Parallelism

Master 1 International

Andrea G. B. Tettamanzi
Université de Nice Sophia Antipolis
Département Informatique
andrea.tettamanzi@unice.fr

Lecture 6, Part a

Describing Concurrent and Parallel Algorithms

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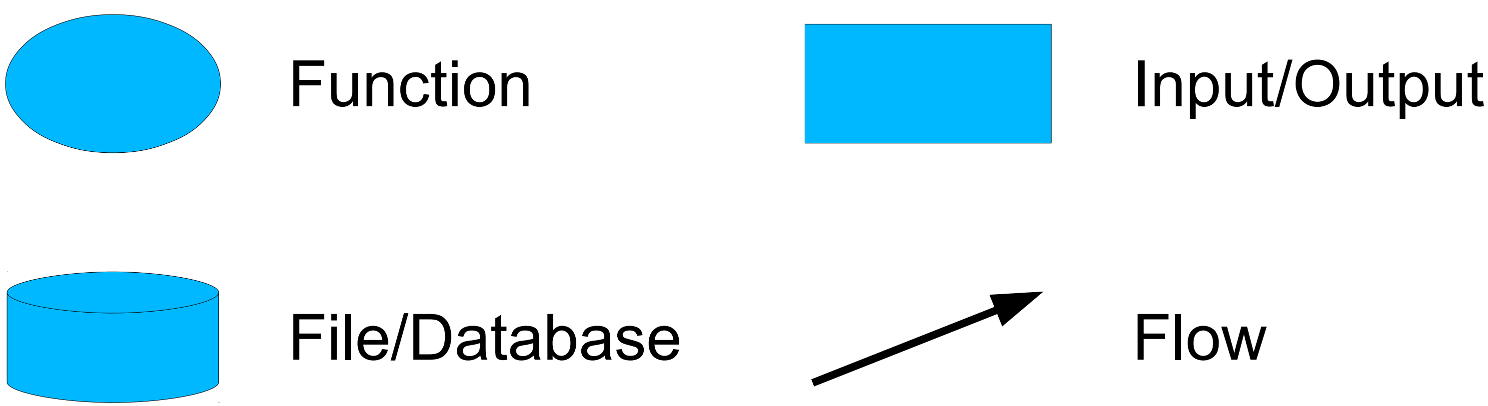
Data Flow

- A model of computation
- Computing nodes execute whenever input data is available
- Nodes are connected by “data paths”
- A special class of algorithms can be modeled as synchronous data flow (SDF) graphs
- A data flow graph is based on data dependencies
- A node can in turn represent another data flow graph (abstraction)
- A node may be implemented as a sequential program

Data-Flow Diagrams

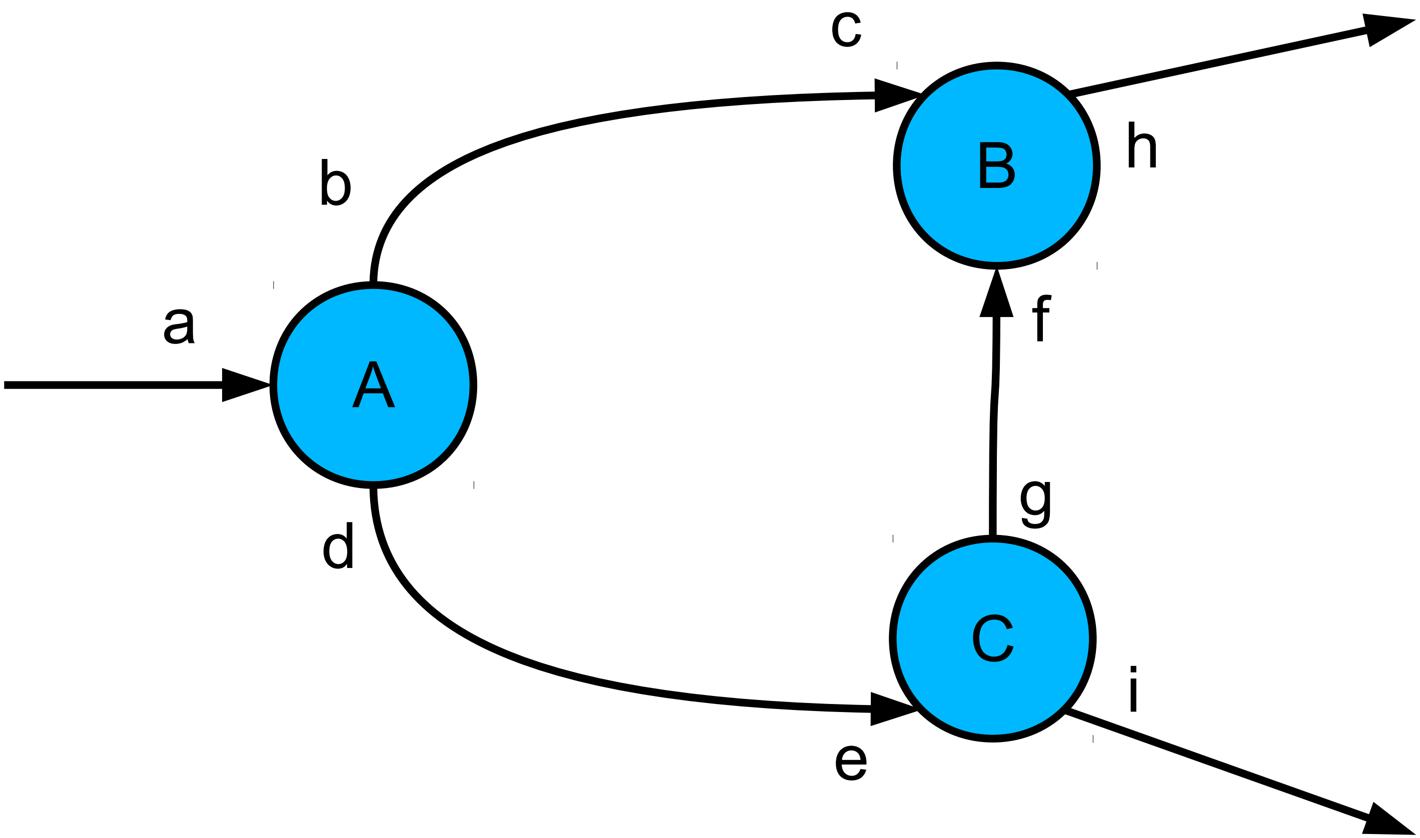
- A time-honored modeling tool in Computer Science
- Graphical representation of the flow of data through an information system
- A DFD shows tasks with their inputs and outputs
- Four graphical elements:



Synchronous Data-Flow Graphs

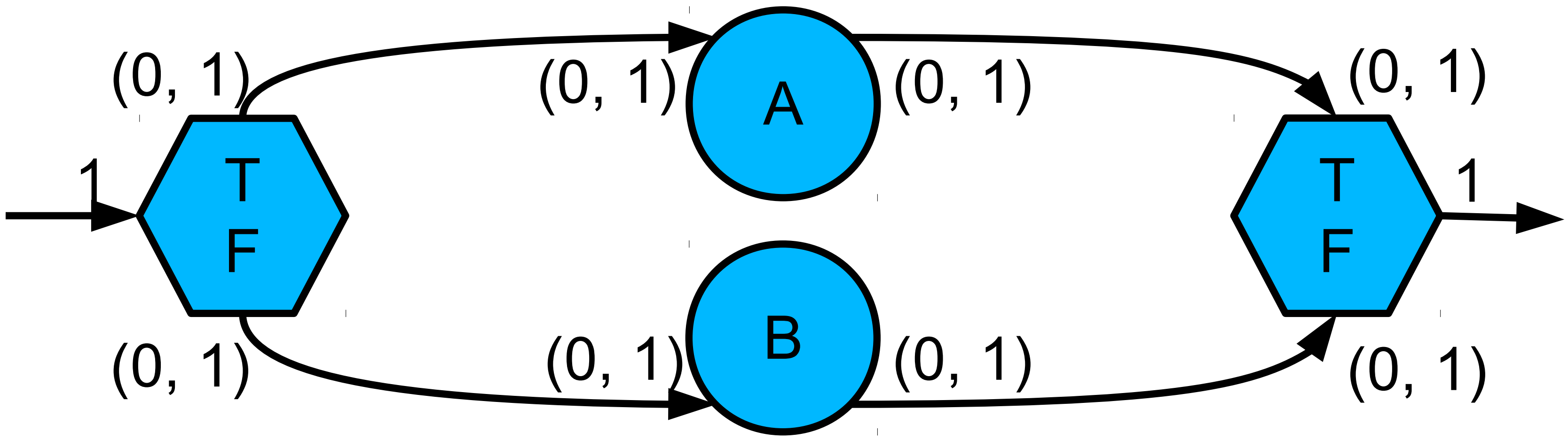
- A special class of algorithms can be modeled as synchronous data flow (SDF) graphs for which efficient implementation methods exist
- An SDF graph is a special case of data flow
- Data are assumed to be made up of “tokens”
- A node is said to be *synchronous* if the number of input tokens that are consumed on each input and the number of output tokens that are produced on each output can be specified a priori.
- Nodes are free from side effects
- Nodes may have a state, but this state does *not* influence the number of tokens consumed and produced in each cycle
- Originally proposed for signal processing

SDF Graphs



SDF Graphs: Control Nodes

- The “switch” and “select” functions cannot be represented as an SDF node because the number of tokens produced (switch) or consumed (select) cannot be decided a priori
- However, the coarse-grained data flow can still be represented as an SDF graph



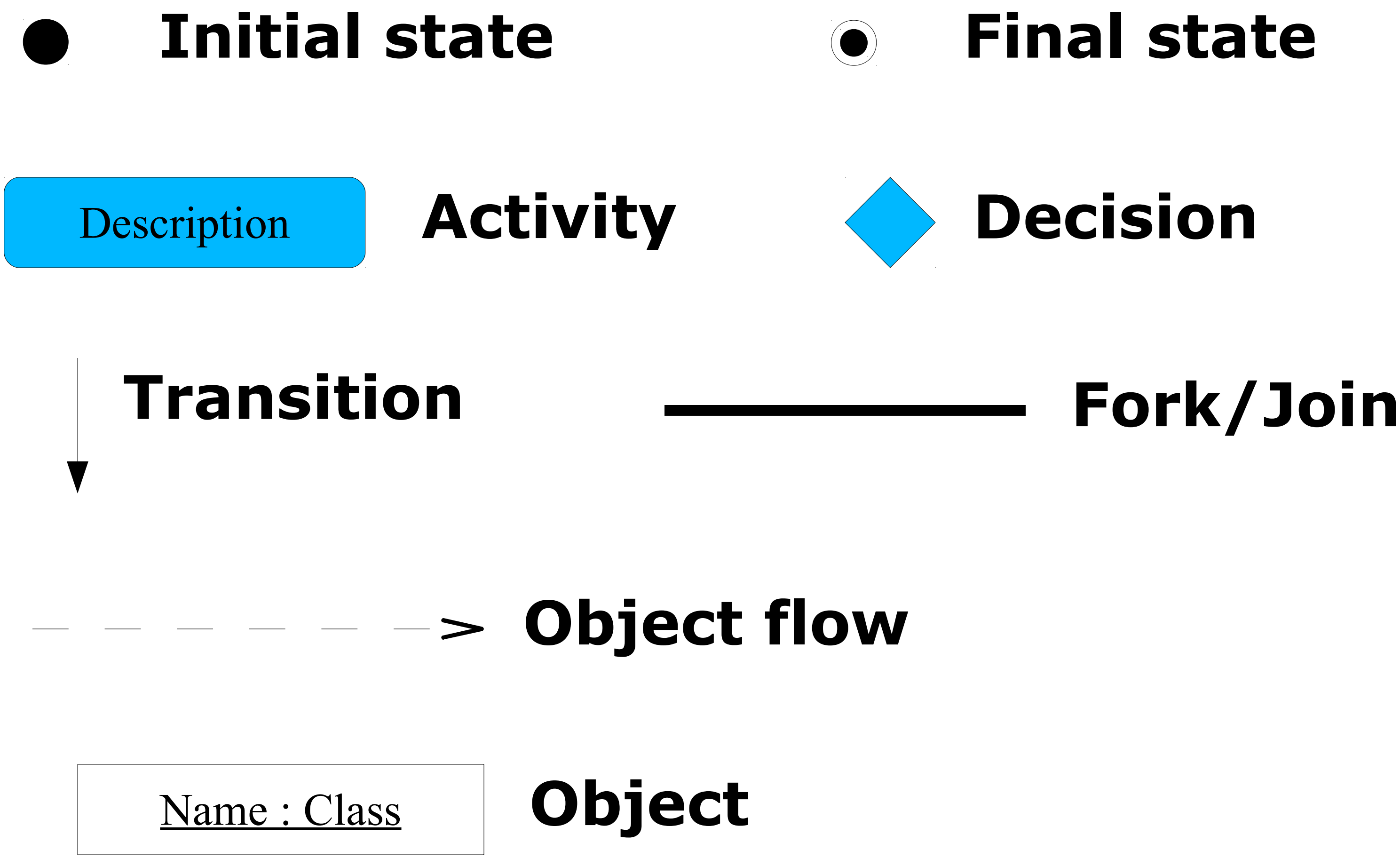
SDF Graphs: Properties

- Compared to data flow, synchronous data flow has the following nice properties:
  - In contrast to data flow graphs scheduling does not have to be done at runtime, but can be done at compile time
  - If a periodic admissible parallel schedule can be found, the memory for buffers is bounded
  - Mathematical methods to derive a schedule exist
- Compiling an SDF graph:
  - find a periodic admissible parallel schedule (PAPS)

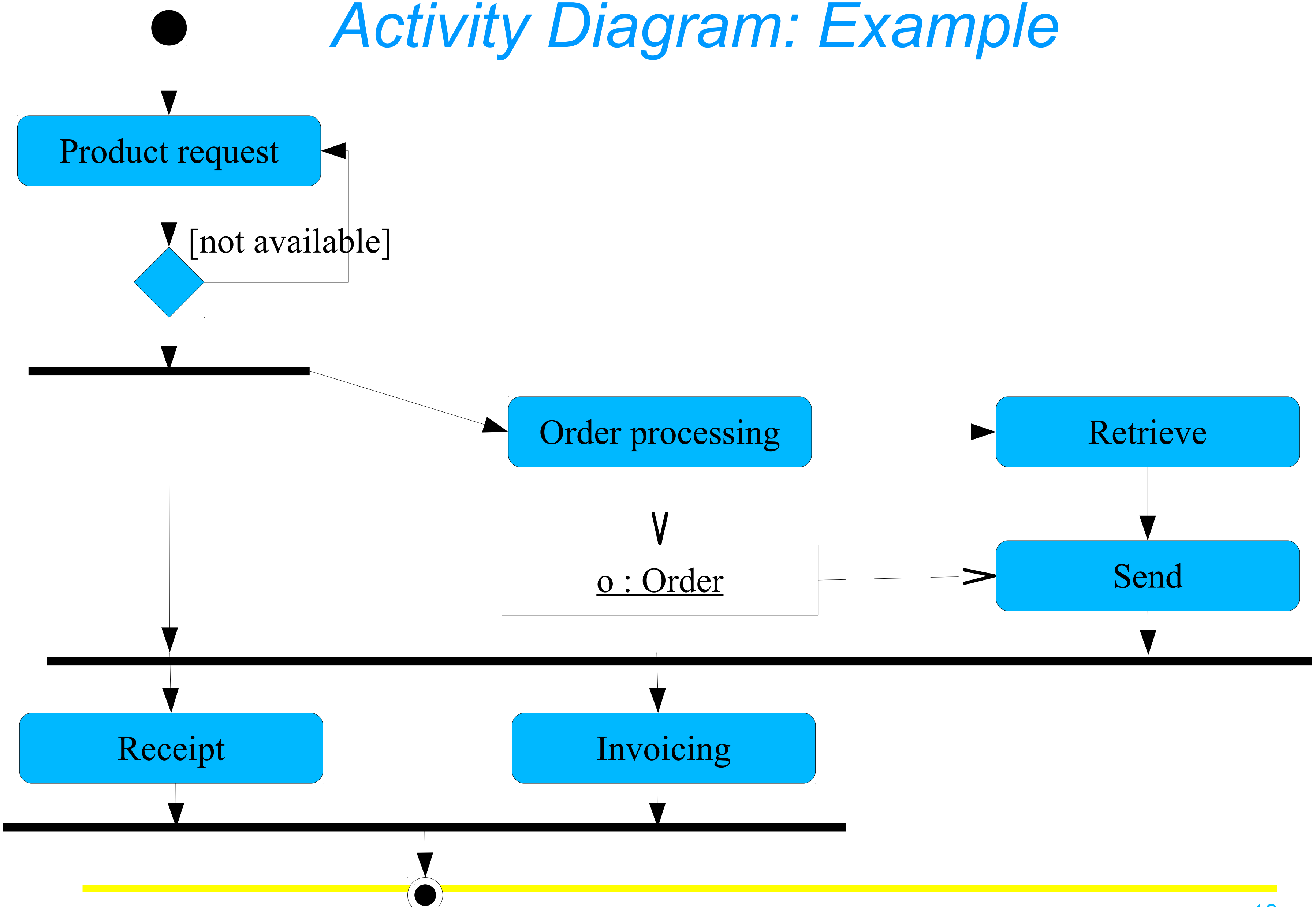
Activity Diagrams

- They are essentially an extension of flow charts
- Part of the UML
- Model the dynamical aspects of a system
- Describe the flow of control from an activity (= task) to another
- Activity
  - Sequence of atomic computations
  - Ends up in an action
- Transition
  - Transfer of control from an activity to another
- Object
  - Result of some activities

Activity Diagrams: Graphical Elements



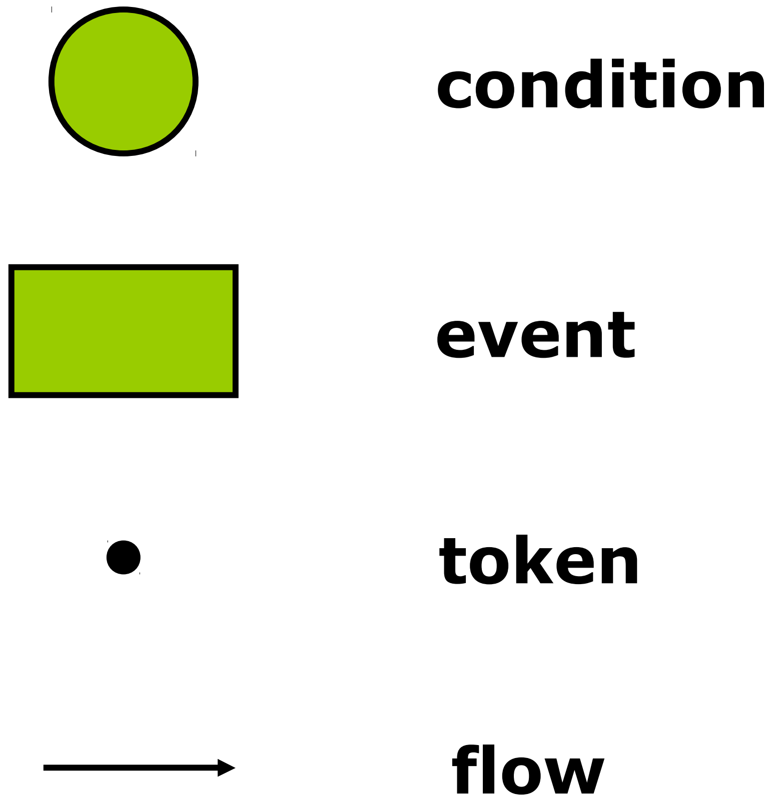
Activity Diagram: Example



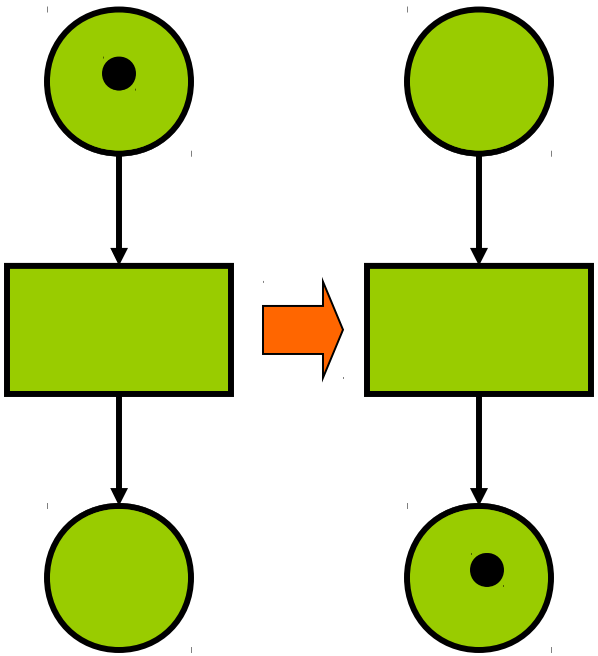
Petri Nets

- Two interesting features
  - Formal definition, allowing formal verification
  - Intuitive graphical representation
- Two types of Petri Nets
  - Place-transition
  - State-event

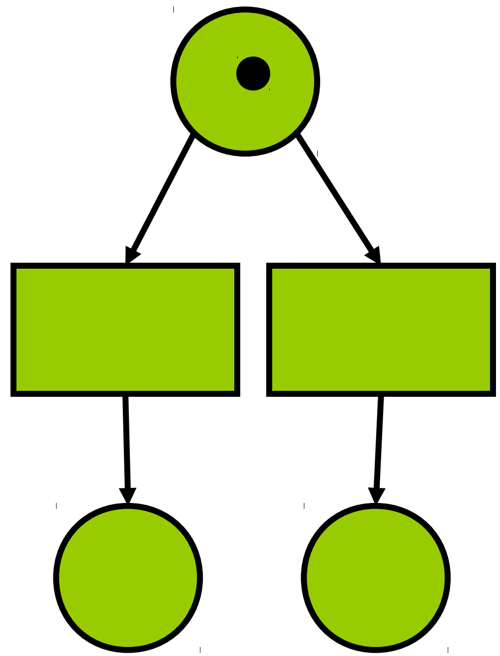
Petri Nets: Graphical Elements



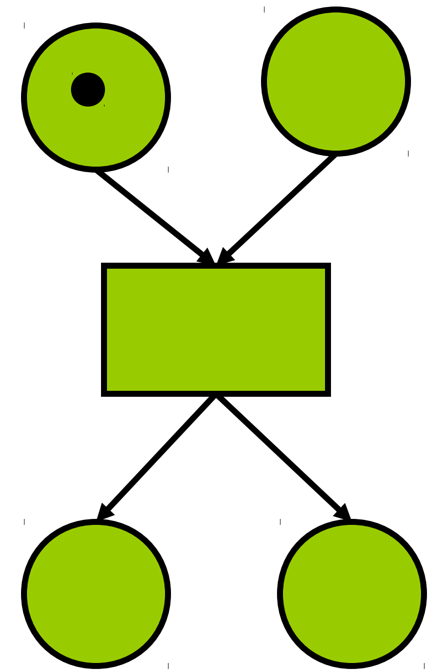
State-Event Petri Nets



Firing of a transition

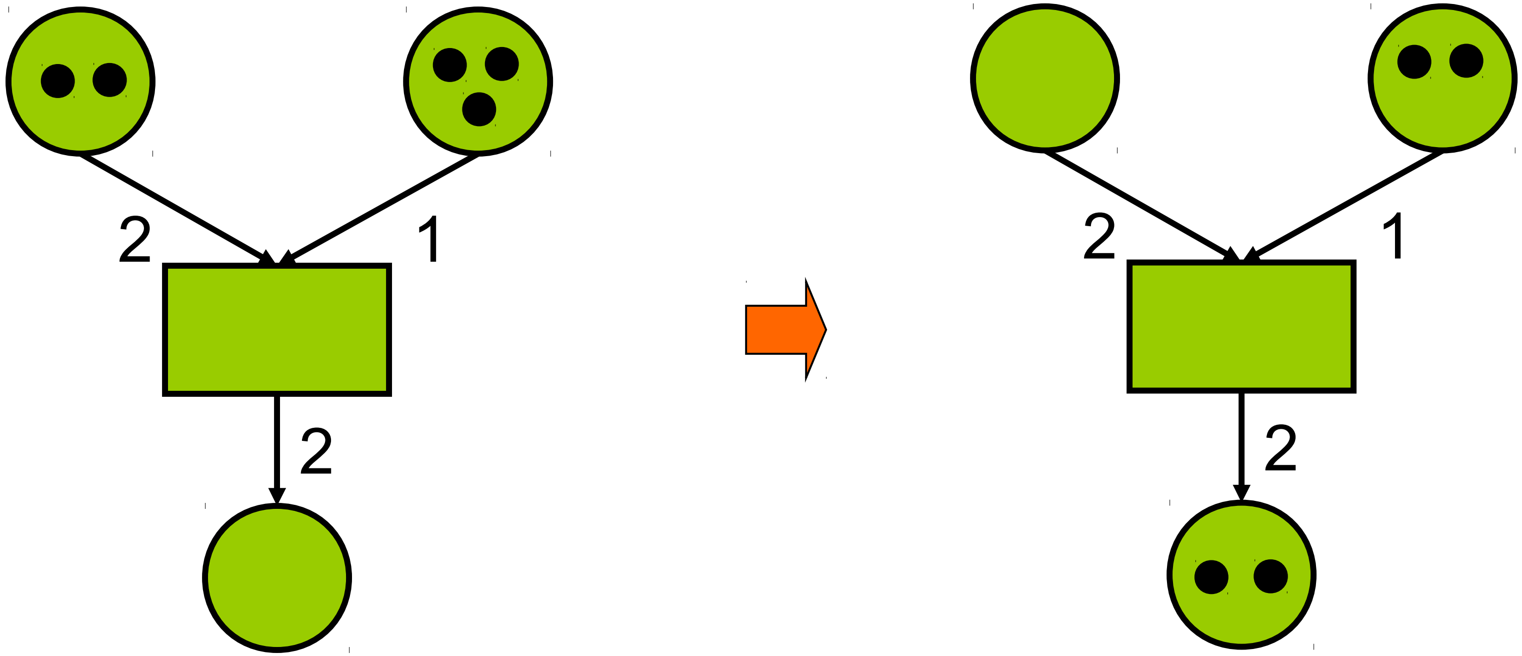


conflict



synchronization

Place-Transition Petri Nets

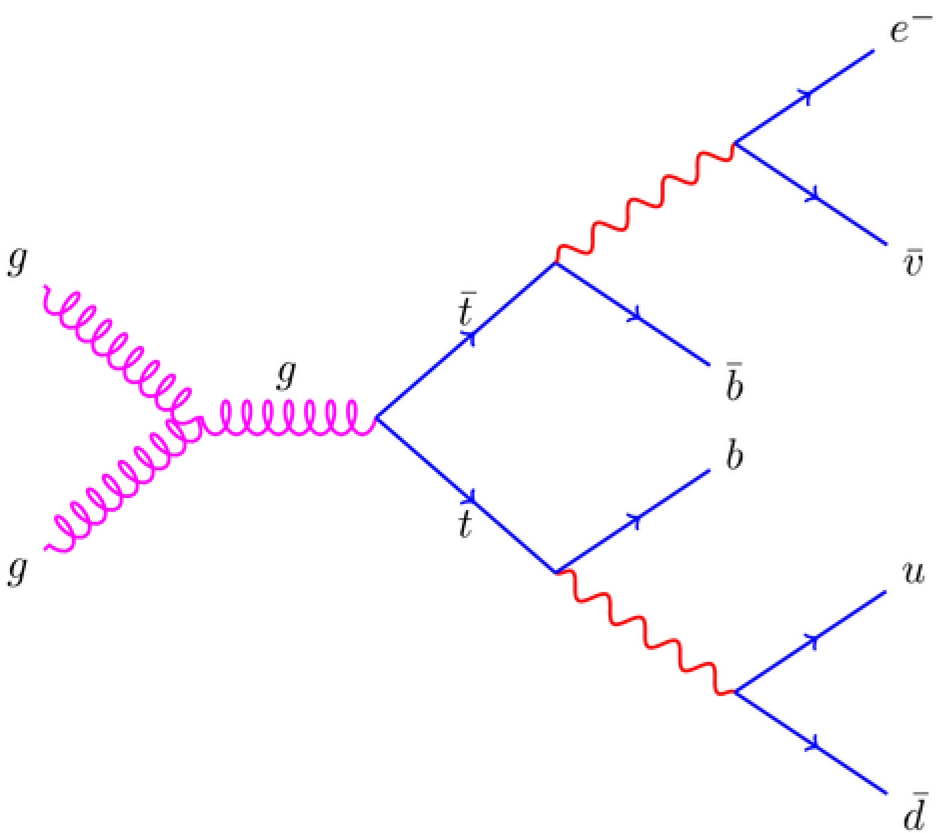


Firing of a transition

Actor Event Diagrams

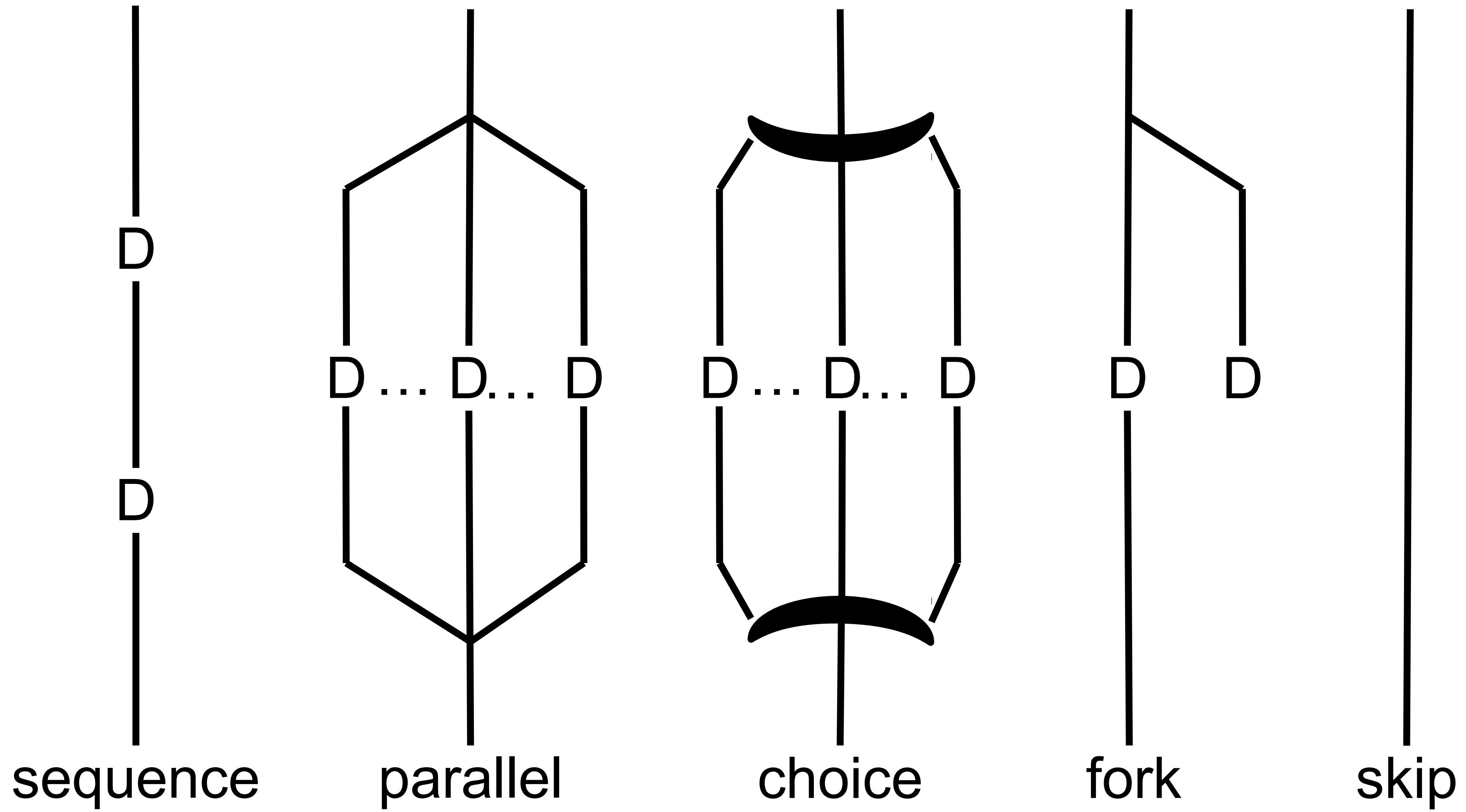
- Based on the Actor model
  - A mathematical model of concurrent computation
  - Actors are the universal primitives of parallel computation
  - Actors = Processes
  - Actors exchange messages
  - Inspired by Physics, including general relativity and quantum mechanics
  - Asynchronous communication
  - Control structures as message passing patterns
- Actor Event Diagrams remind Feynman Diagrams.

Feynman Diagrams



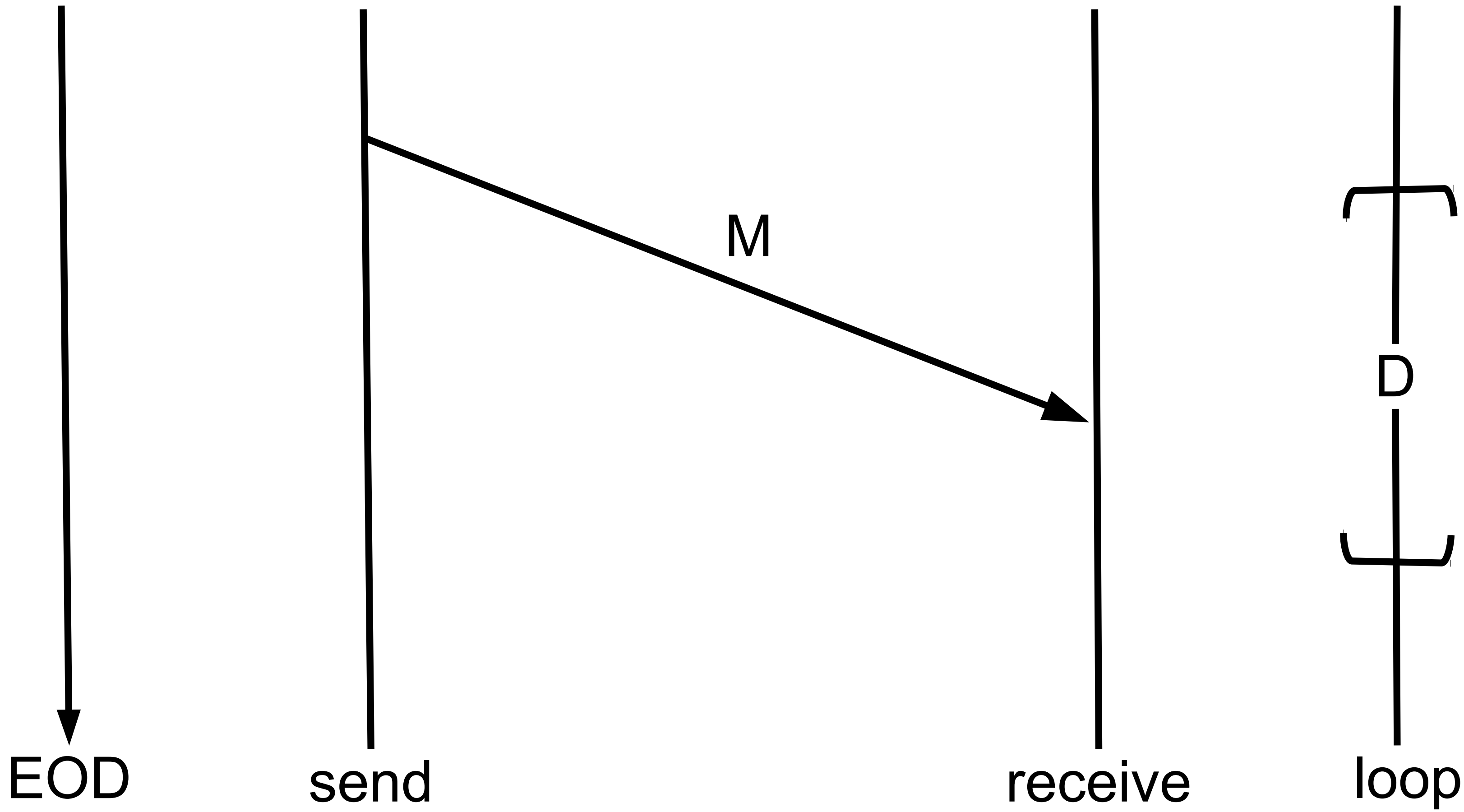
D = diagram

Actor Event Diagrams



D = diagram

Actor Event Diagrams



Algorithmic Skeletons

- Also known as Parallelism Patterns
- Take advantage of common programming patterns to provide an abstract description of parallel and distributed applications
- Some important skeleton patterns:
  - FARM, PIPE, FOR, MAP, D&C, WHILE, IF, SEQ
- Many libraries implement algorithmic skeletons

Algorithmic Skeletons

- FARM (or master-slave): task replication and execution in parallel
- PIPE: staged computation, different tasks performed in parallel on different stages of the pipe
- FOR: fixed iteration
- WHILE: conditional iteration
- IF: conditional branching
- MAP: split task into subtask, execute in parallel, and merge
- D&C (divide & conquer): task recursively subdivided
- SEQ: tasks are executed sequentially

Design of Parallel Algorithms

- Is there a principled way to design parallel algorithms?
- Ian Foster proposed a design process in 4 stages
  - Partitioning
  - Communication
  - Agglomeration
  - Mapping
- Partitioning and communication focus on concurrency and scalability
- Agglomeration and mapping focus on locality and performance

Partitioning

- Decompose the computation and the data into several small tasks
- Data
  - Domain/Data Decomposition
  - Partition data into smaller units that can be distributed
- Algorithm
  - Functional Decomposition
  - Partition the algorithm into tasks that can be performed in parallel/concurrently

Communication

- Focus on the flow of information and coordination among the tasks
- Four design dimensions/decisions:
  - Local vs Global
  - Structured vs Unstructured
  - Static vs Dynamic
  - Synchronous vs Asynchronous

Agglomeration and Mapping

- Agglomeration
  - Group small tasks into larger tasks to improve performance
- Mapping
  - Assign tasks to processors
  - Minimize communication cost

Thank you for your attention