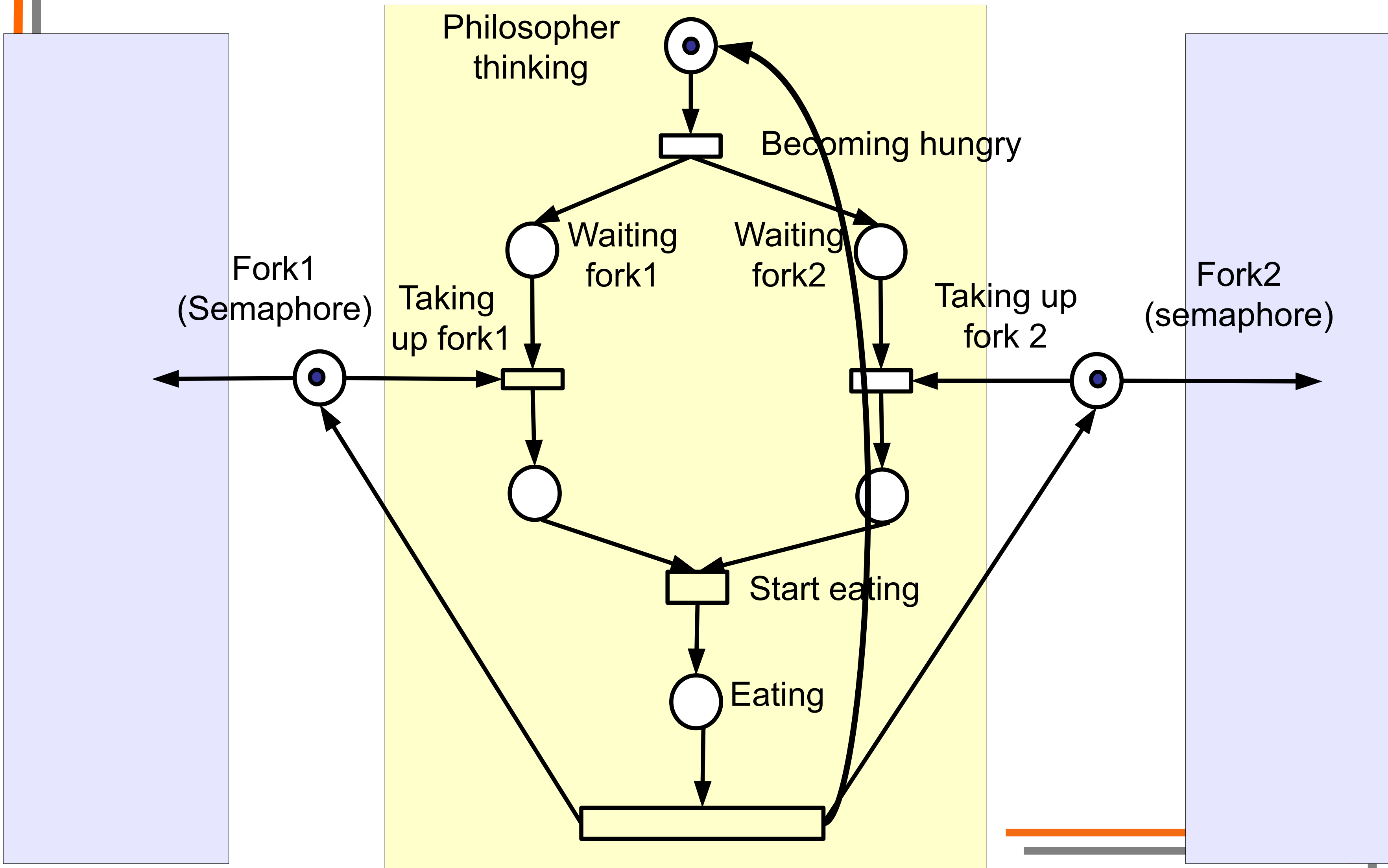


# Semaphores For Mutual Exclusion

Binary or counting semaphores: depends on the capacity of the semaphore place



# Dining Philosophers



# Advantage

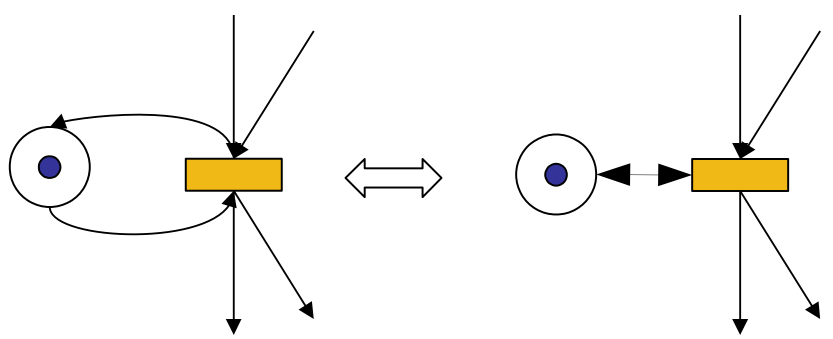
- Patterns can be used to model specific requirements
- PN can be checked for patterns by Pattern Matching (Graph Rewriting)
  - Patterns can be restructured (refactorings)
  - Patterns can be composed (composition)
- Further semantic analysis of PN: Parallel, indeterministic systems can be checked for
  - Absence of deadlocks: will the parallel system run without getting stuck?
  - Liveness: will all parts of the system work forever?
  - Fairness: will all parts of the system be loaded equally?
  - Bounded resources: will the system use limited memory, and how much? (important for embedded systems)
  - Whether predicates hold in certain states (model checking)

# 3.3 Refactorings (Reduction Rules) for Petri Nets

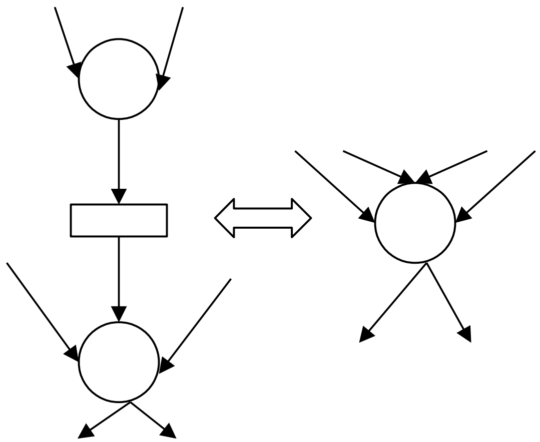
.. in the form of graph rewrite rules

# Special Restructuring Patterns (Refactorings)

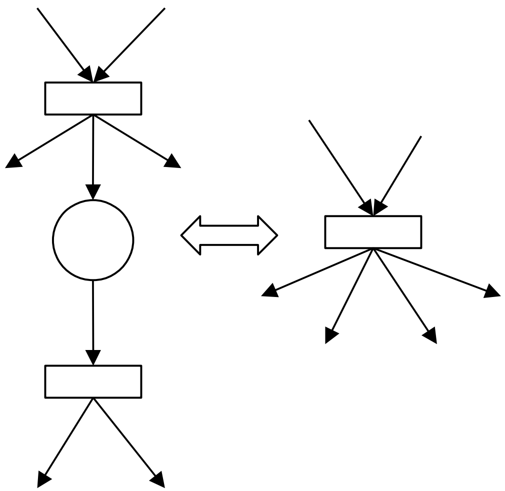
- *Source transitions* are always enabled, i.e., generate tokens (*token generator)*
- *Sink transitions* are always enabled and swallow tokens (*token sink)*
- A *self-loop* is a pair of a place *p* and a transition *t* if *p* is both output and input place of *t*
  - A PN without any self-loops is *pure.* Its arc relation is irreflexive



# Simple Reduction Rules

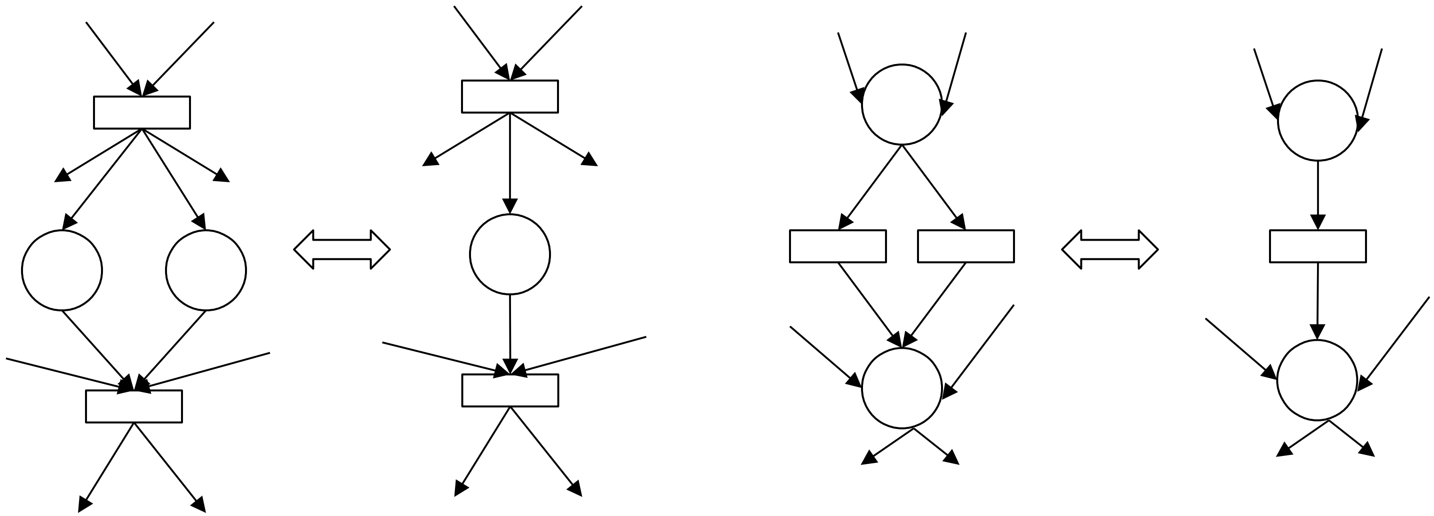


1) Fusion of Series Places (FSP)
(Bridge elimination)



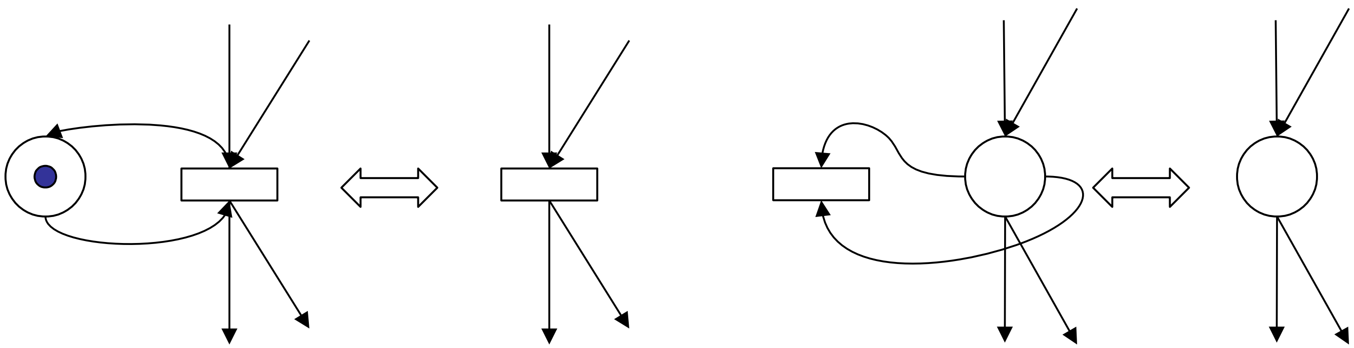
2) Fusion of Series Transitions (FST)
(Intermediate buffer elimination)

# Simple Reduction Rules



3) Fusion of Parallel Places (FPP) 4) Fusion of Parallel Transitions (FPT)

# Simple Reduction Rules



5) Elimination of Self-loop Places (ESP) 6) Elimination of Self-loop Transitions (EST)

All transformations preserve liveness, safeness and boundedness.

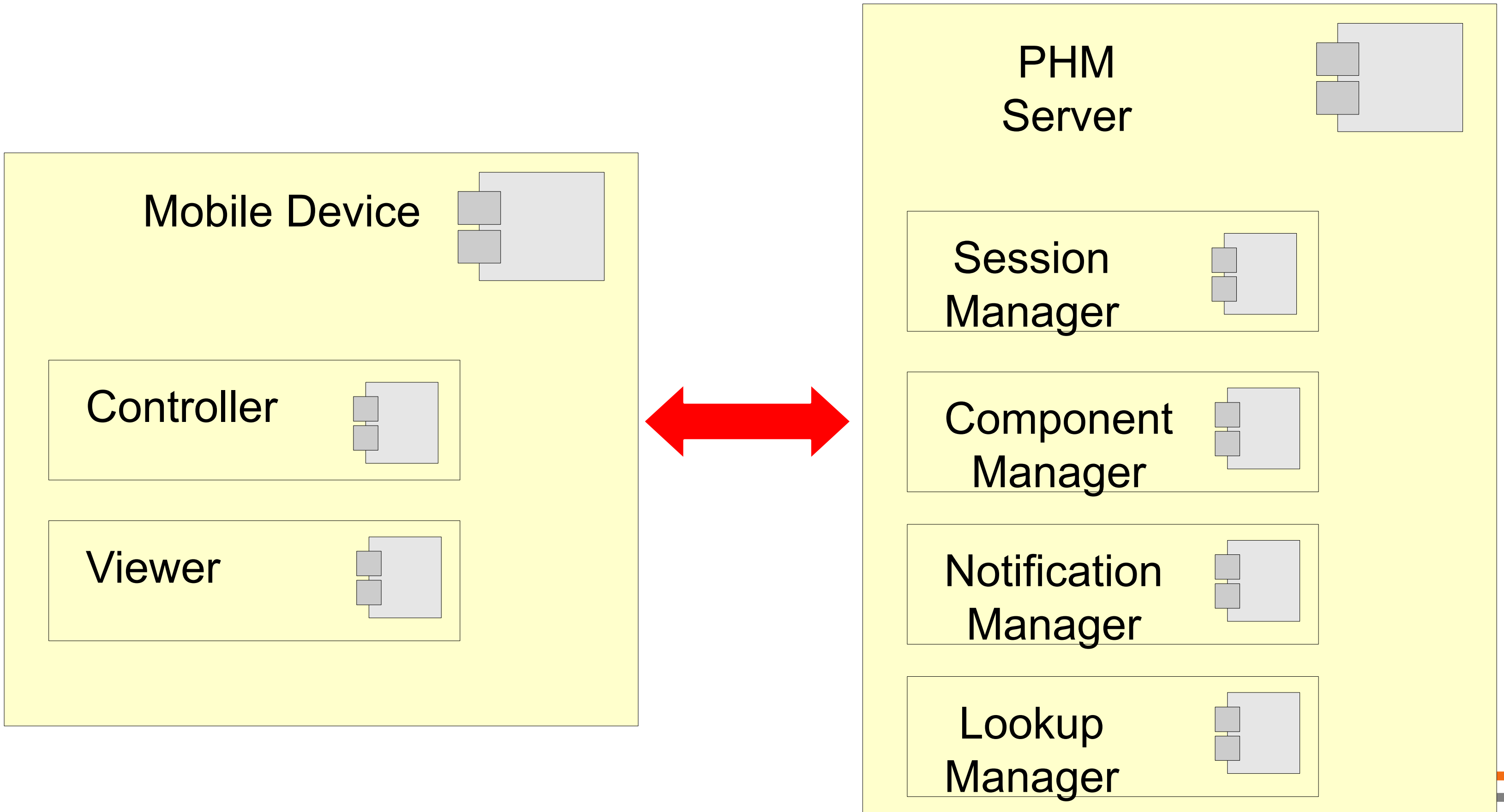
# 3.4 Composability of CPN

# Case Study for Composition: Pervasive Healthcare Middleware (PHM)

- in development at the Pervasive Computing Center, University of Aarhus
- Basic idea:
  - Specify the structure of an application with UML
  - and the behavior with CPN, describing the behavior of the classes/objects (object lifecycle)
  - Glue behavior together with page glueing mechanism
- Electronic patient records (EPR) replace the papers
  - First version in 2004, on stationary PC
  - Next versions for pervasive computing (PDA, wireless):
    - Hospital employees will have access to the patient's data whereever they go, from Xray to station to laboratories
  - For instance, medication plans are available immediately

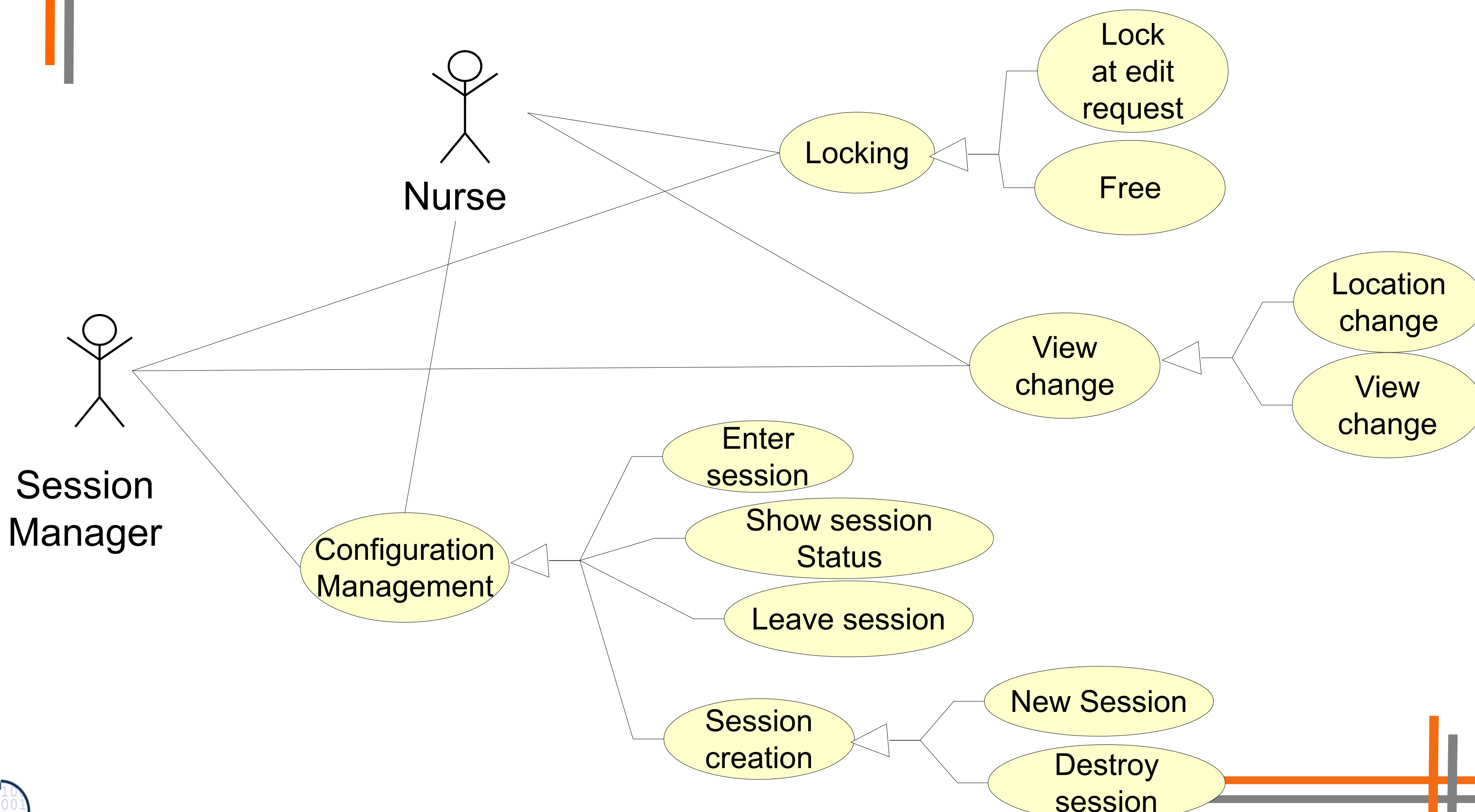
# The PHM Architecture

- A *session* is entered by several mobile devices that collaborate

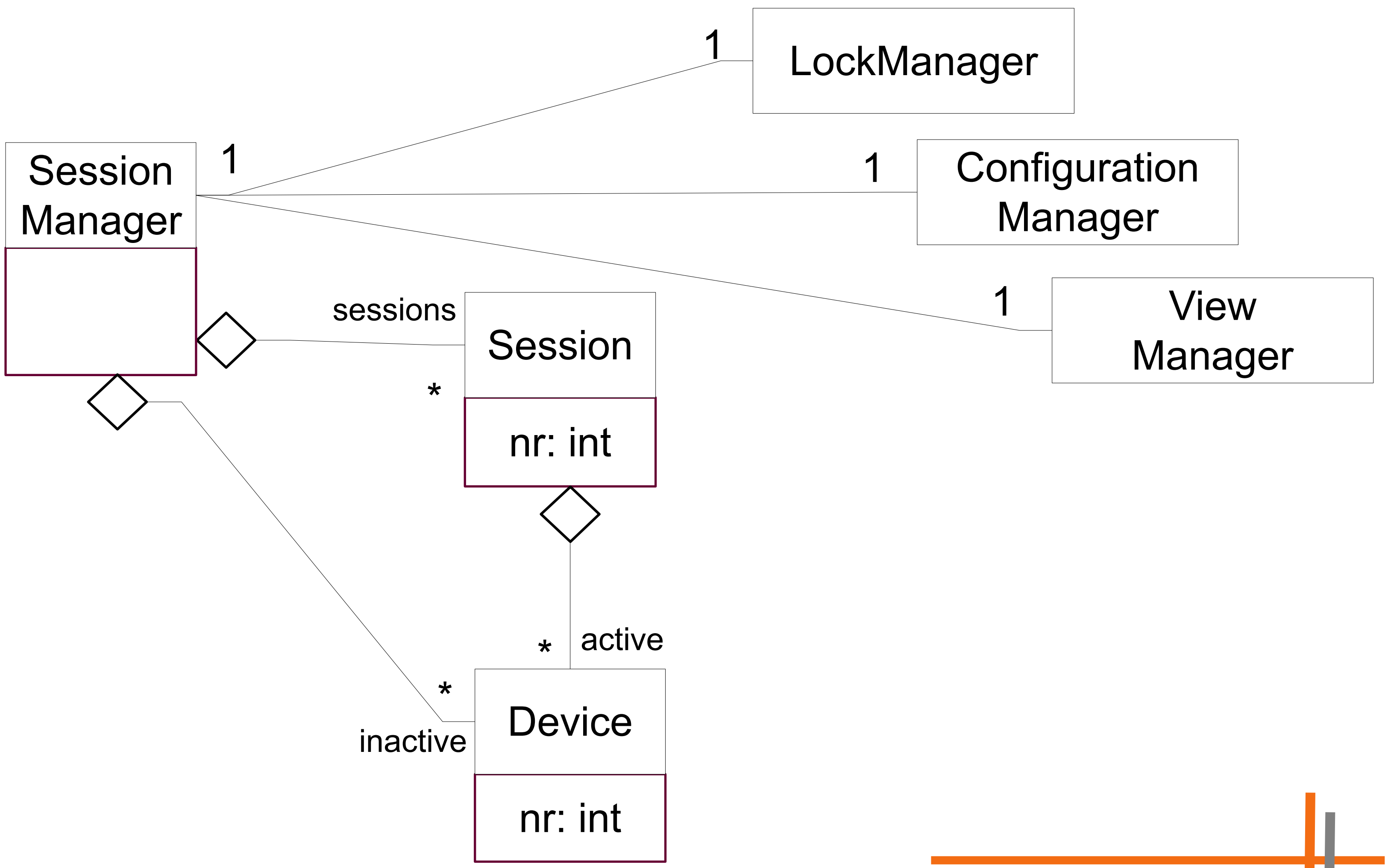


# Session Manager Use Cases

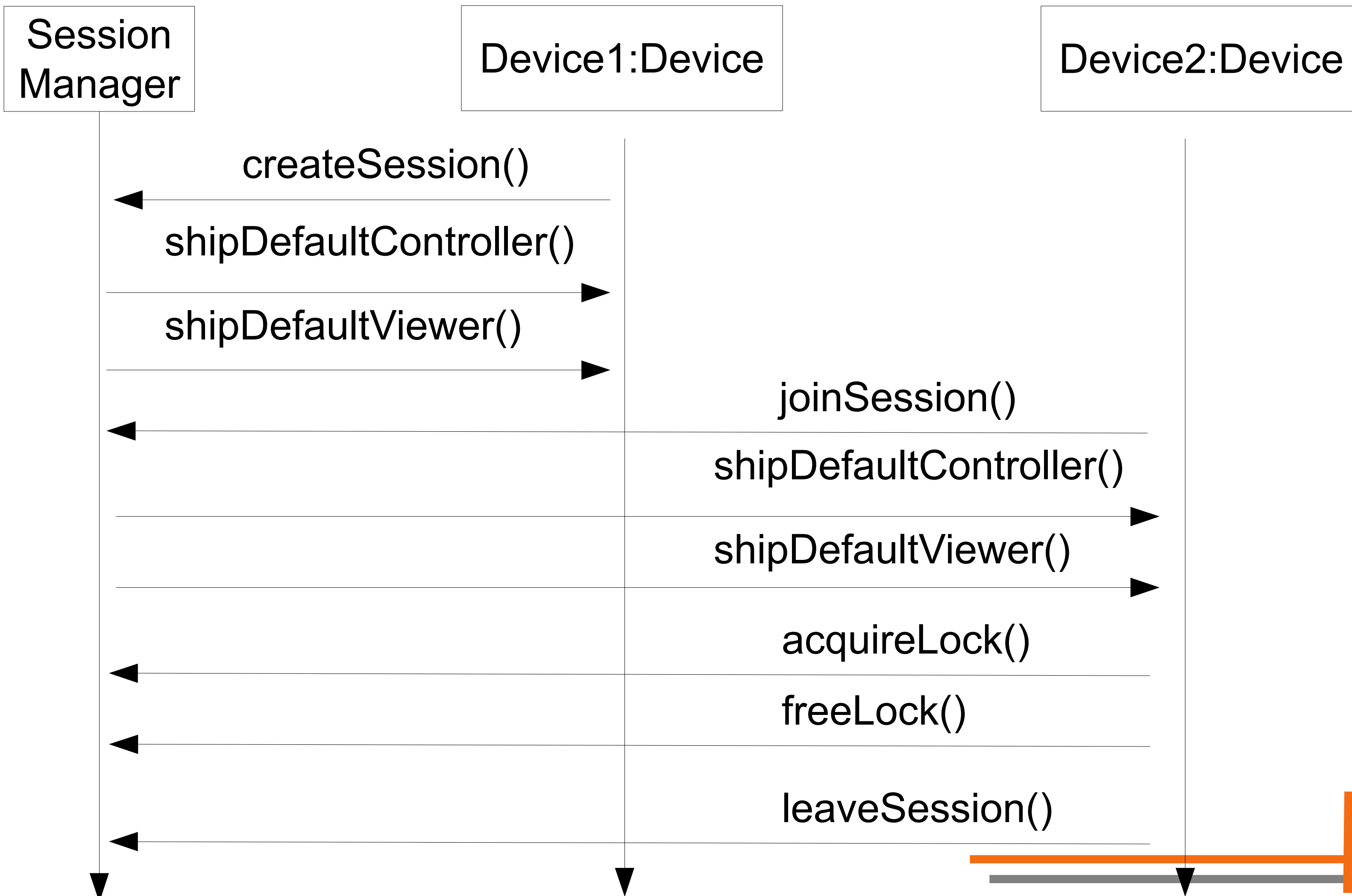
- The *session manager* manages all mobile devices that collaborate in a certain scenario



# Class Diagram Session Manager

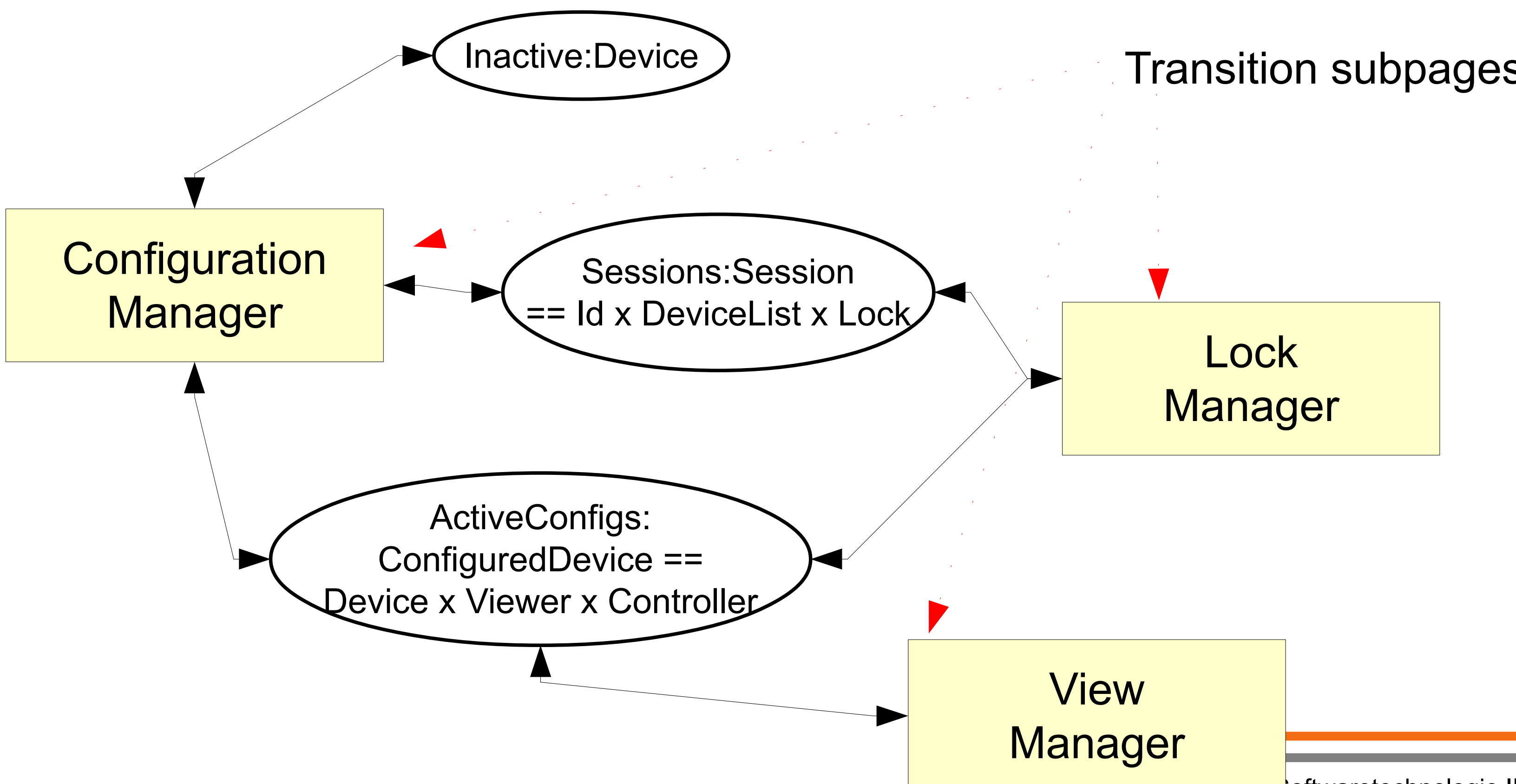


# Sequence Diagram Session Manager



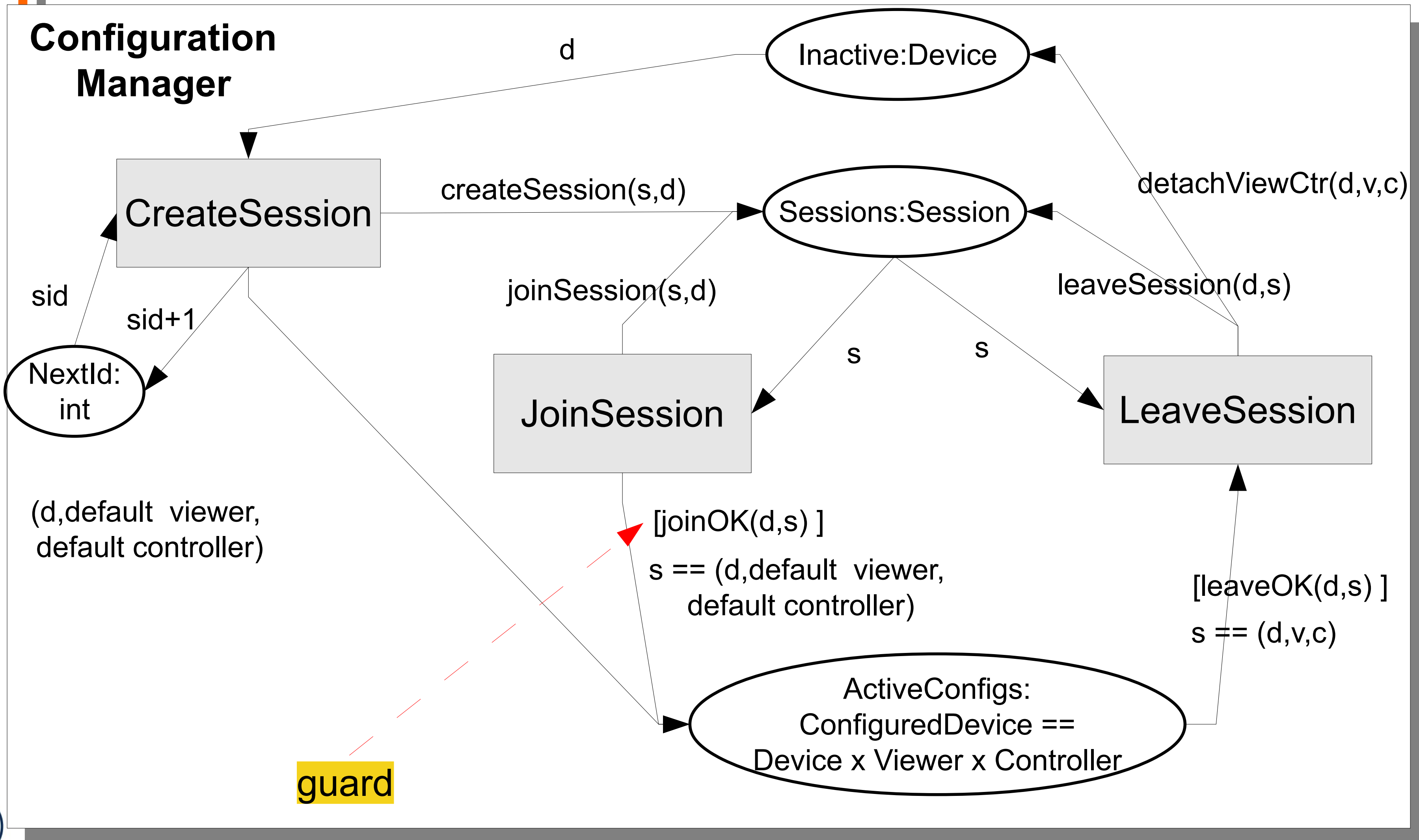
# Session Manager Top-Level CPN

- Double arrows indicate that arrows run in both directions
- Basic Types
  - `Session ::= SessionId DeviceList LockType`
  - `ConfiguredDevice ::= Device Viewer Controller`

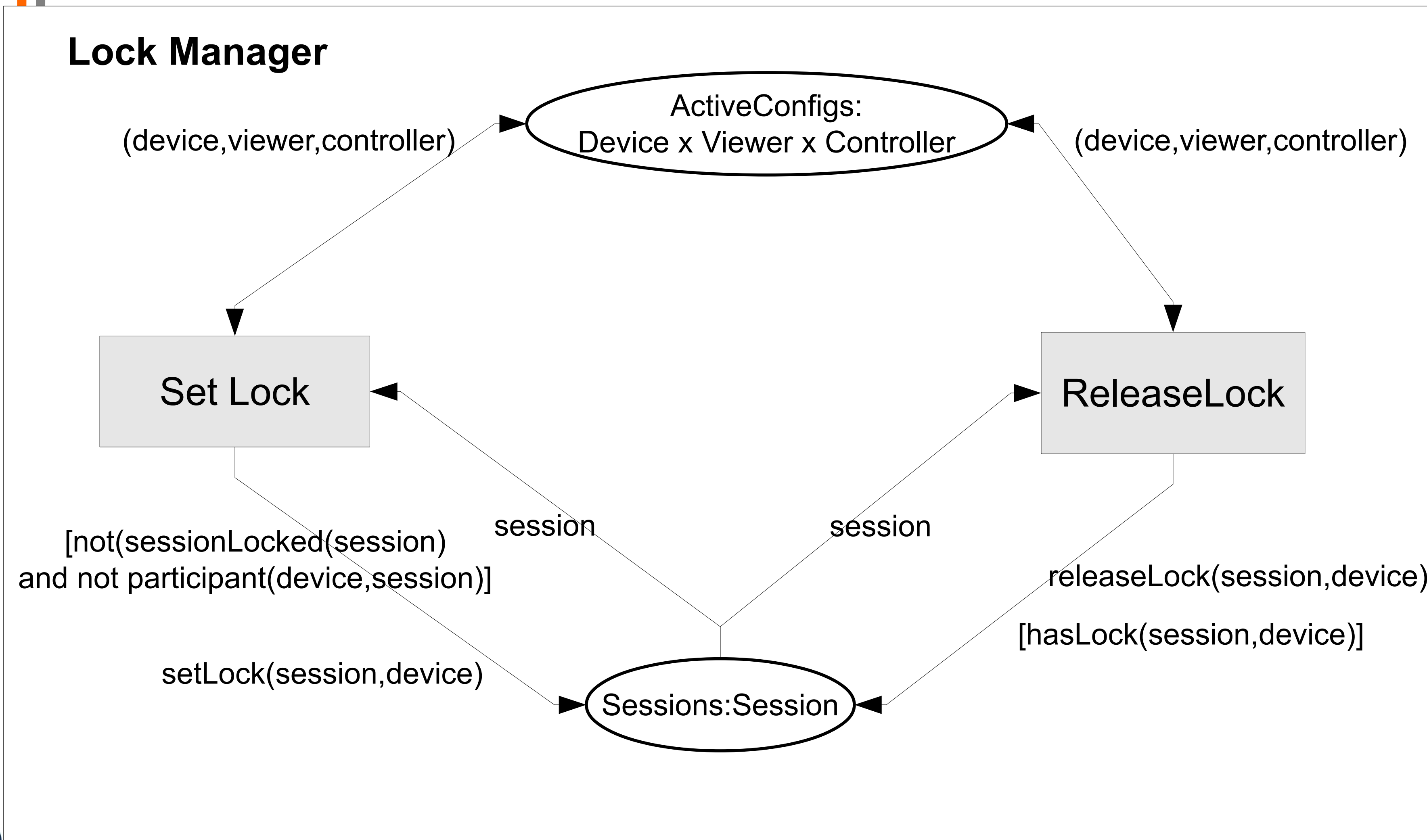


# Configuration Manager Page

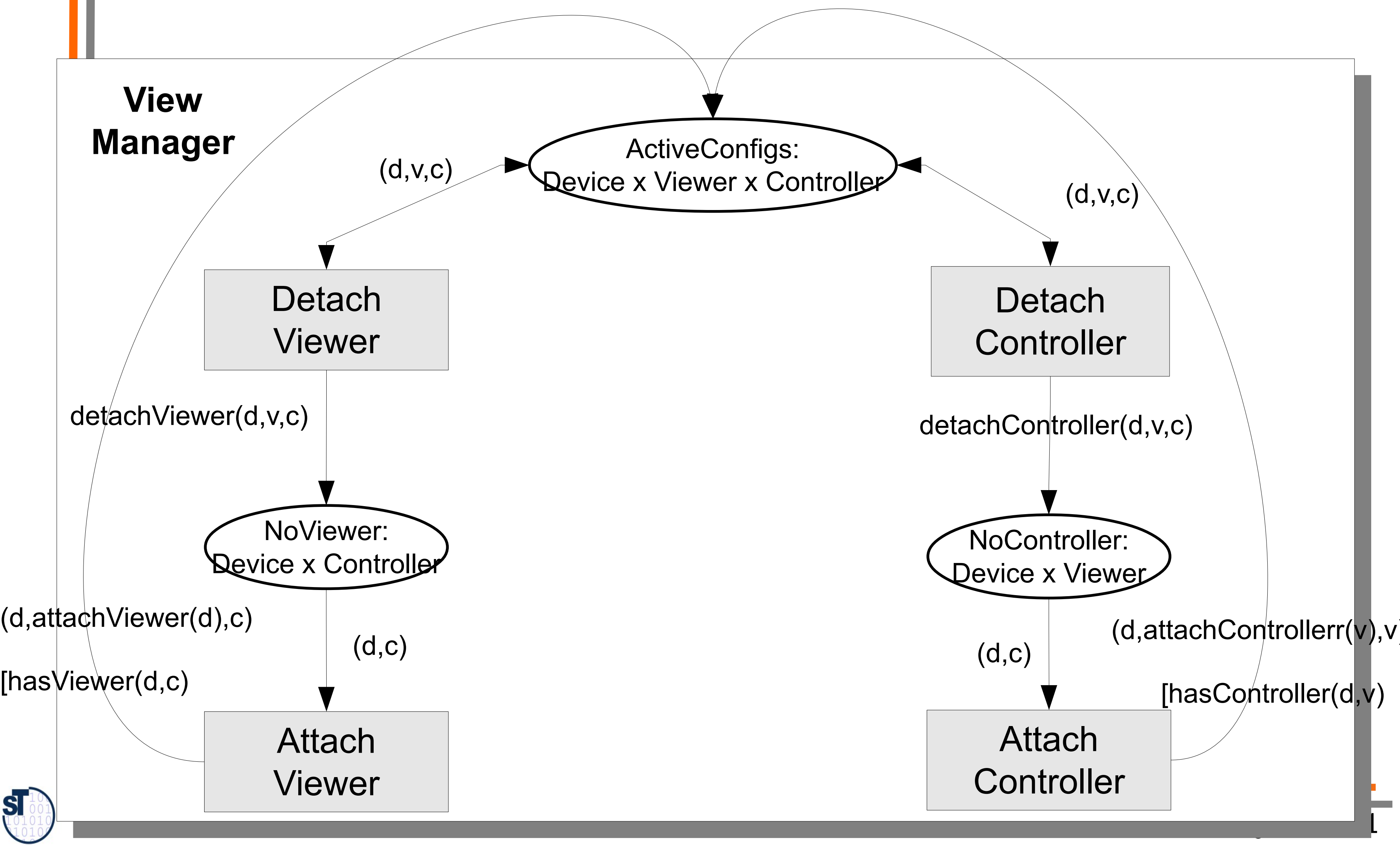
- Page is fused along common names of nodes



# Lock Manager Page



# View Manager Page



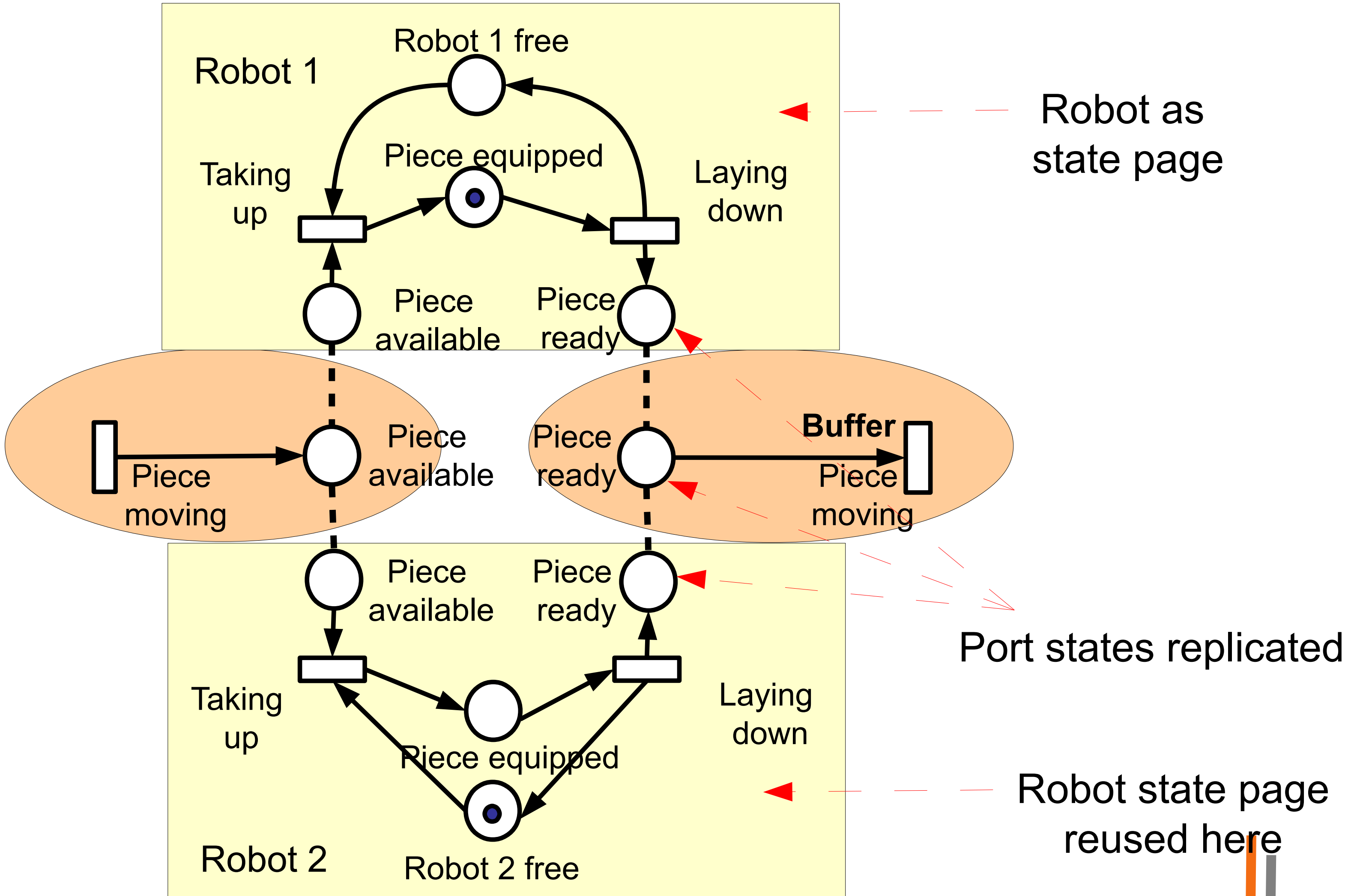
# Remarks

- The CPN pages are attached to UML classes, i.e., describe their behavior
  - States and transitions are marked by UML types
- Every subpage is coupled to others
  - via common states (*port* or *join states*)
    - The union of the pages via join states is steered by OR, i.e., the pages add behavior, but do not destroy behavior of other pages
  - Via common transitions (*port* or *join transitions)*
    - The union of the pages via join transitions is steered by AND, i.e., the pages add behavior and synchronize with transitions of other pages
- Transitions are interpreted as coarse-grain events
  - On the edges, other functions (actions) are called
  - Hence, CPN are *open:* if something is too complicated to model as a PN, put it into functions

# Coupling of Place and Transition Pages

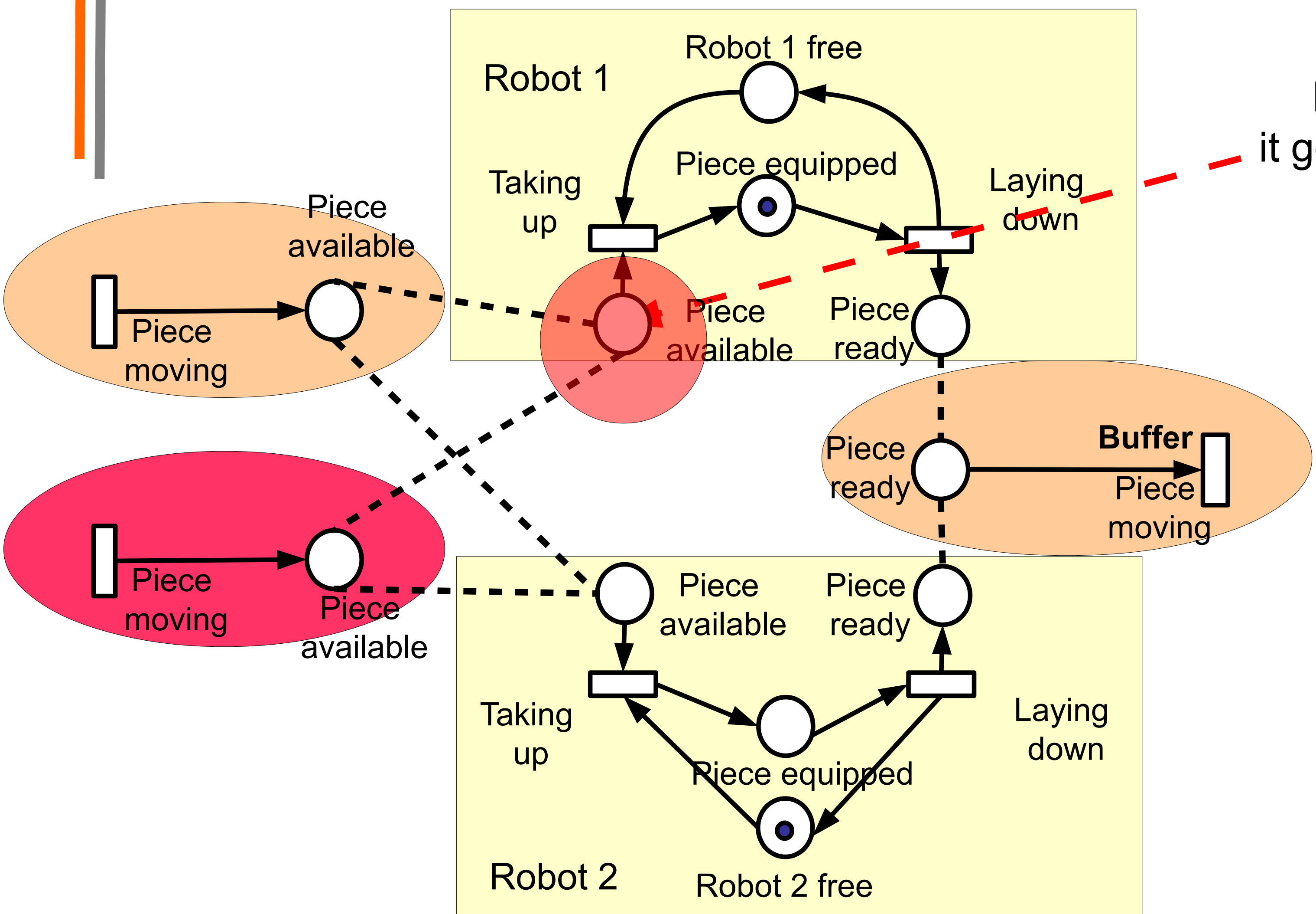
- **Port state coupling** (or **fuse, merge, composition**)**:** Place pages are coupled to other place pages via common states (port states)
  - The union of the pages is steered by OR, i.e., the pages add behavior, but do not destroy behavior of other pages
- **Port transition coupling:** Transition pages are coupled to other transition pages via common transitions (port transitions)
  - The union of the pages is steered by AND, and every page changes the behavior of other page
  - Events must be available on every incoming edge of a transition
  - The transitions of the combined net only fire if the transitions of the page components fire

# Robots with State Pages, Coupled by Replicated State Ports



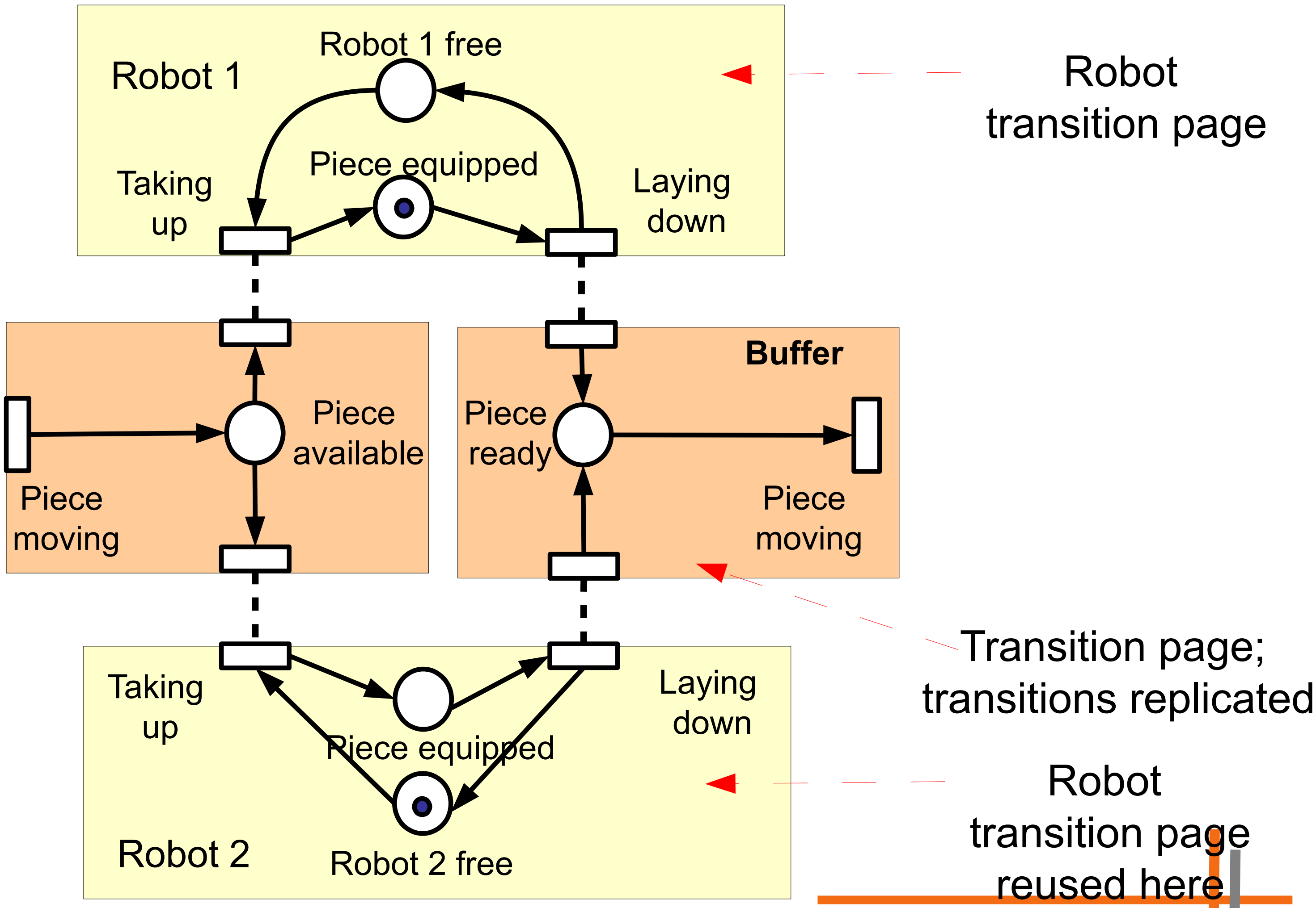

[Helmut Balzert]

# A Robot OR-composed View

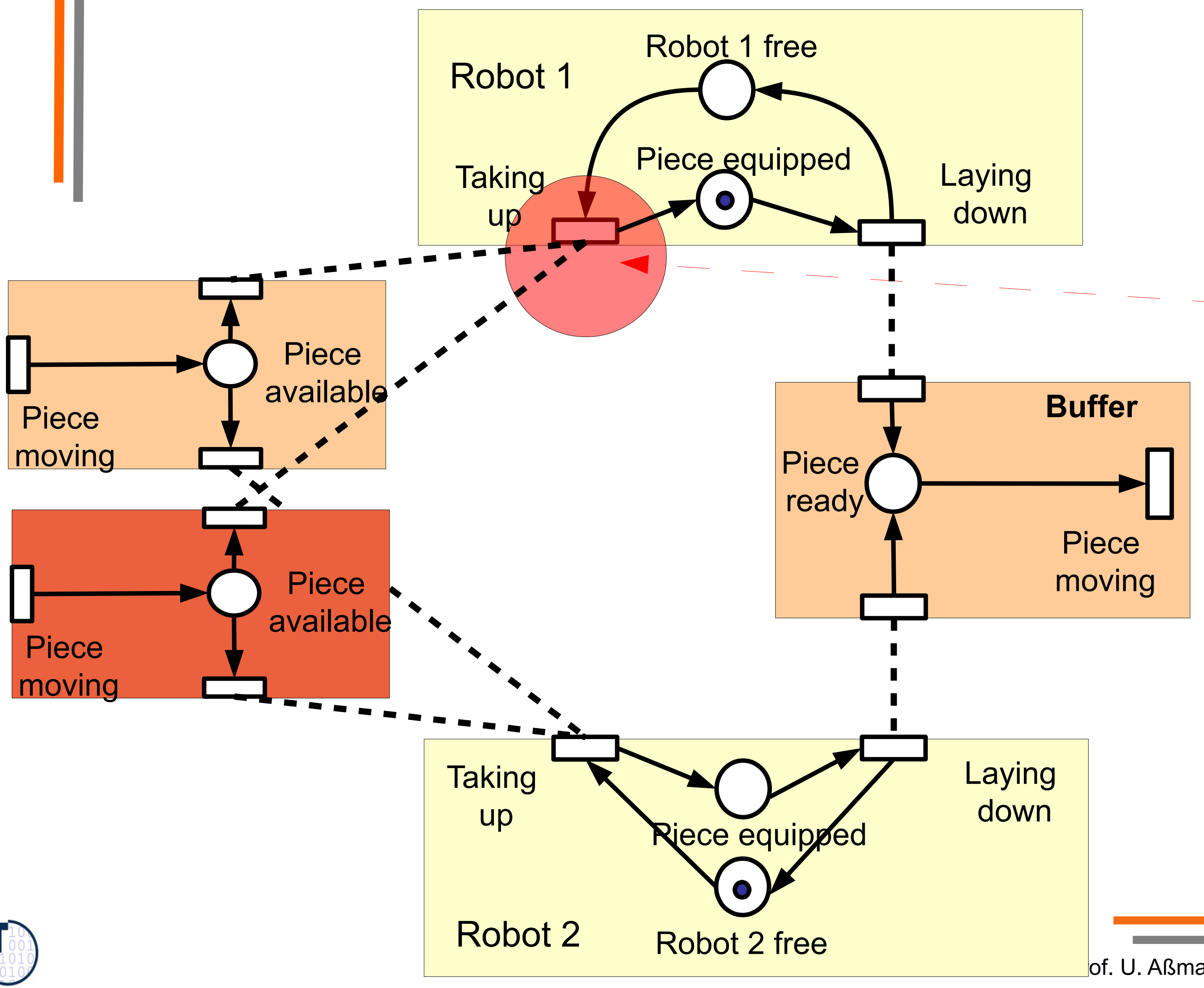



Robot works if it gets piece A OR B

# Robots with Transition Pages, Coupled by Transition Ports



# A Robot AND-composed view




Robot works if it gets Piece A AND B

# Advantages of CPN for the PHM

- The PHM is a distributed and mobile scenario
  - Devices can fail (battery empty, wireless broken, etc)
  - The resulting CPN can be checked on deadlock, i.e., will the PHM session manager get stuck?
- Compact specification
  - Usually, CPN are much more compact than statecharts
- Variability
  - The pages are modular, i.e., can be exchanged for variants easily (e.g., other locking scheme)

# 3.4 Parallel Composition of Colored Petri Nets

# Parallel composition of PN

- Complex synchronization protocols can be abstracted to a pattern (als called transition page or a place page)
- When joining PN with AND (i.e., joining transition pages), synchronization protocols can be overlayed to existing sequential specifications

# Unforeseeable Extensible Workflows

- Workflows are described by Colored Petri Nets (CPN) or languages built on top of CPN:
  - YAWL language [van der Aalst]
  - Workflow nets

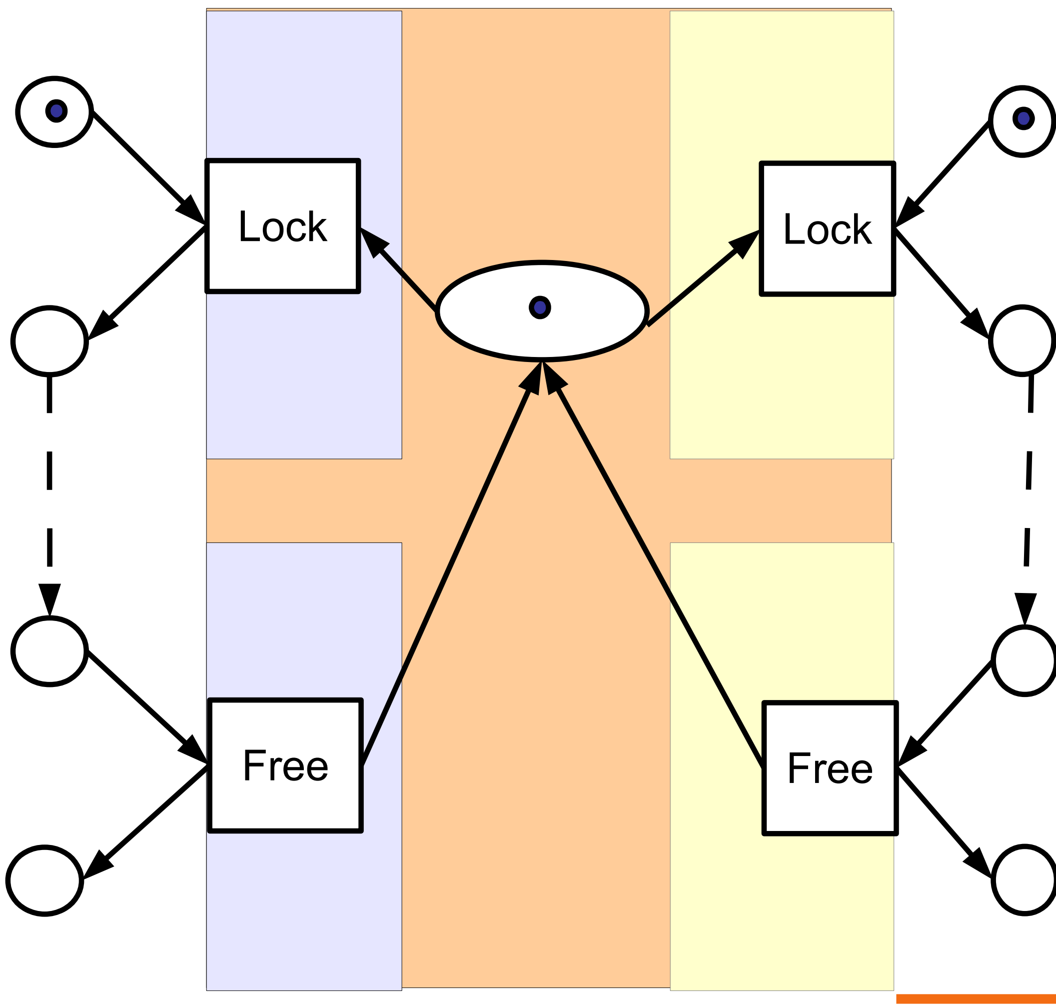
- We can use the extension of CPN for workflow composition, enriching a workflow *core* with a workflow *aspect:*
  - **Place extension (State extension):** adding more edges in and out of a place (state):
    - OR-based composition: Core OR view: Core-place is ORed with Aspect-Place
  - **Transition extension (Activity extension):** adding more edges in and out of a transition (activity)
    - AND-based composition: Core-transition is ANDed with Aspect-transition

# Weaving Patterns for Synchronization Protocols with AND Composition

- Complex synchronization protocols can be abstracted to a transition page
- Weaving them with AND, they can be overlayed to existing sequential specifications

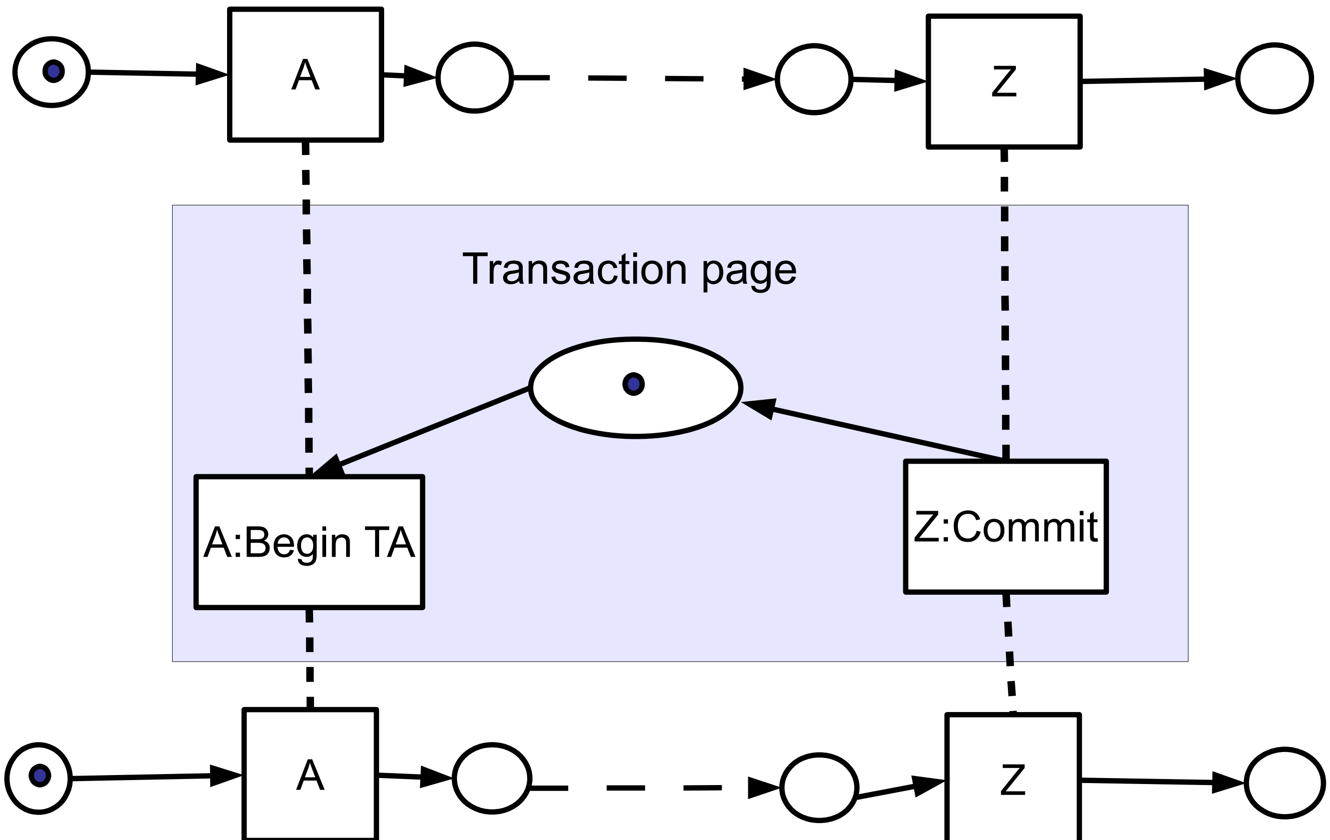
# Semaphores For Mutual Exclusion Revisited

- Forms a synchronisation aspect via ANDed Lock transitions



# Transaction Protocols as AND-Aspects

- Crosscut between processes (cores) and transaction protocol (aspect)



# Insight

- AND-Merge and OR-Merge of CPN are sufficient basic composition operators for building complex aspect weavers for workflow languages built on CPN

AND-weaving for synchronization

OR-weaving for functional extension

# 3.5 The Application to Modelling

# Petri Nets Generalize UML Behavioral Diagrams

**Activity Diagrams**

- Activity Diagrams are similar to PN, but not formally grounded
  - Without markings
  - No liveness analysis
  - No resource consumption analysis with boundness
  - No correspondence to UML statechart, although for PN holds that PN with finite reachability graphs correspond to finite automata
- I.e., it is difficult to prove something about activity diagrams, and difficult to generate (parallel) code from them.

**Data-flow diagrams**

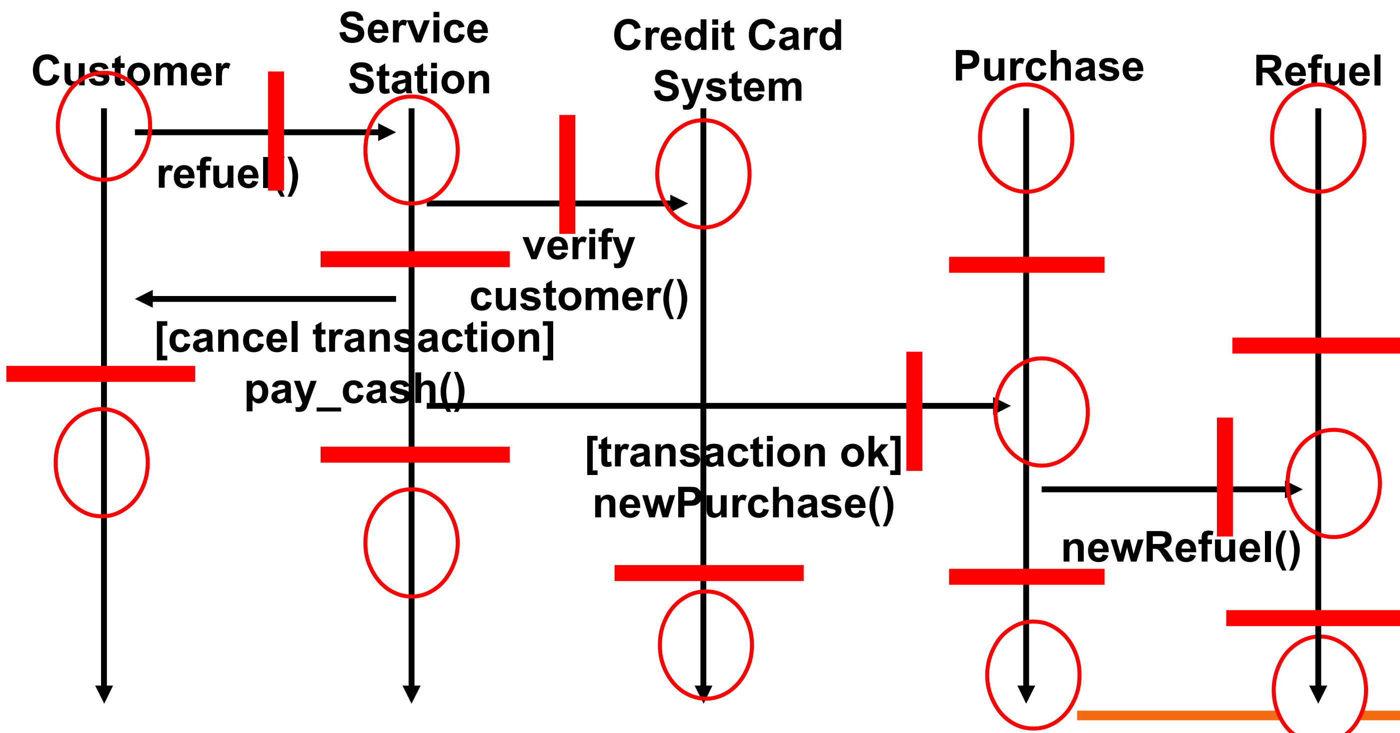
- DFD are special form of activity diagrams, and correspond to Marked Graphs

**Statecharts**

- Finite automata are restricted form of Petri nets
- The hierarchical structuring in Statecharts is available in High-Level Petri Nets (e.g., CPN)

# Petri Nets Generalize UML Sequence Diagrams

- The object life lines of a sequence diagram can be grouped into state such that a PN results
- All of a sudden, liveness conditions can be studied
  - Is there a deadlock in the sequence diagram?
  - Are objects treated fair?



# A Simple Modelling Process for Safety-Critical Software with CPN

- **Elaboration**: Identify active and passive parts of the system
  - Active become transitions, passive to places
- **Elaboration**: Find the relations between places and transitions
- **Elaboration**: How should the tokens look like: boolean? Integers? Structured data?
  - Use UML class diagrams as token type model
- **Restructure**: Group out subnets to separate ”pages”
- **Refactor**: Simplify by reduction rules
- **Elaboration**: Analyse the specification on liveness, boundedness, reachability graphs, fairness. Use a model checker to verify the CPN
- **TransformRepresentation**: Produce views as statecharts, sequence, collaboration, and activity diagrams..

# How to Solve the Reactor Software Problem?

- Specify with UML and CPN
  - Verify it with a model checker
  - Let a prototype be generated
  - Test it
  - Freeze the assembler
- Then, verify the assembler, because you should not trust the CPN tool nor the compiler
  - Any certification agency in the world will require a proof of the assembler!
- However, this is much simpler than programming reactors by hand...

# The Gloomy Future of PN

- PN will become the major tool in a future CASE tool or integrated development environment
  - Different views on the PN: state chart view, sequence view, activity view, collaboration view!
- Many isolated tools for PN exist, and the world waits for a full integration into UML
- CPN will be applied in scenarios where parallelism is required
  - Architectural languages
  - Web service langauges (BPEL, BPMN, ...)
  - Workflow languages
  - Coordination languages

# The End

- Thanks to Björn Svensson for help in making slides, summarizing [Murata]