Embedded Control System Development with

Giotto

www.eecs.berkeley.edu/~fresco/giotto

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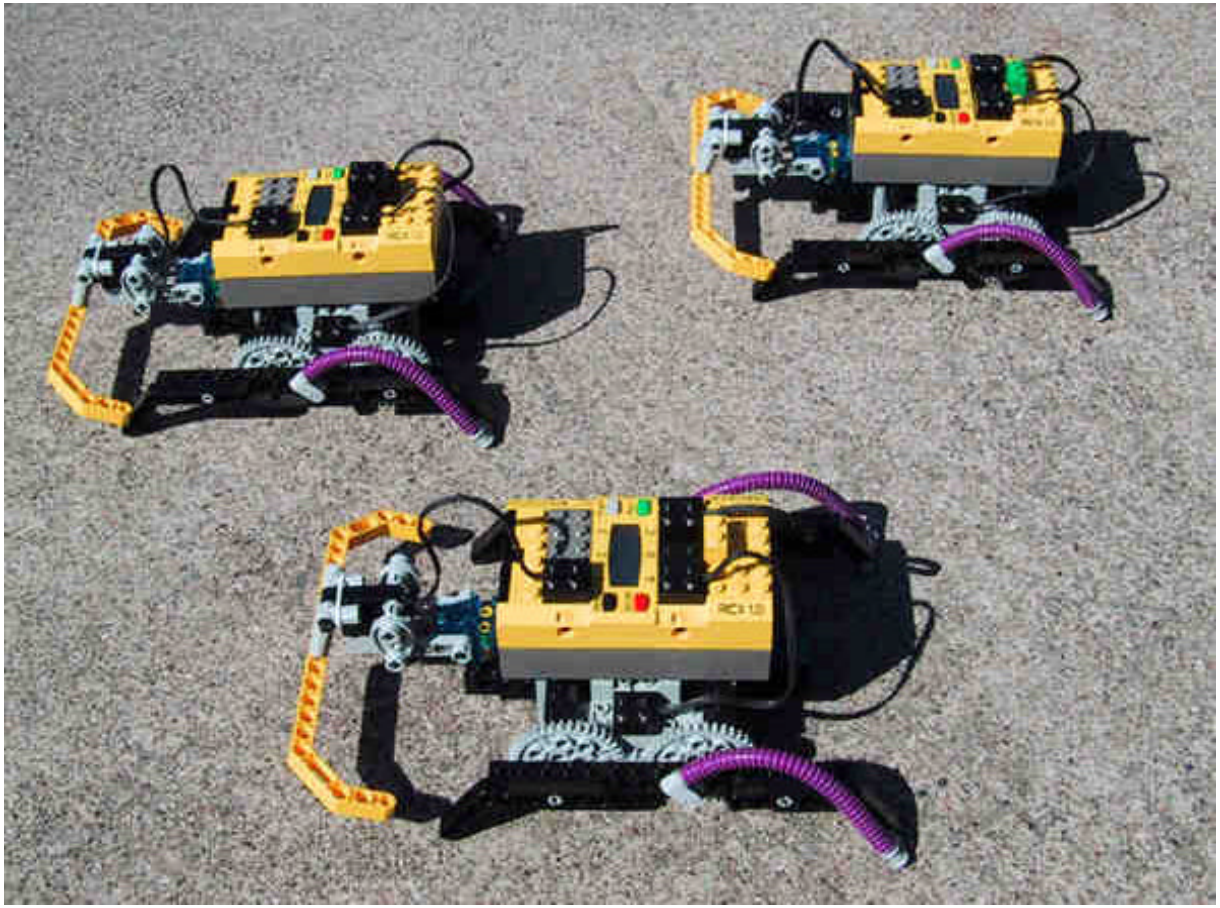
Giotto

- Giotto is a time-triggered and platform independent programming language + compiler + runtime library
- Giotto aims at hard real-time control applications on distributed platforms (safety-critical applications)

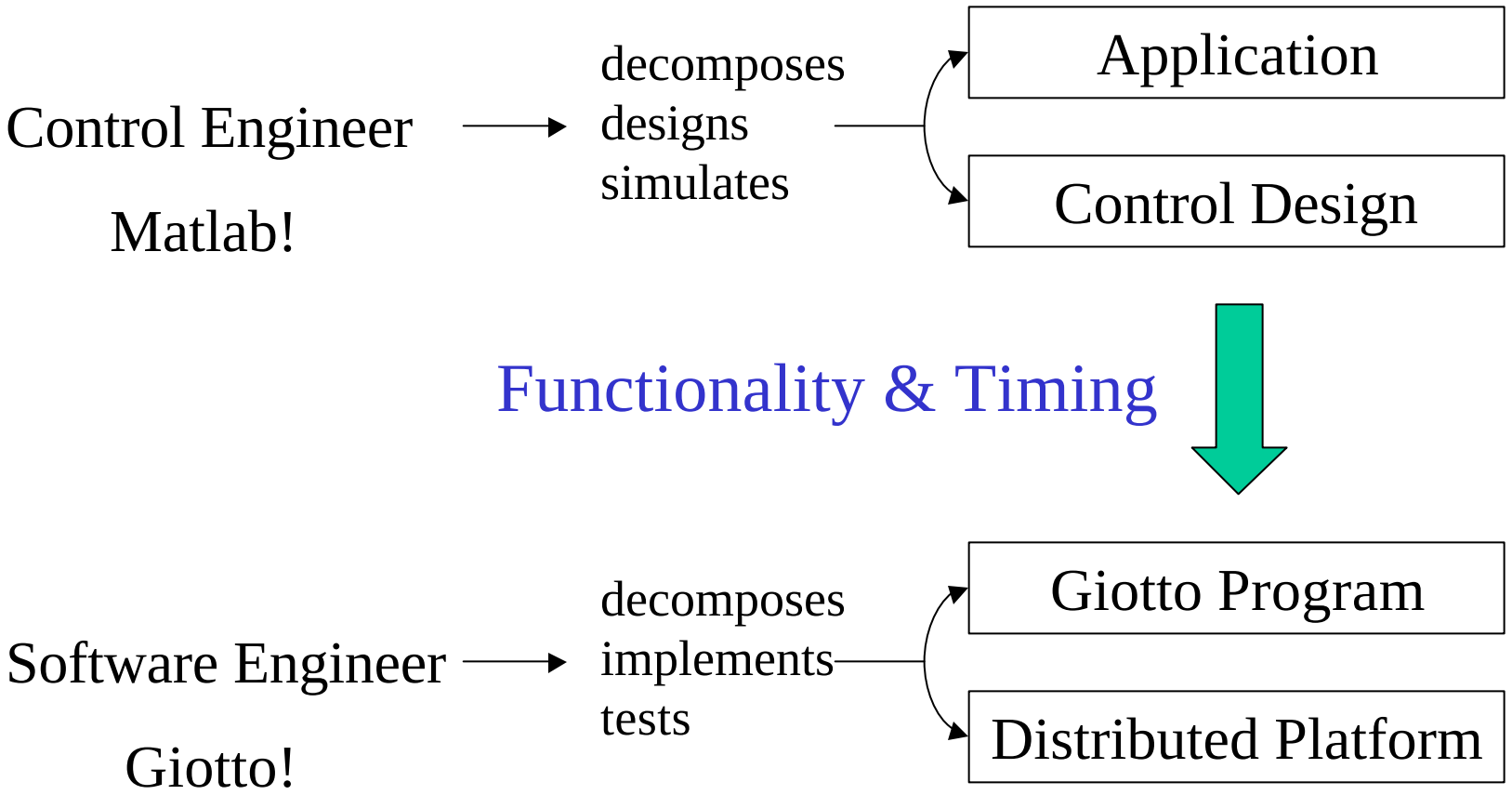
- Giotto provides an abstract programming model for embedded control system development

- Giotto runtime library for VxWorks, model of computation in Ptolemy II (Edward Lee, UC Berkeley)

Sneak Preview



Embedded System Development



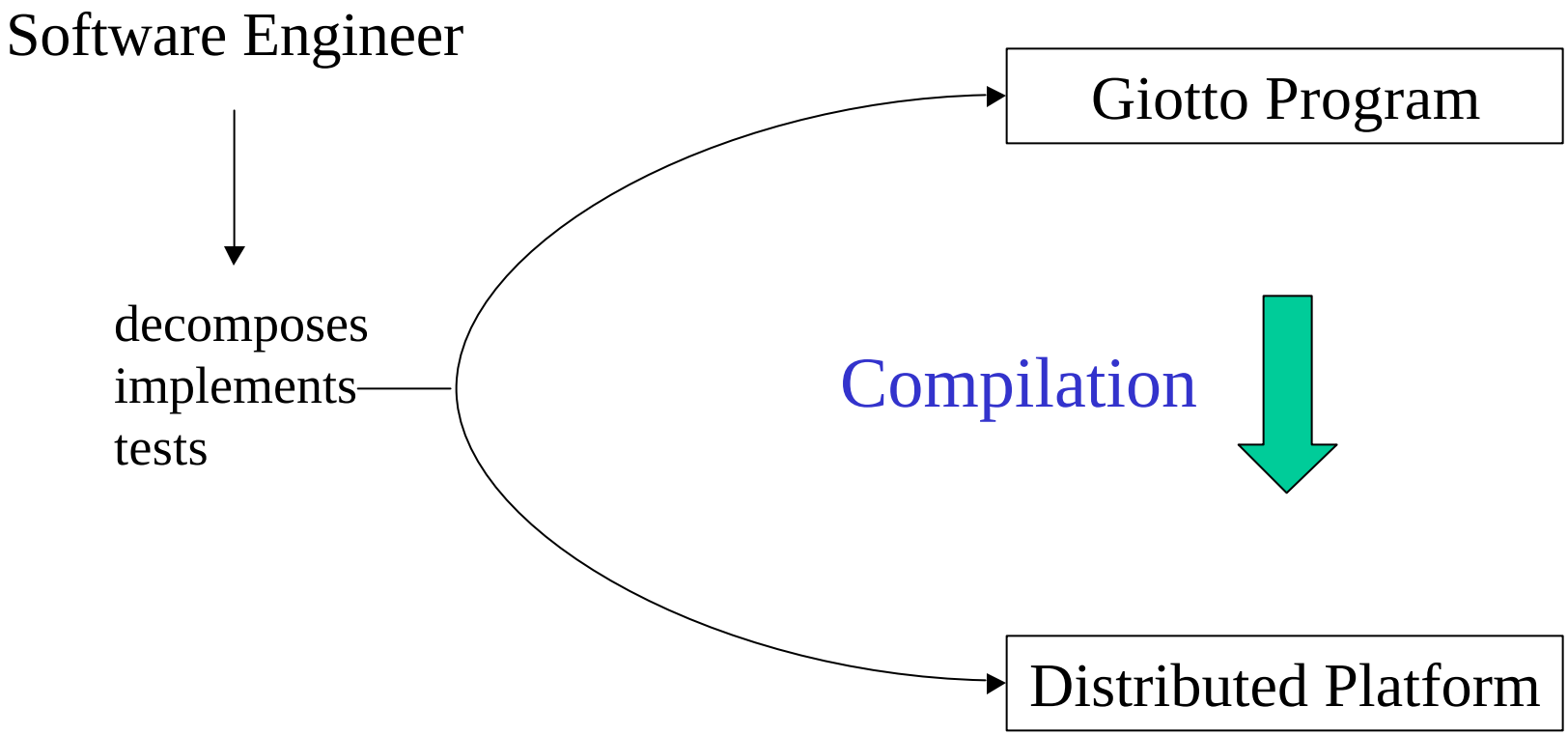
Decomposition: Giotto Modes

Control Engineer → decomposes → Control Design

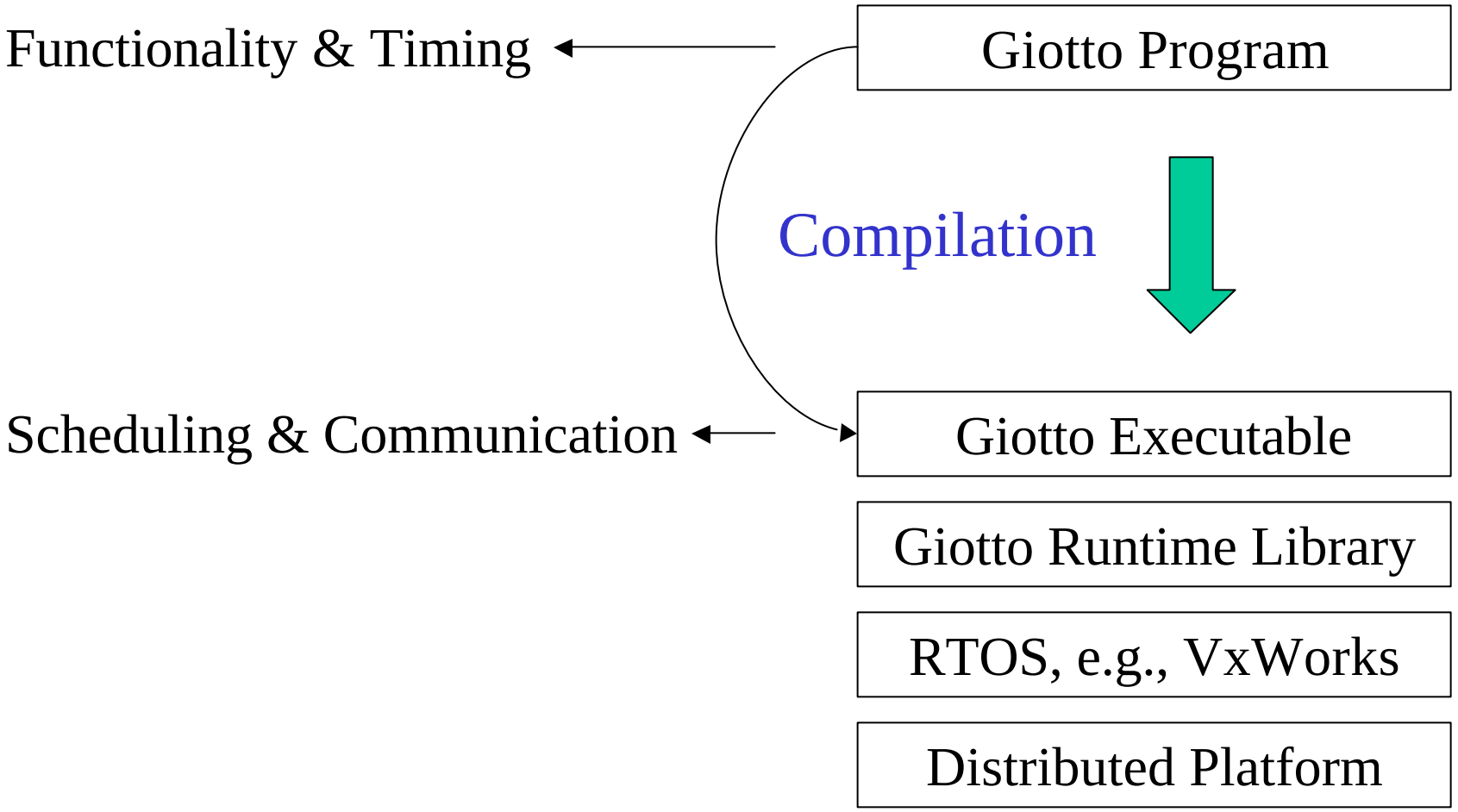
Preserving Structure ↓

Software Engineer → decomposes → Giotto Program

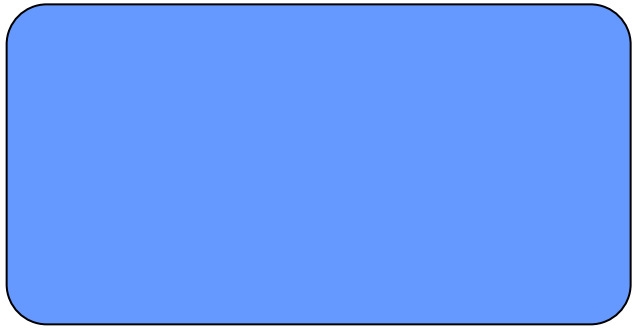
The Giotto Compiler



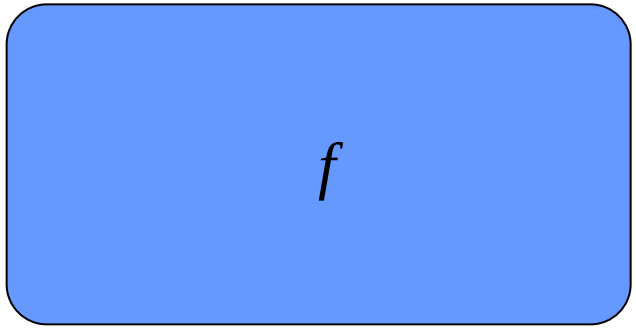
The Giotto Compiler



A Task



Abstract Syntax of a Task



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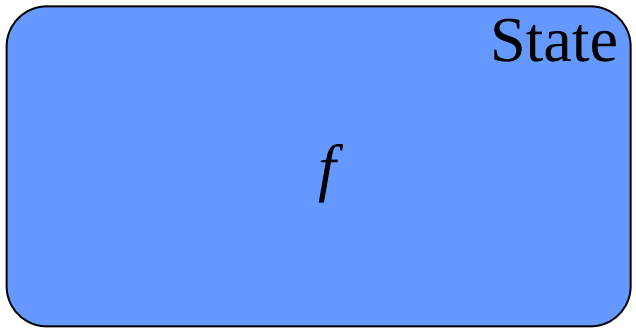

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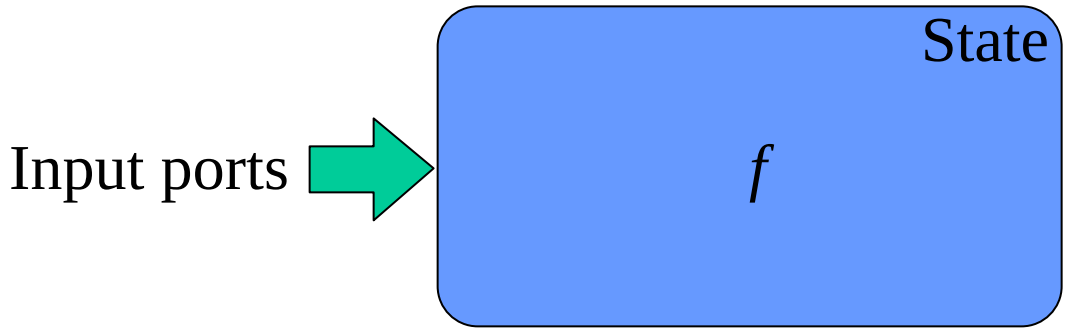

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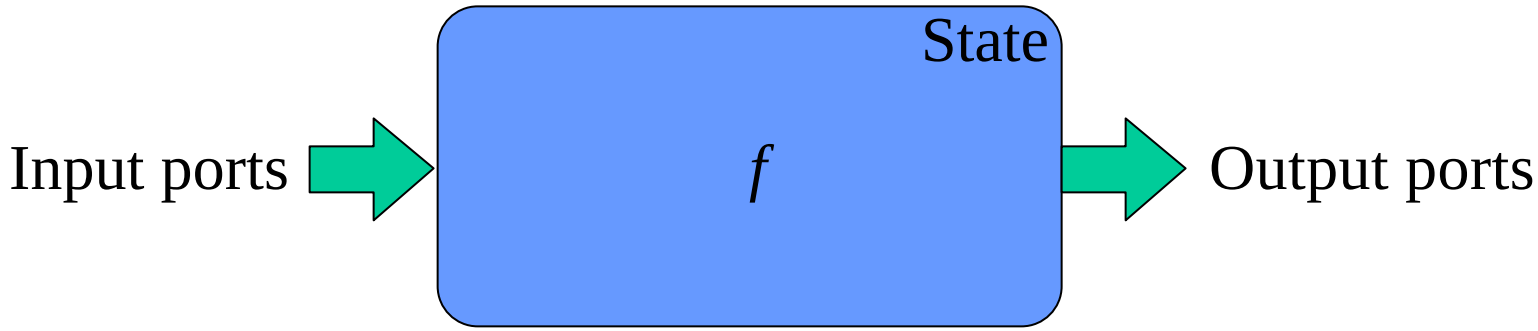

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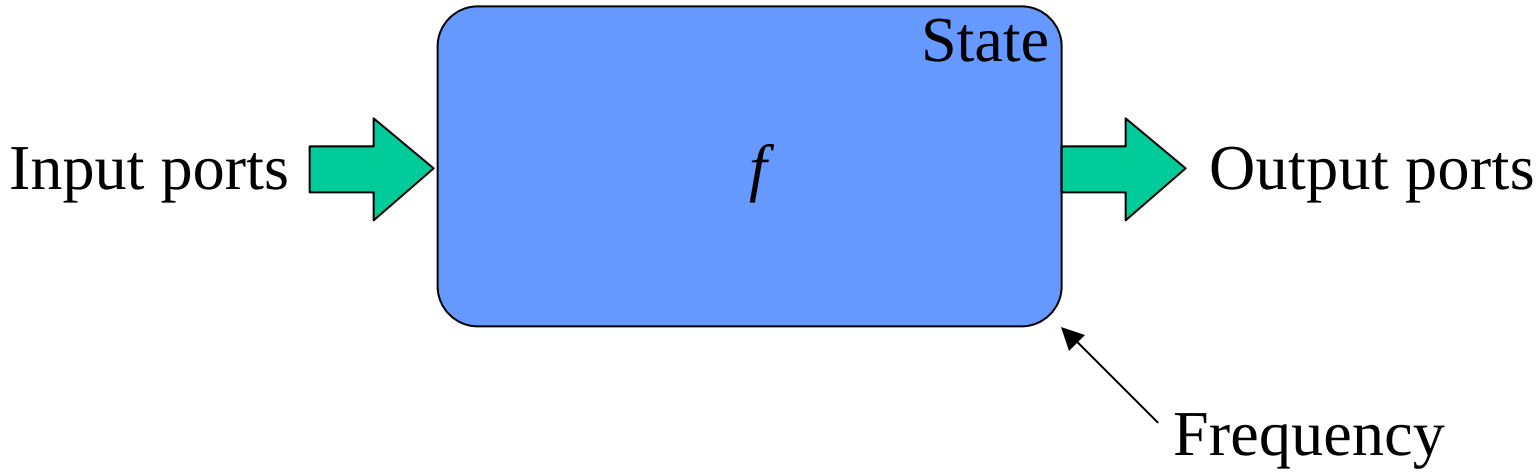
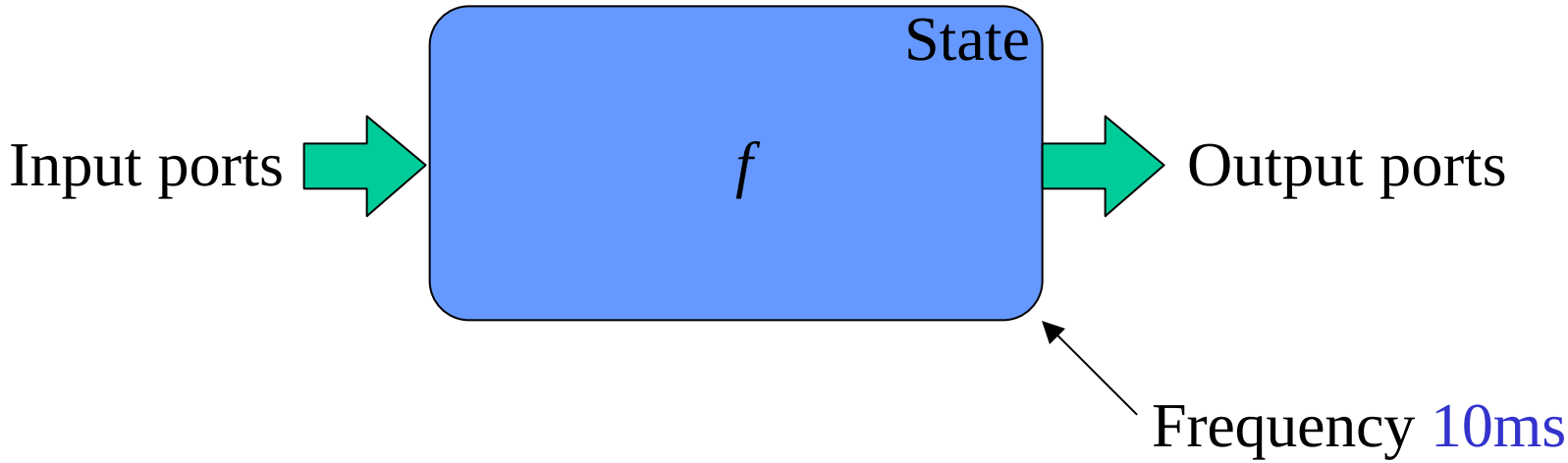


Semantics of a Task



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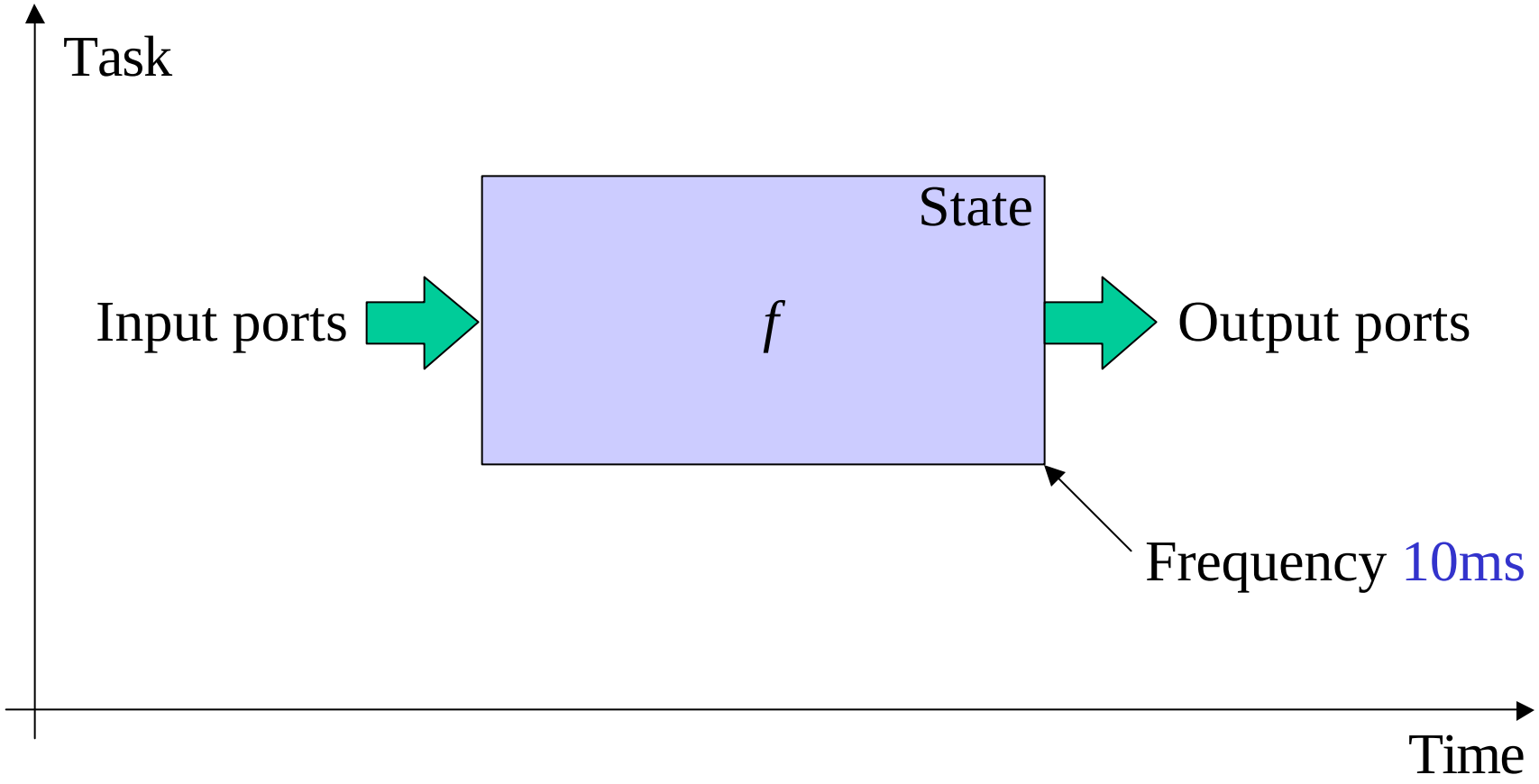

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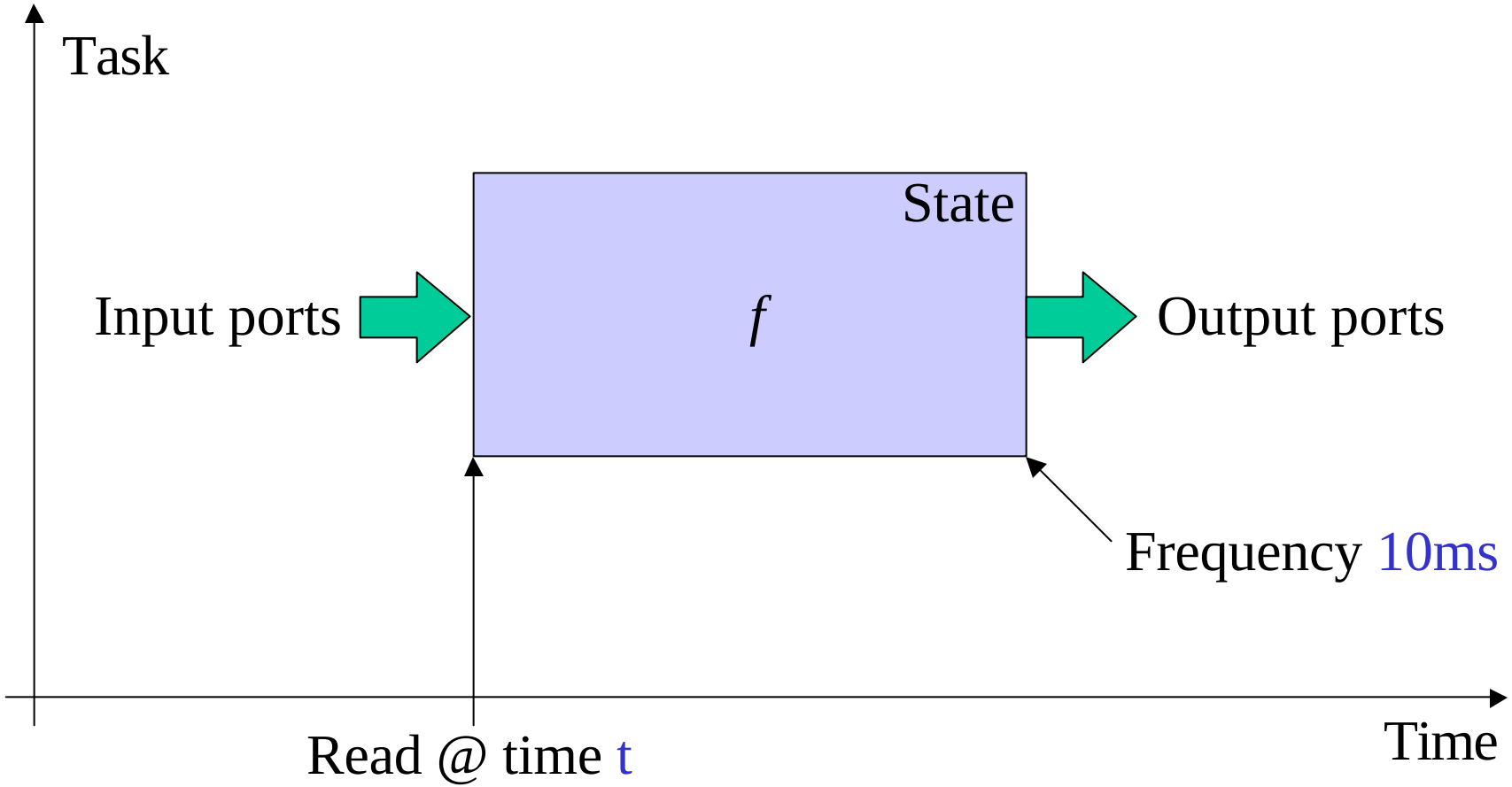

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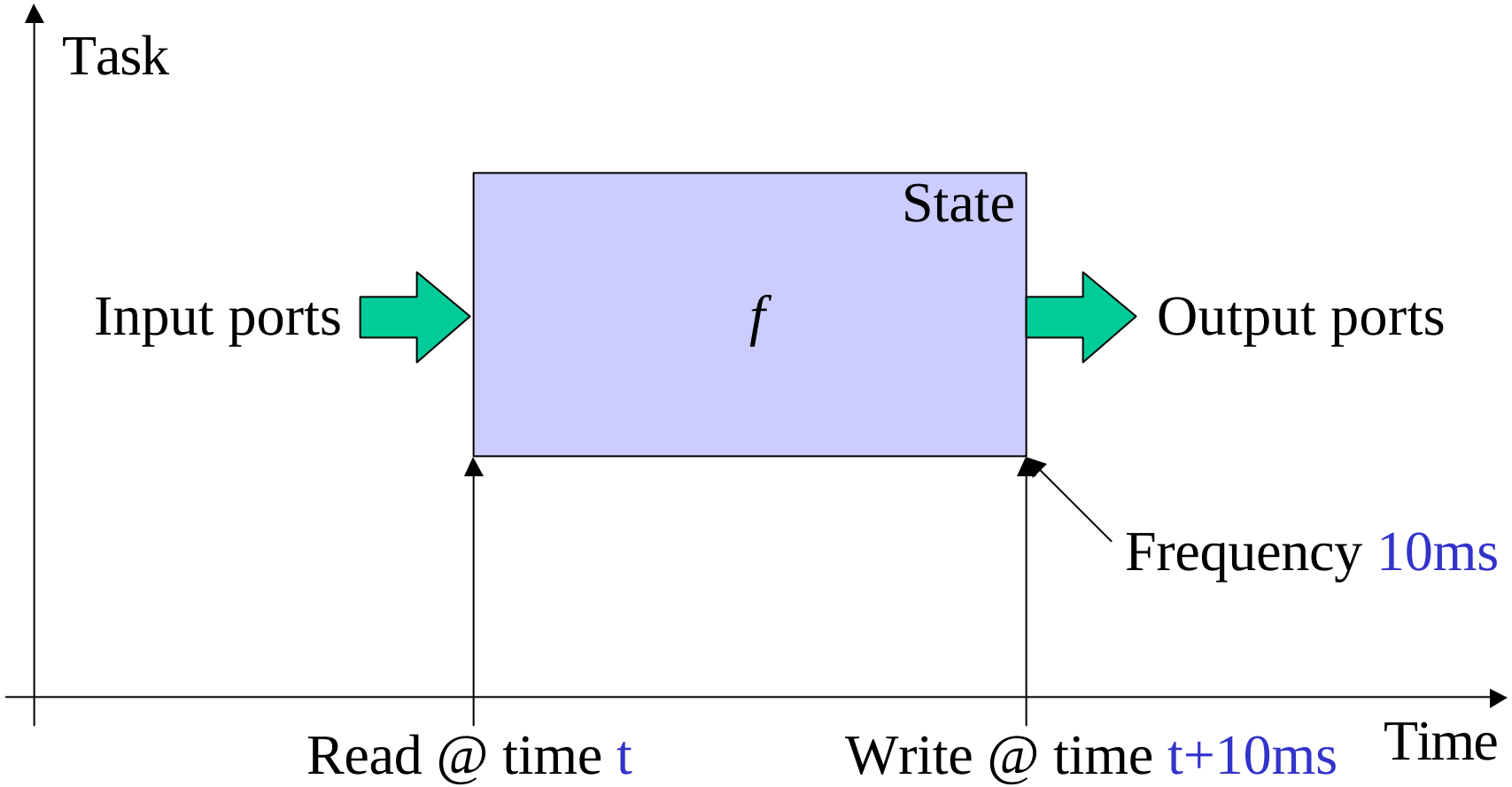

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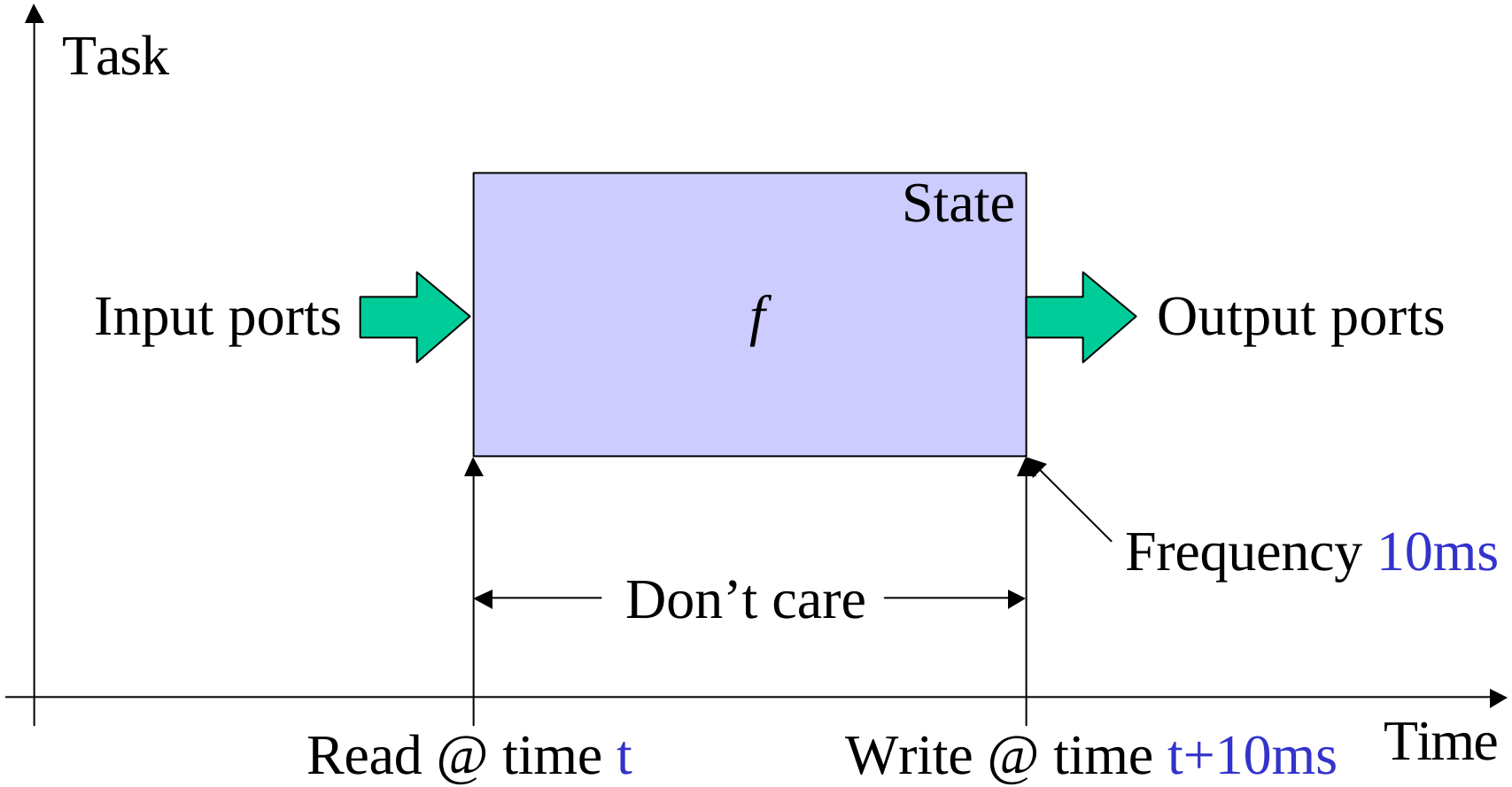
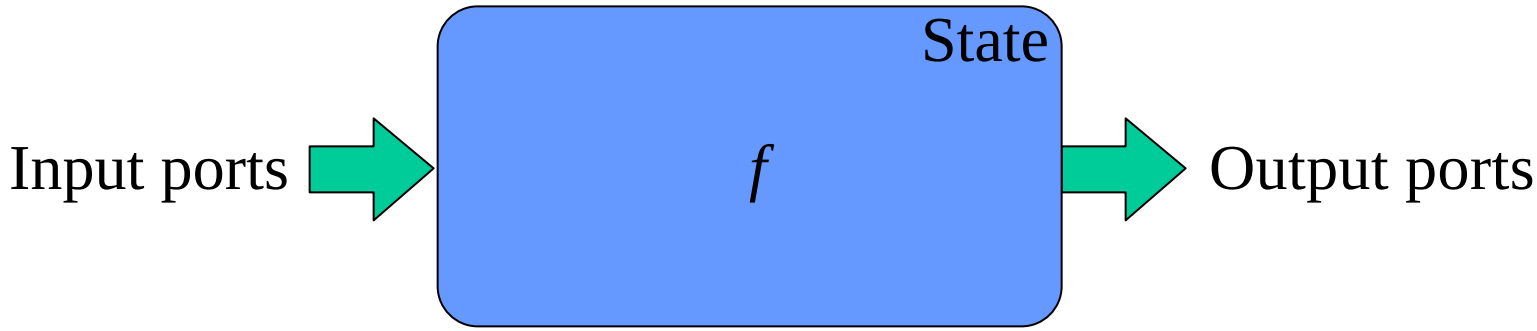
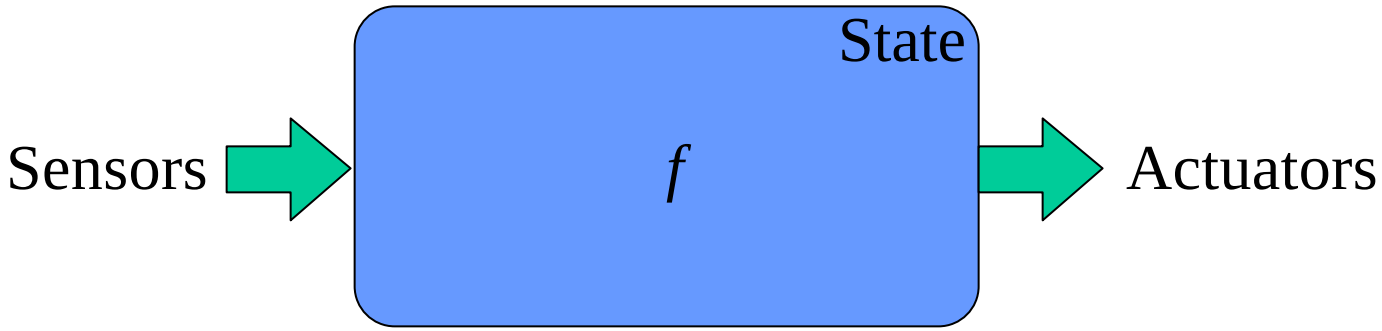


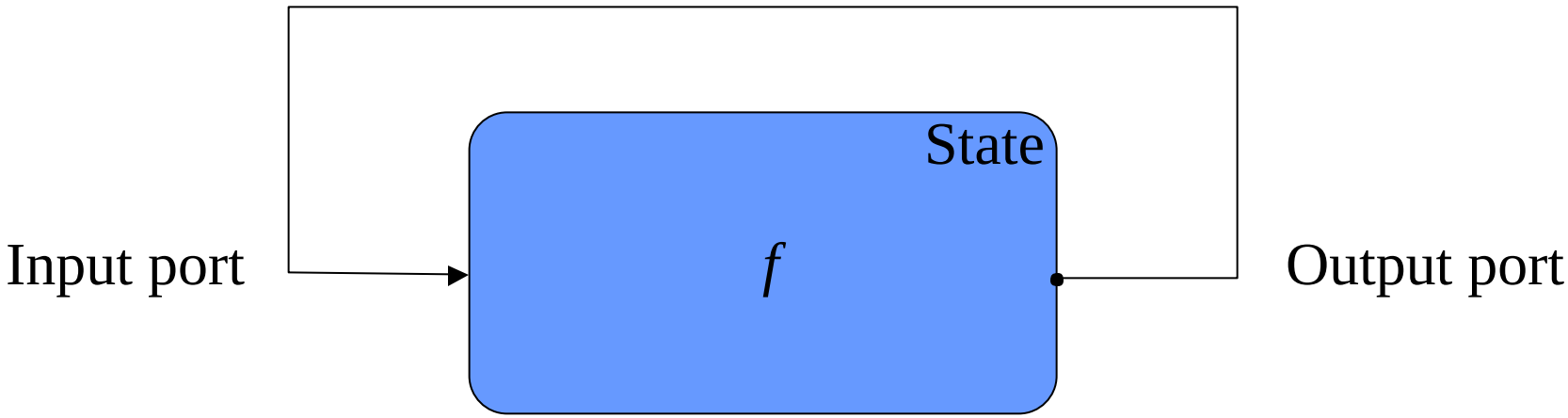
Data Flow



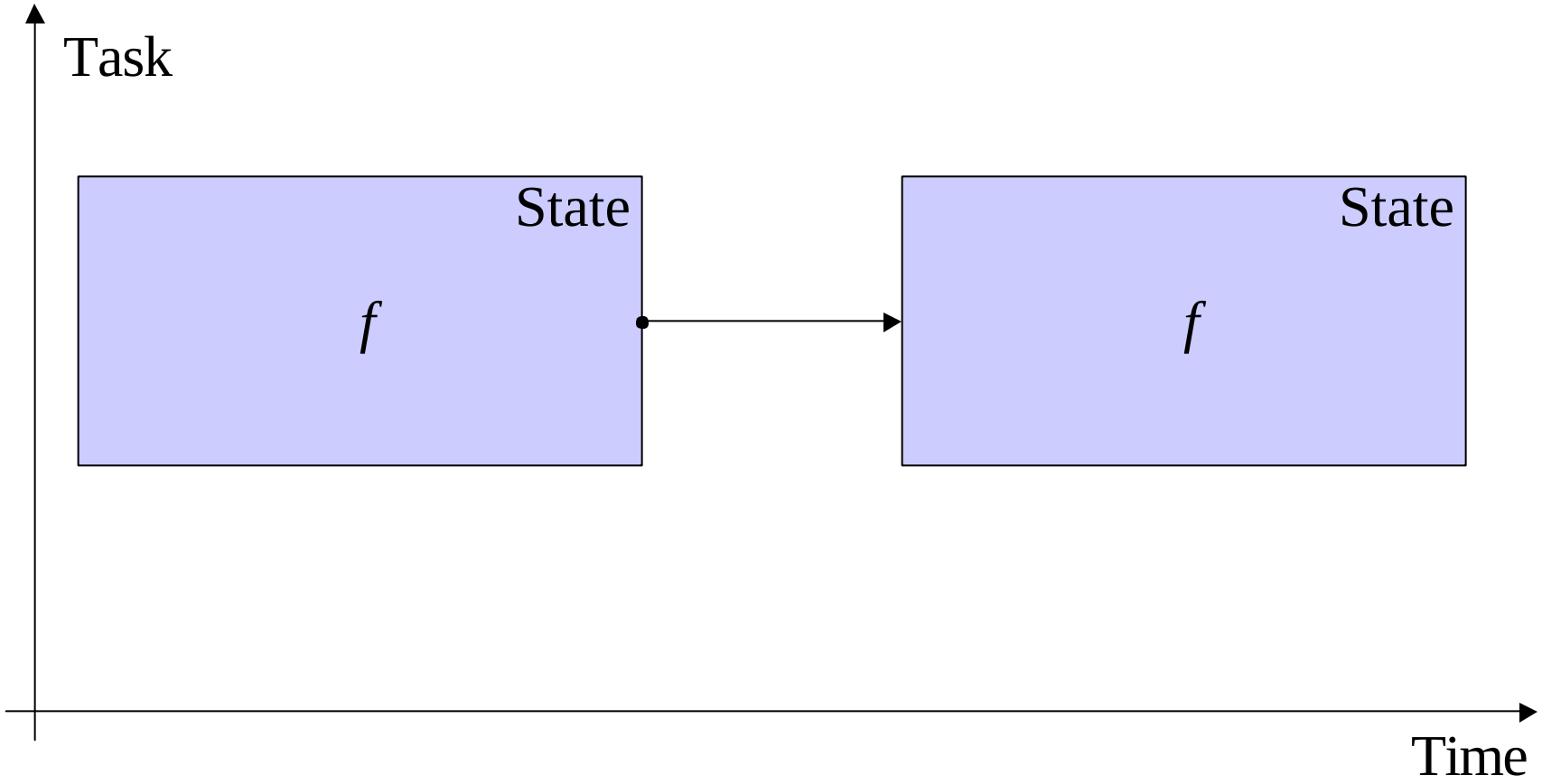
Sensor - Control Law - Actuator



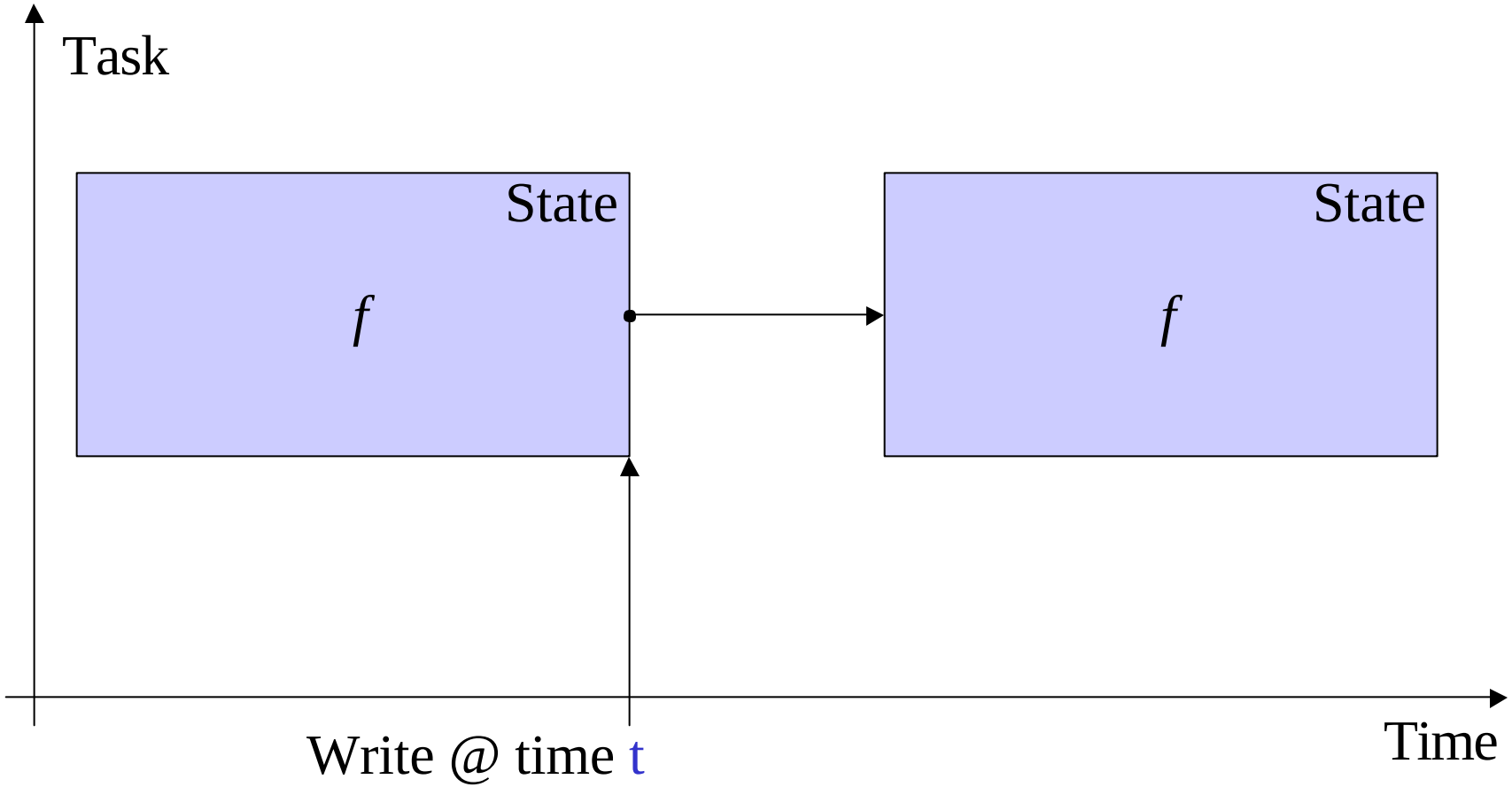
Intertask Communication



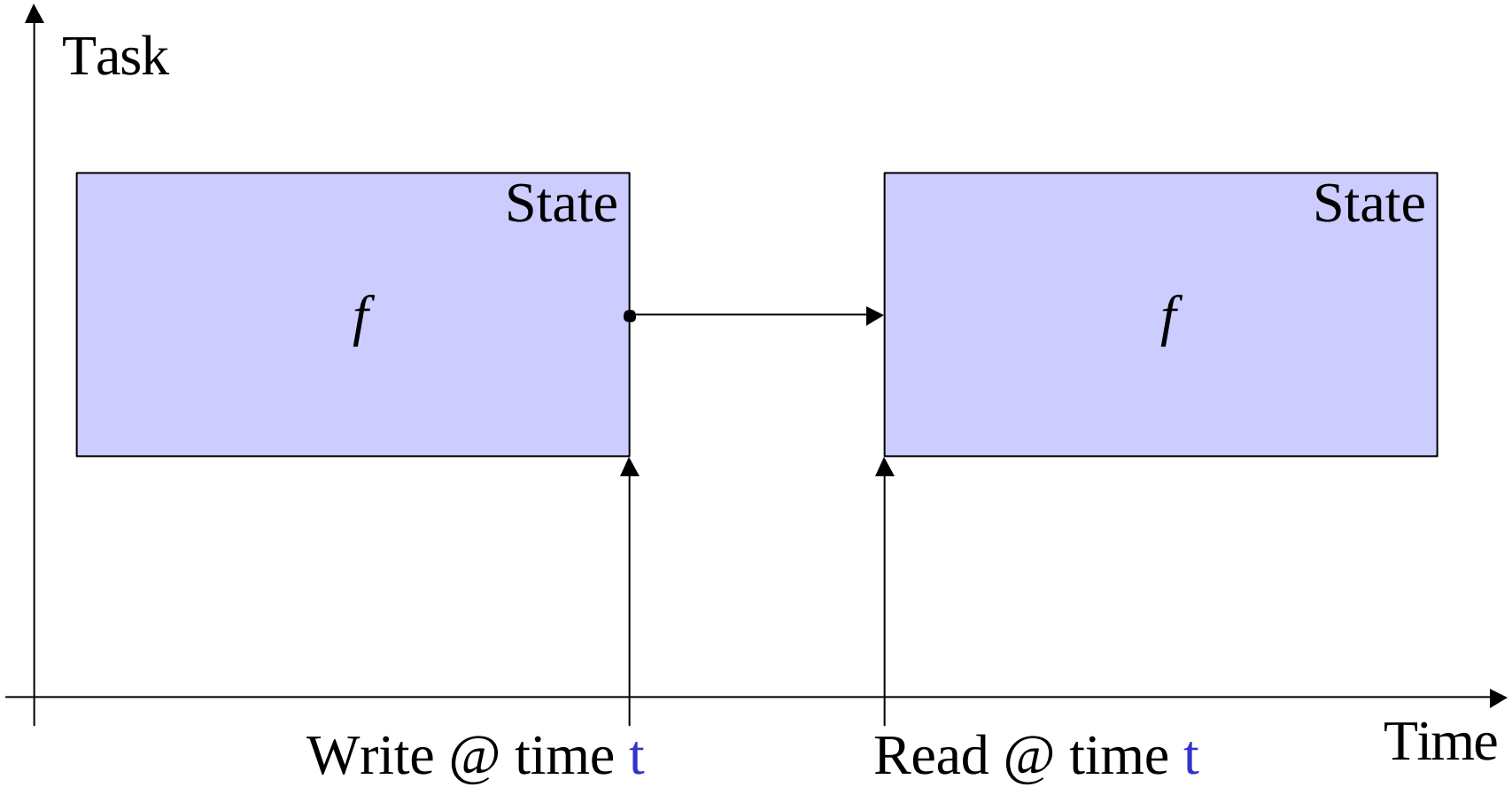
Data Flow Semantics



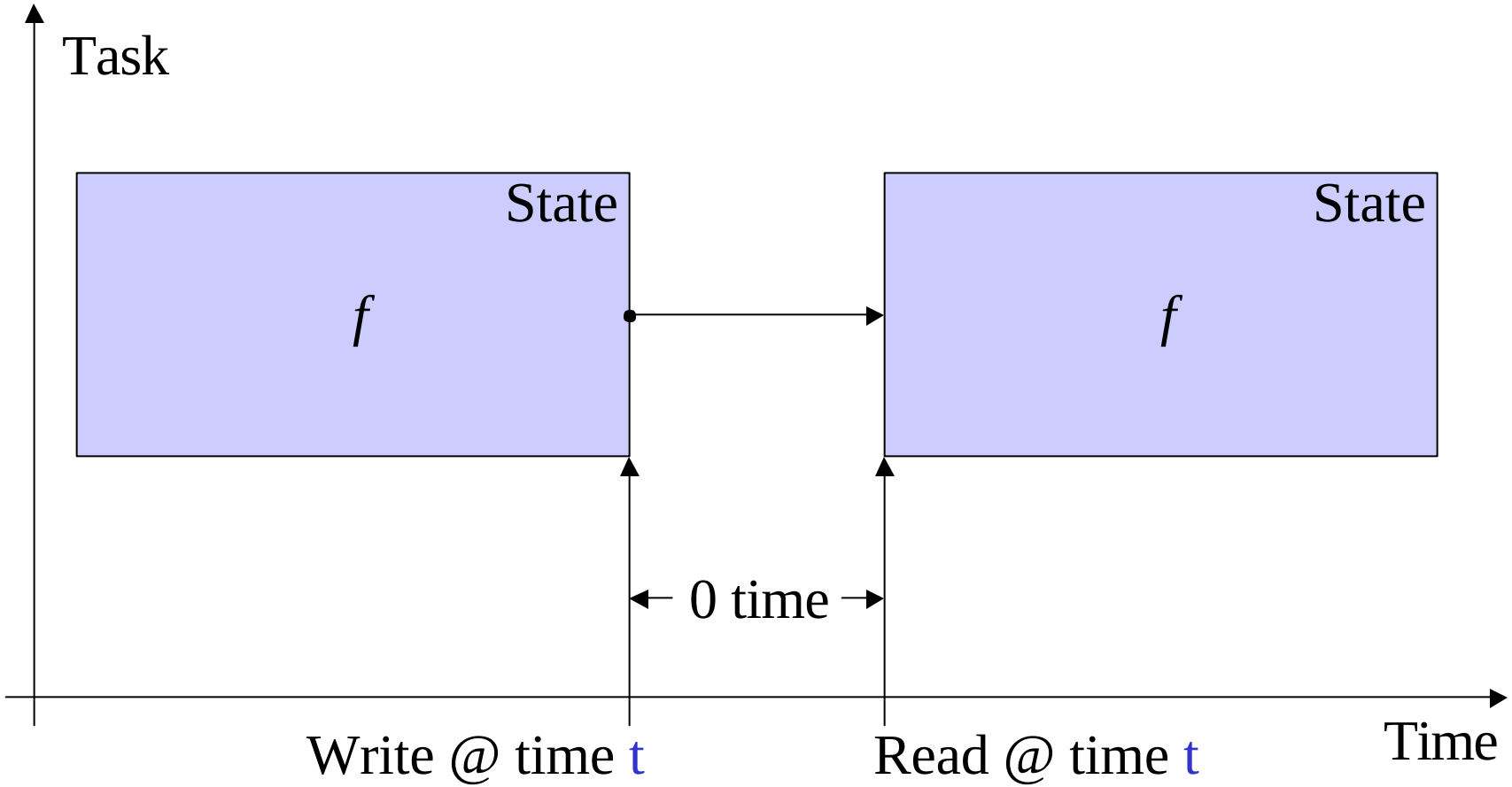
Data Flow Semantics



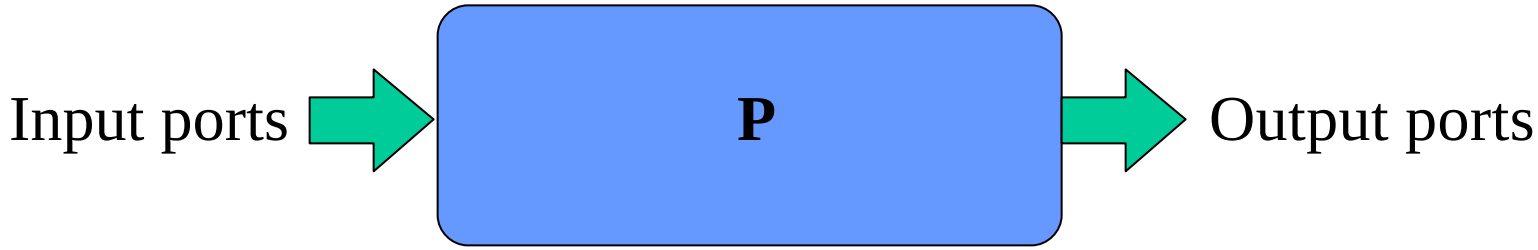
Data Flow Semantics



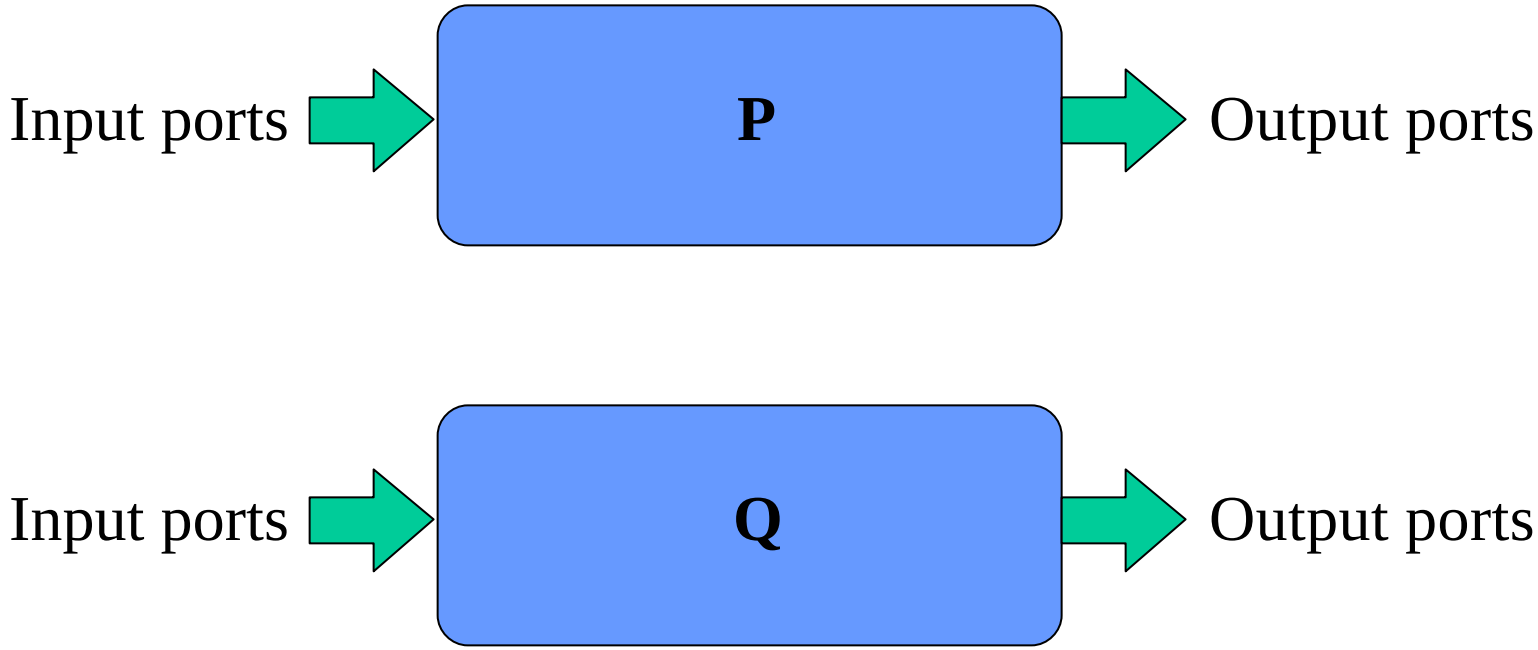
Data Flow Semantics



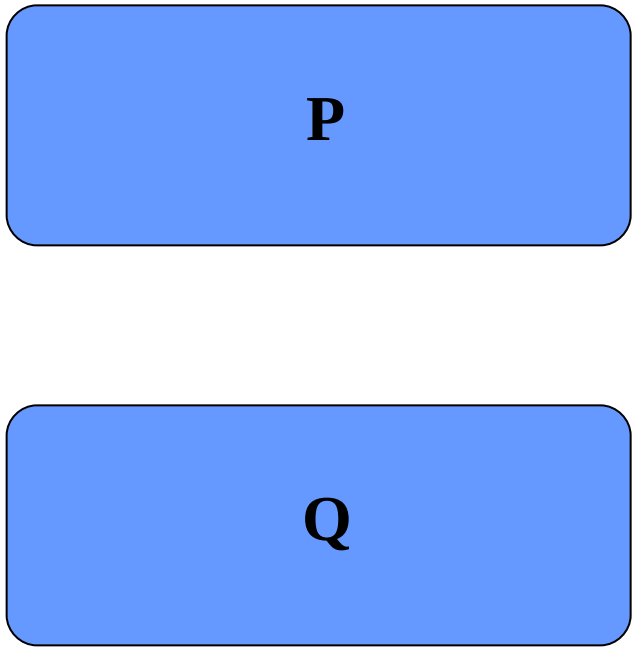
Two Tasks



Two Tasks



Connections



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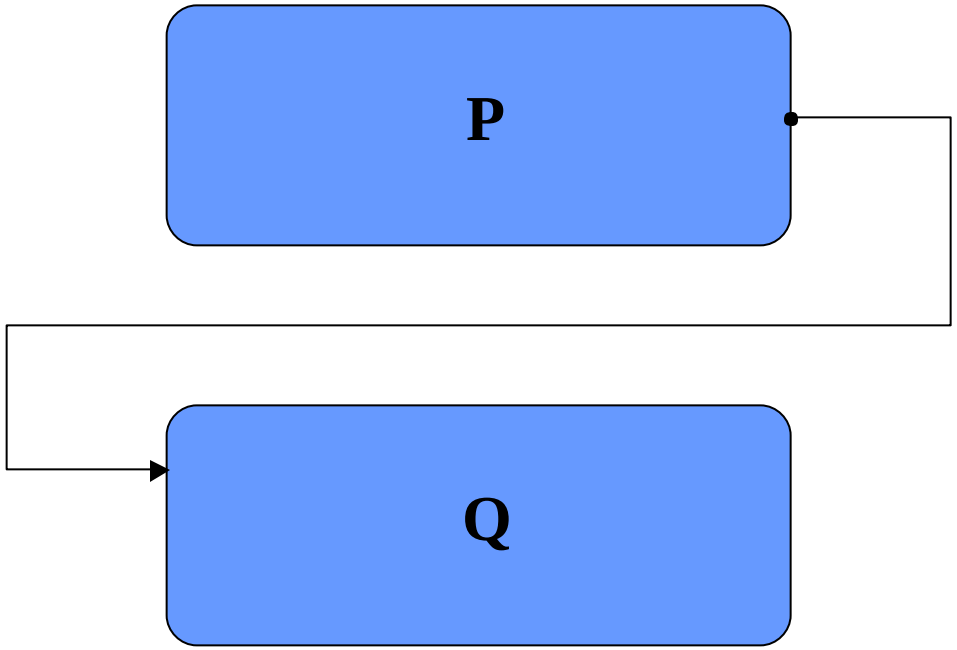

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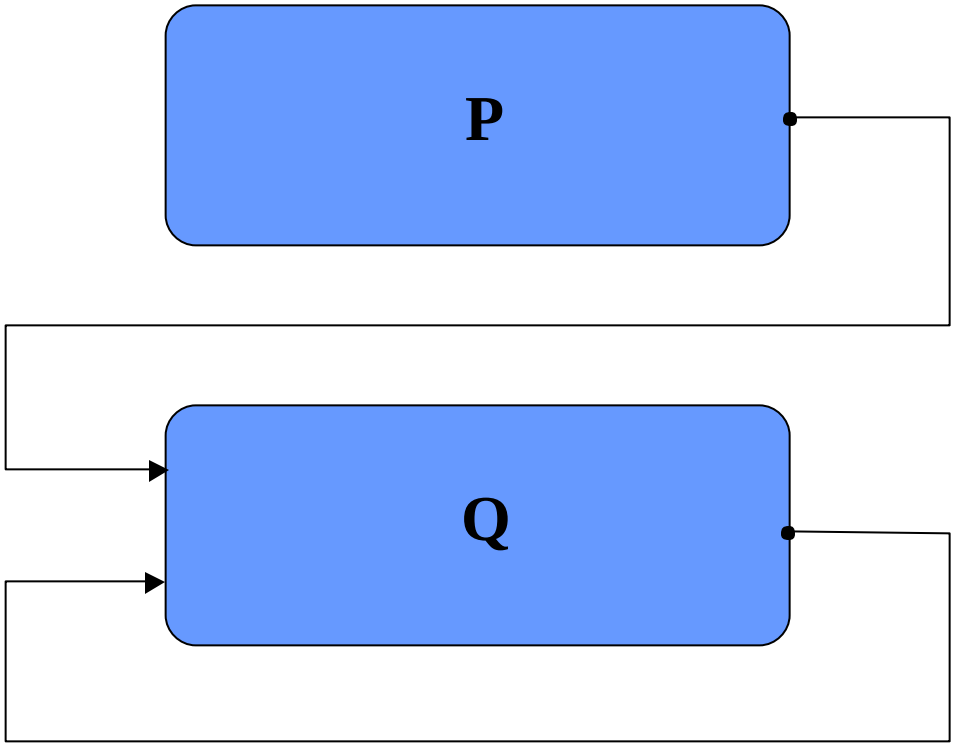
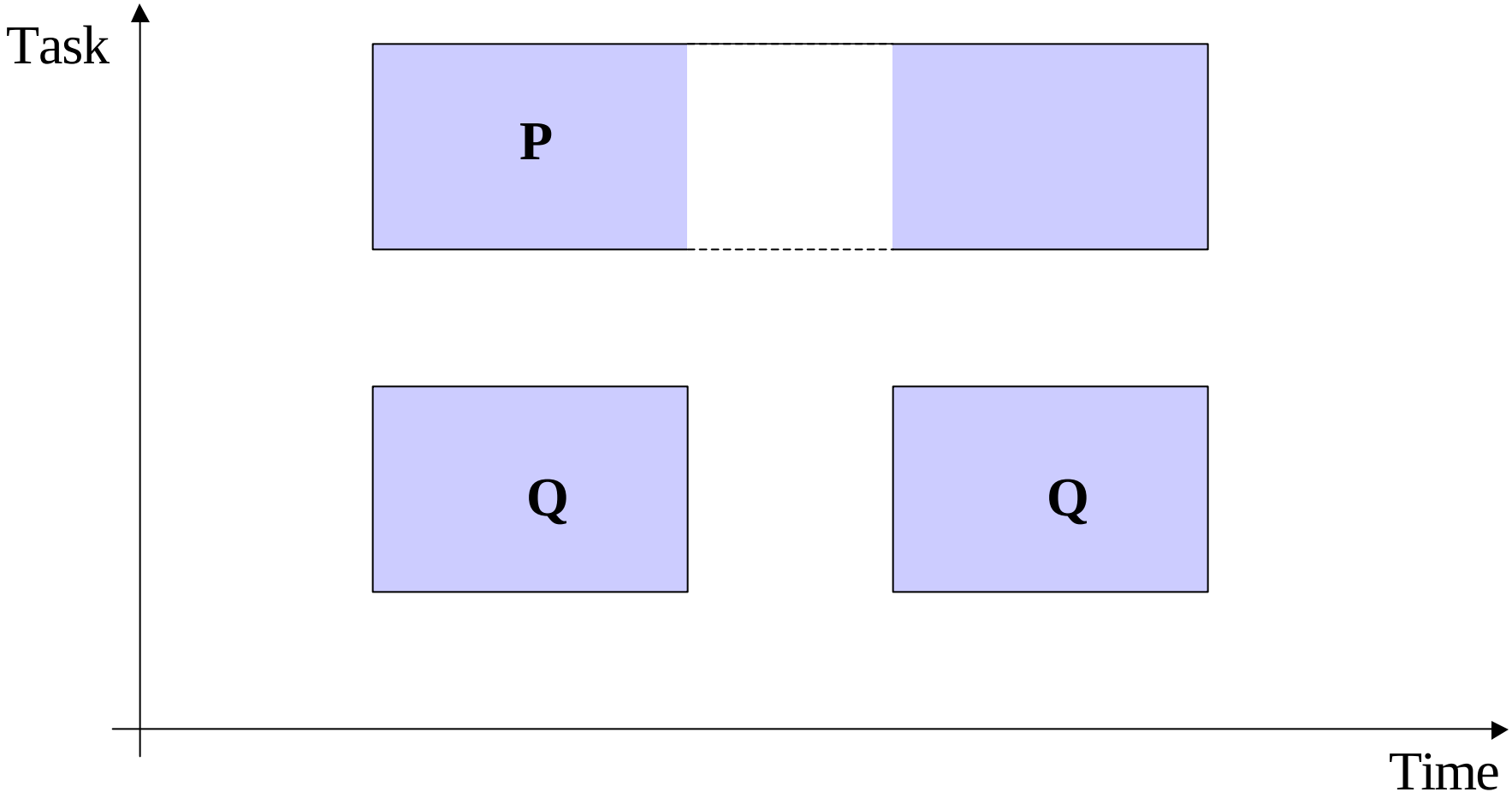
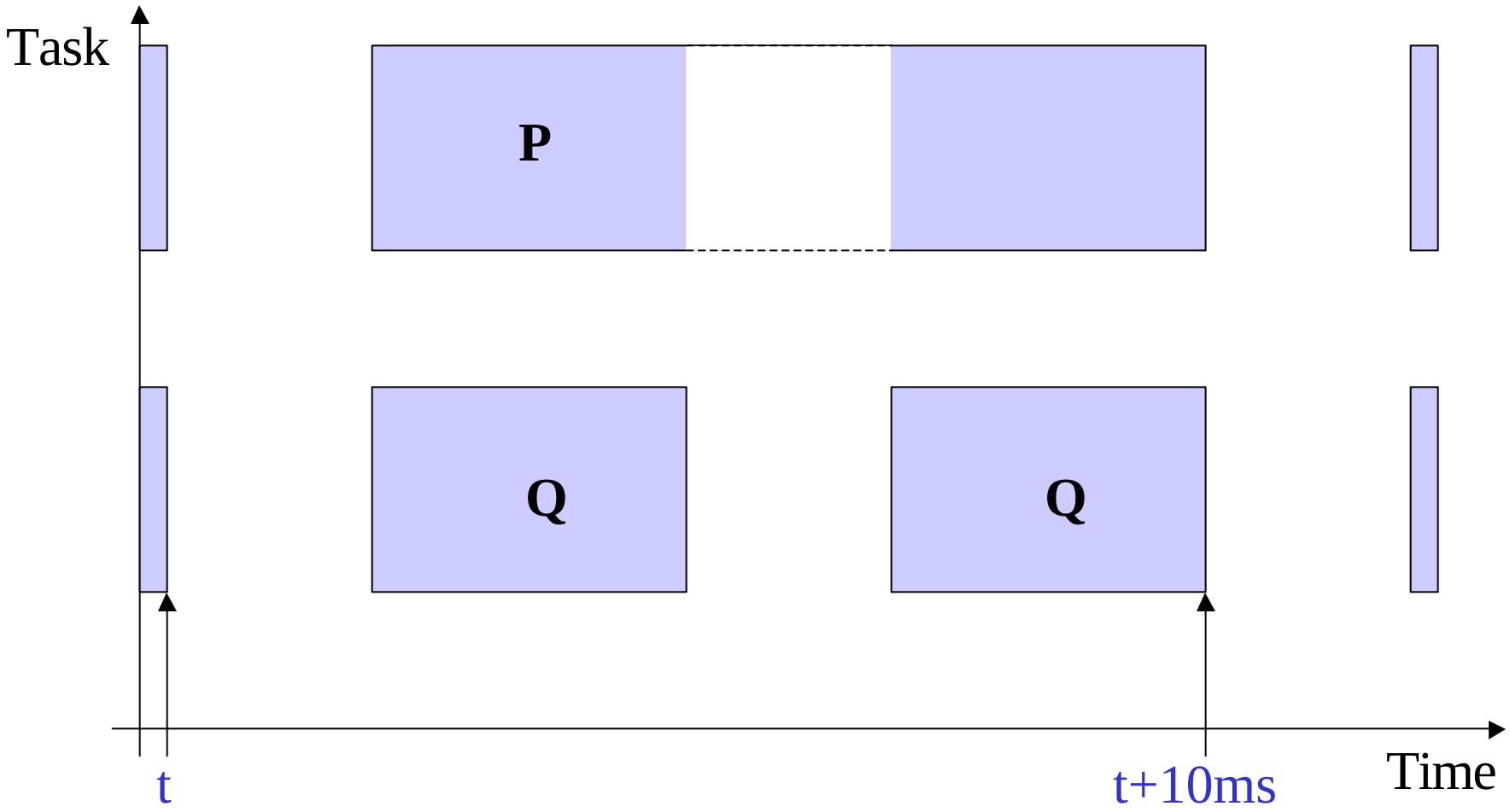


Different Periodicity



Semantics



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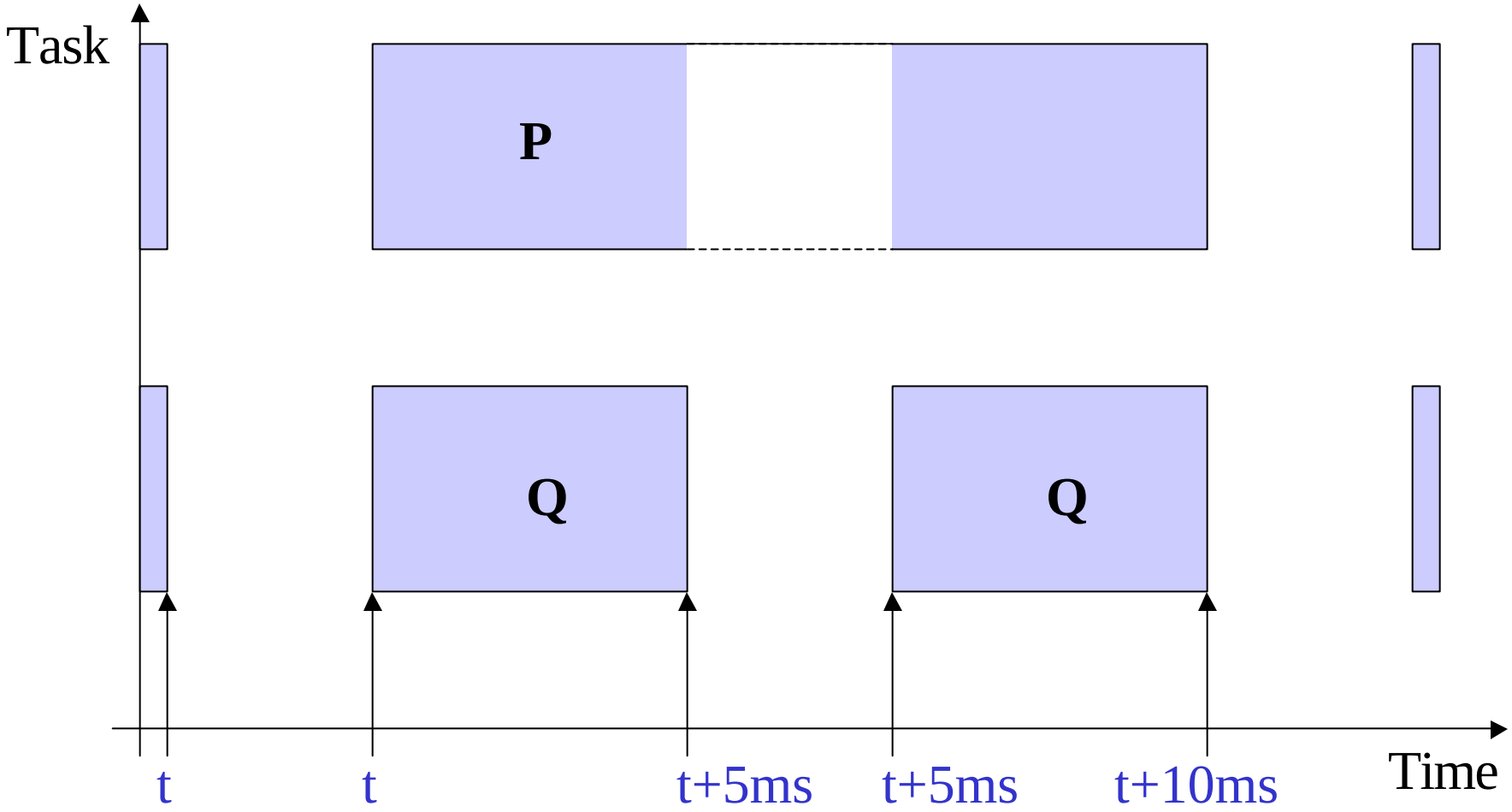

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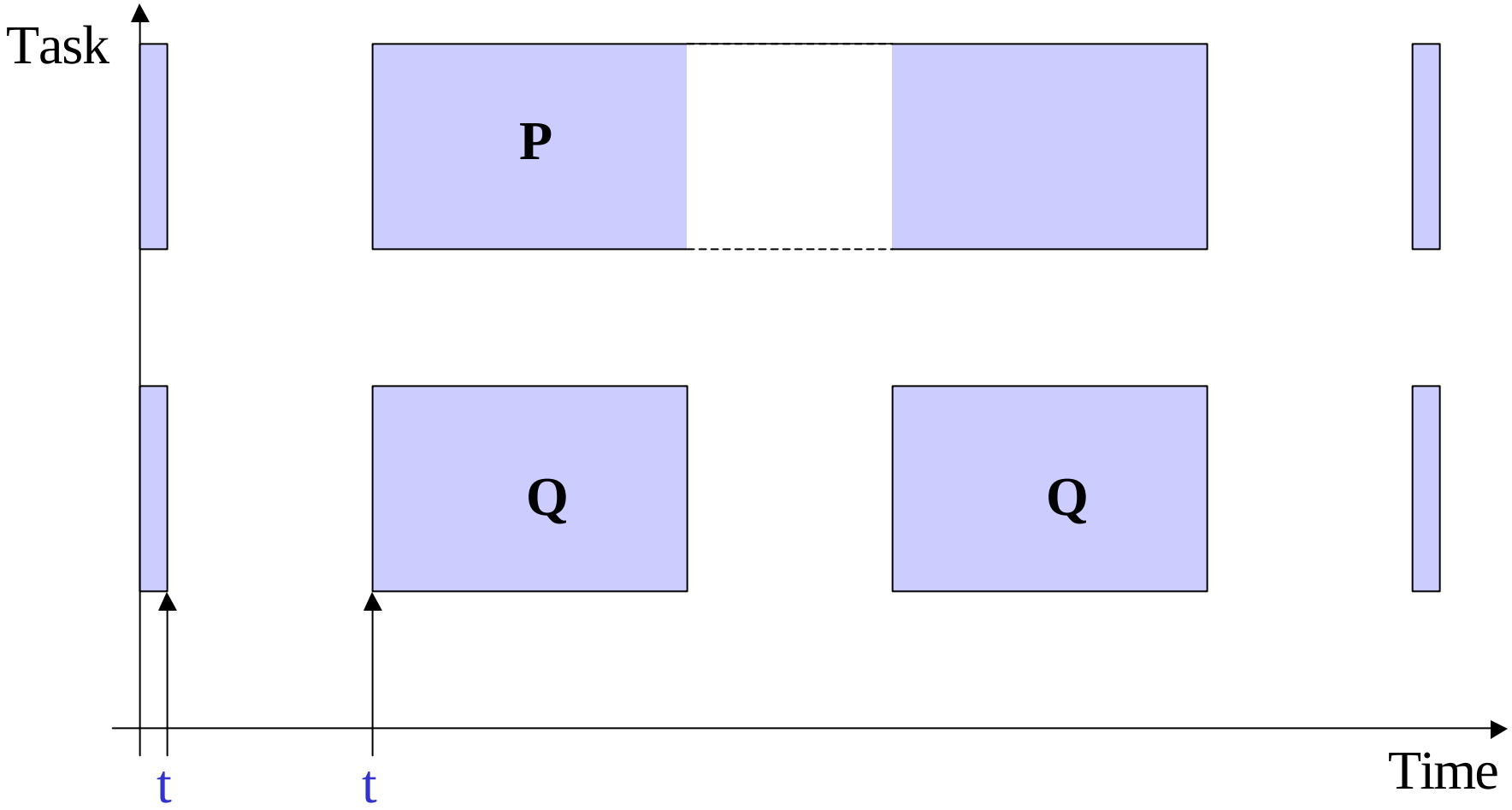

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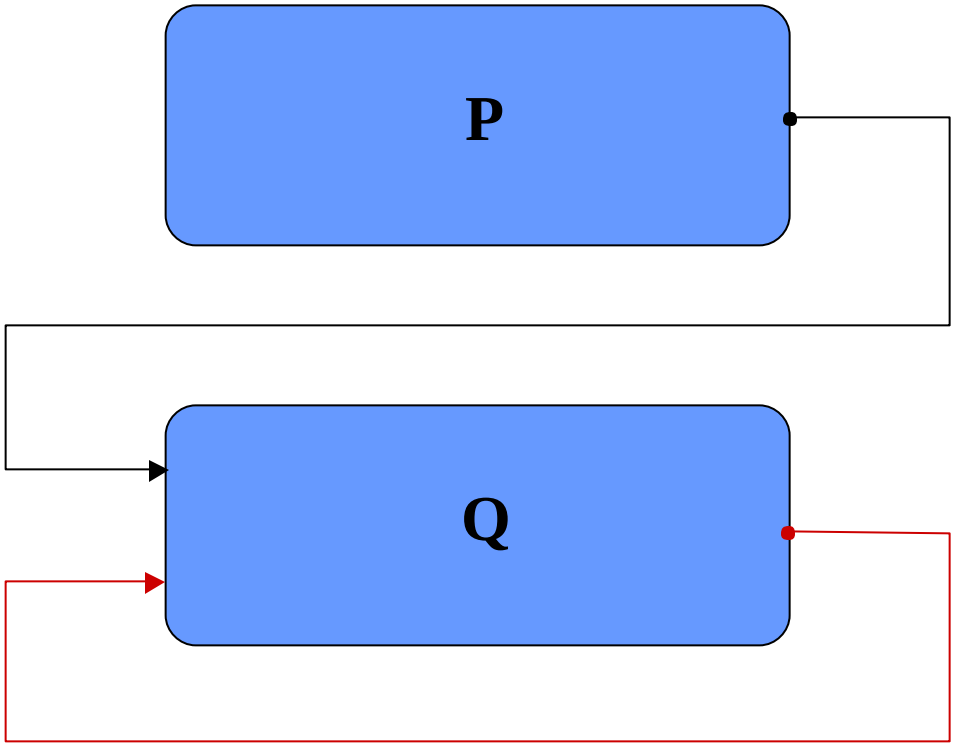

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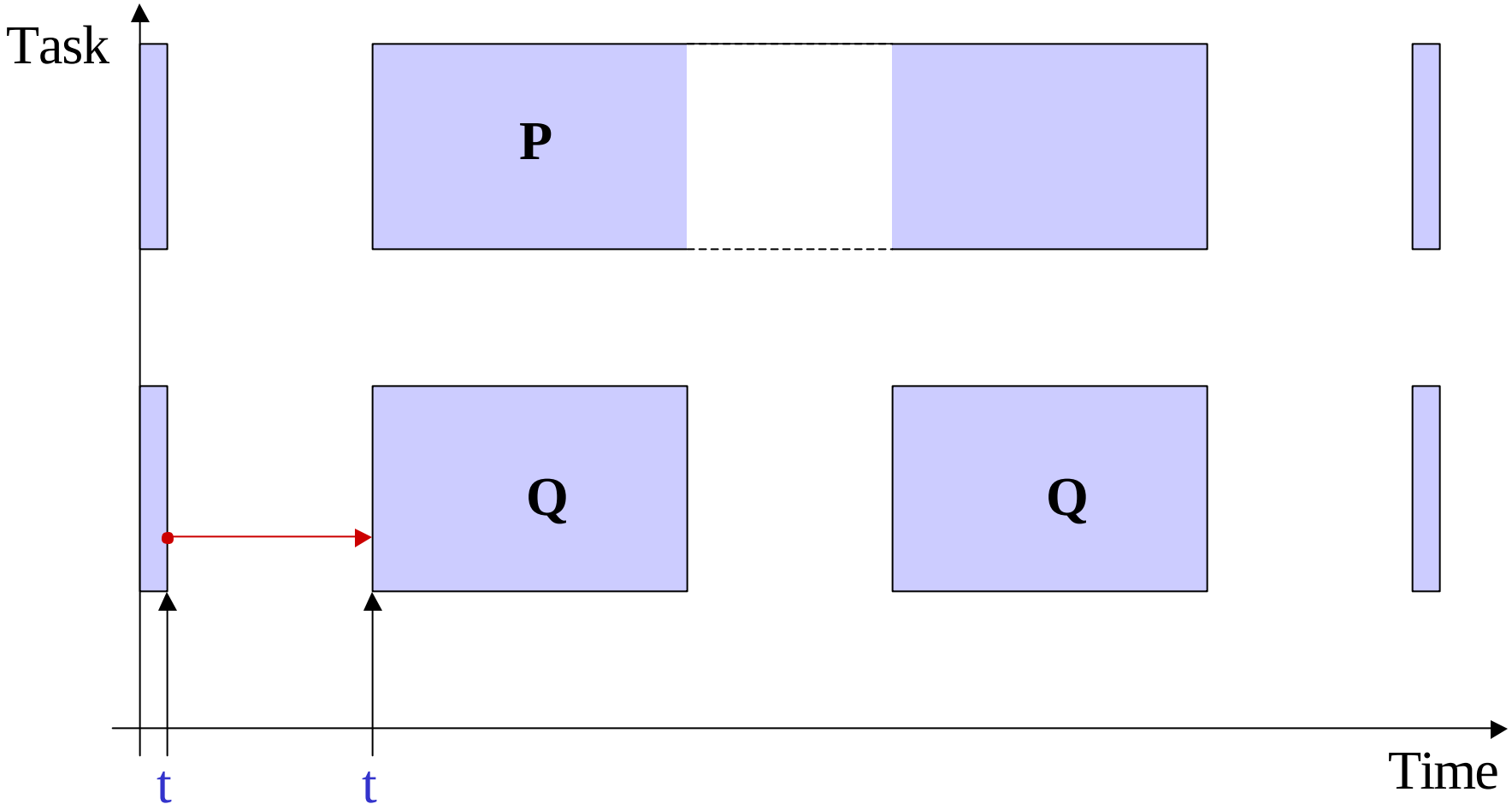

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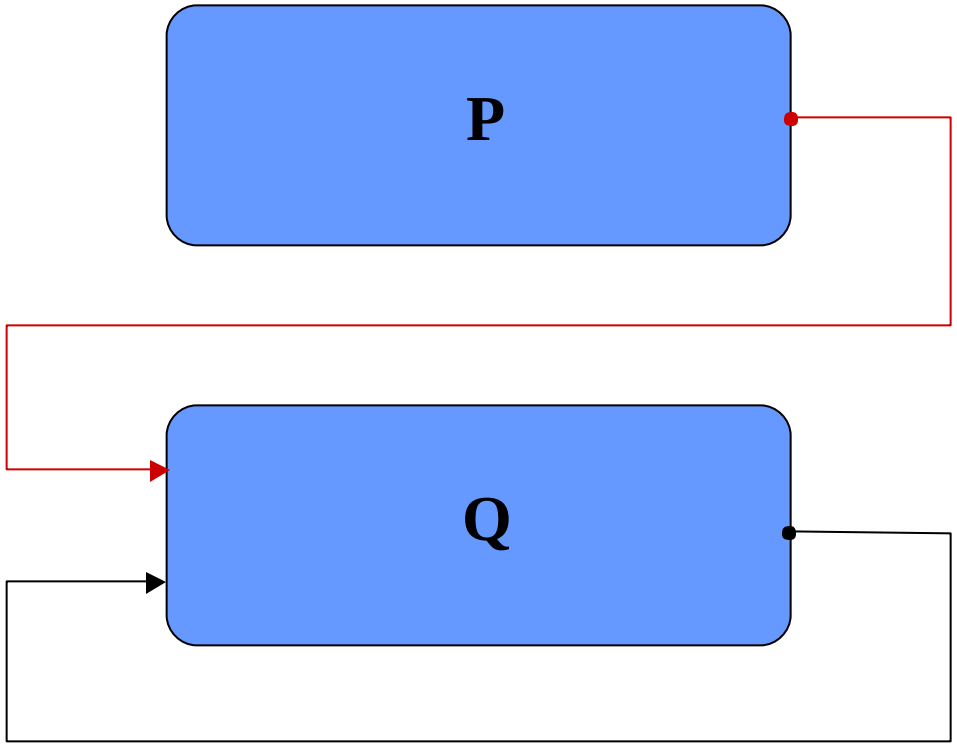

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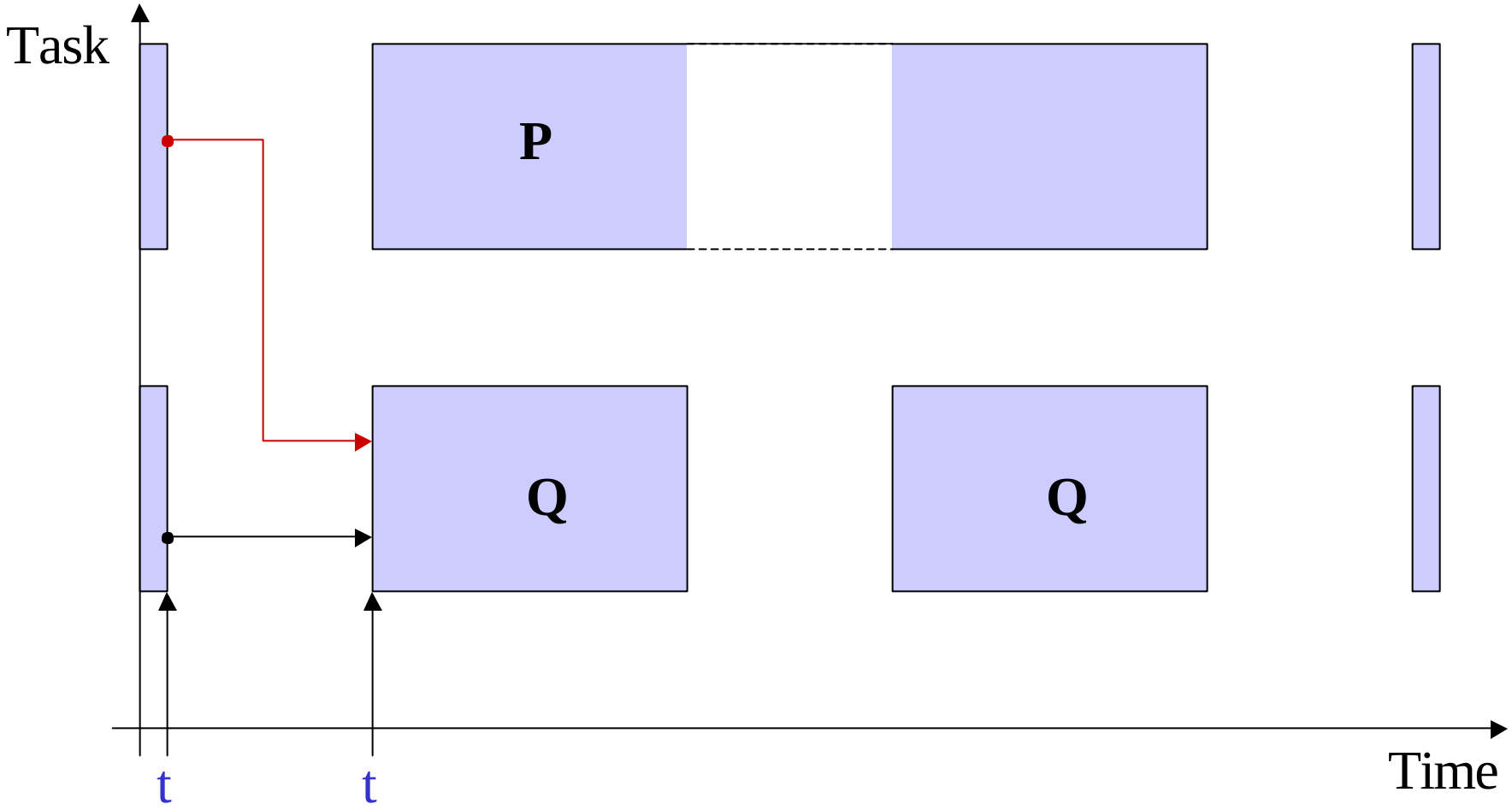

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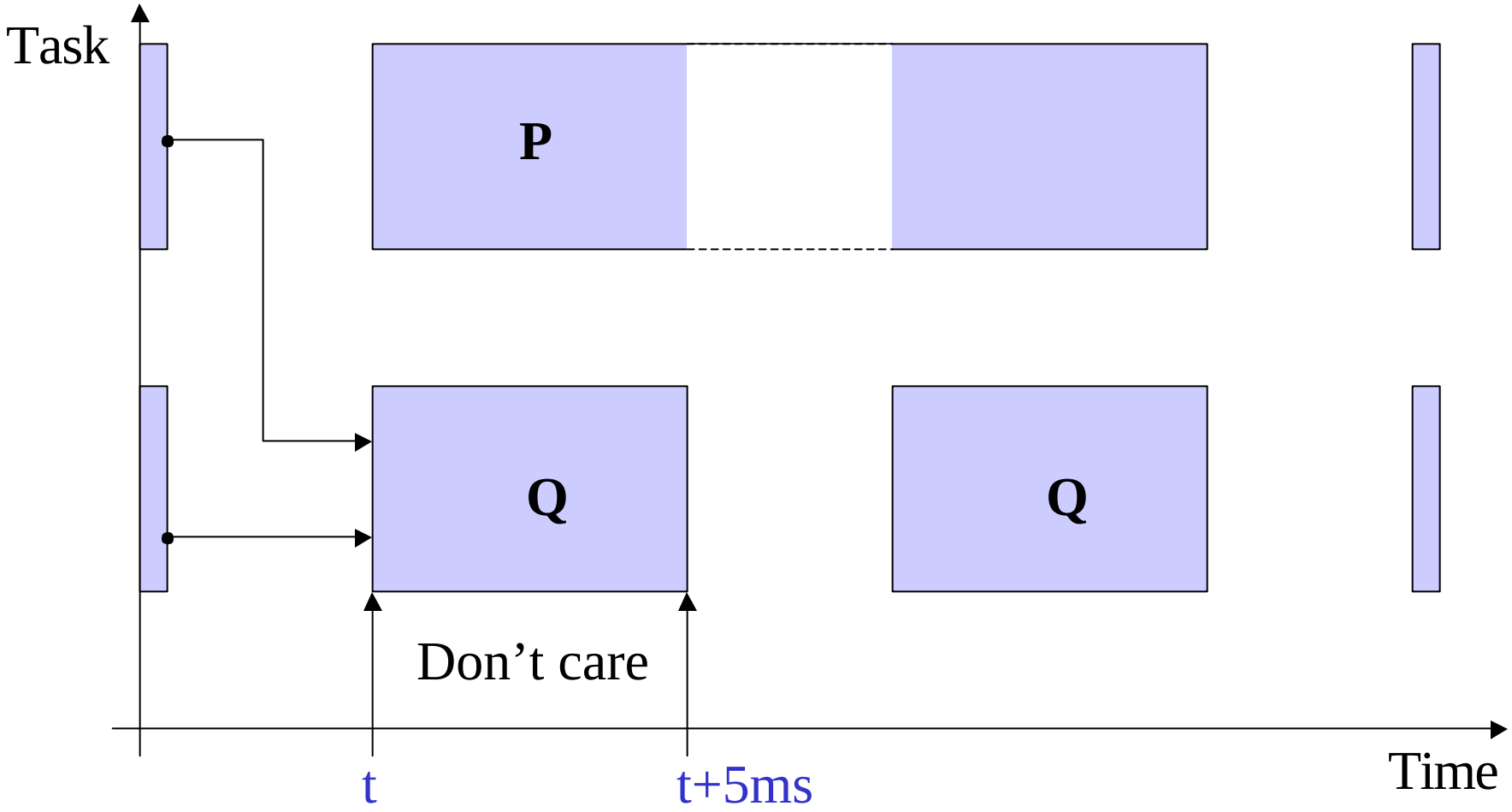

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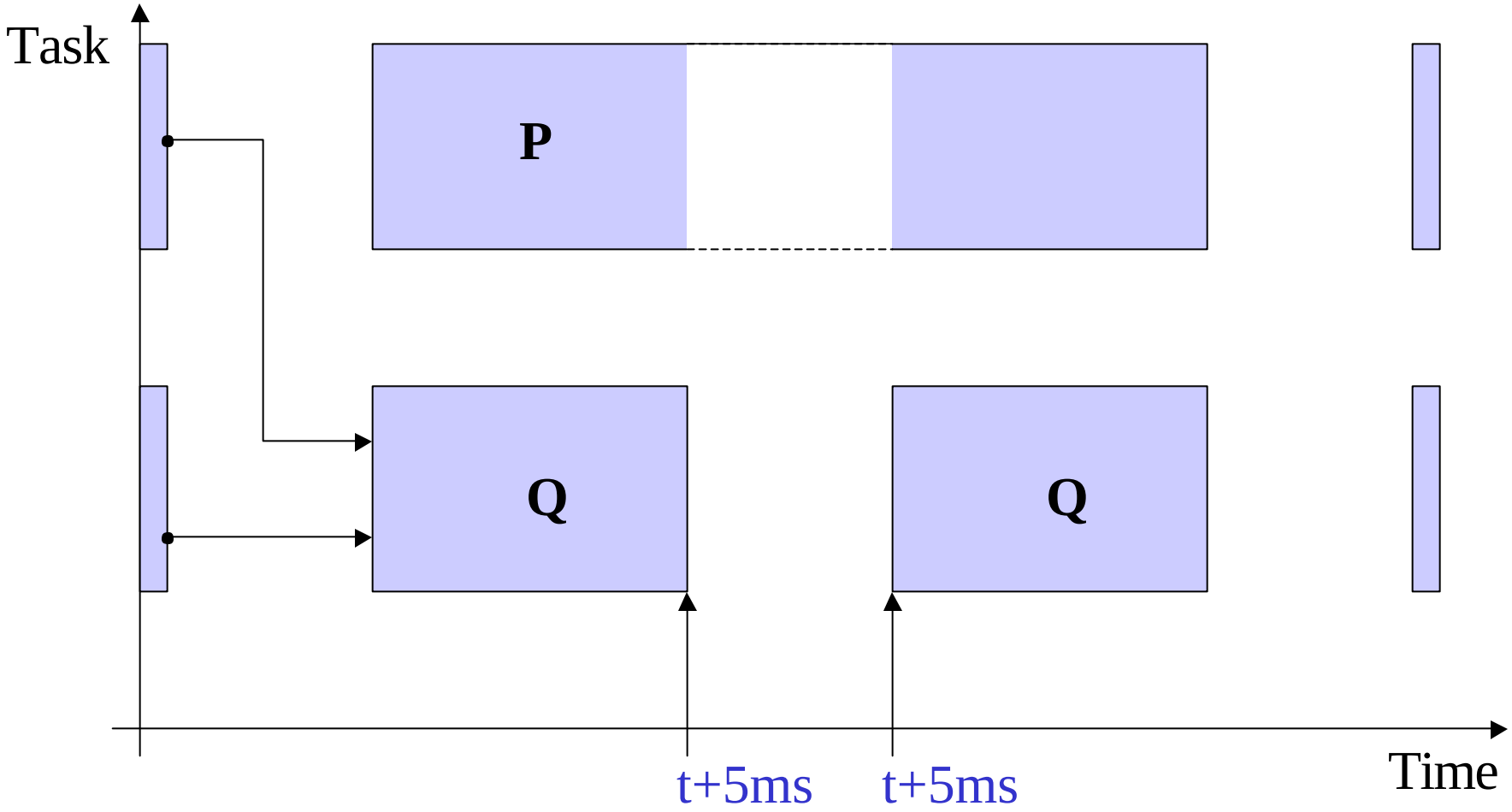

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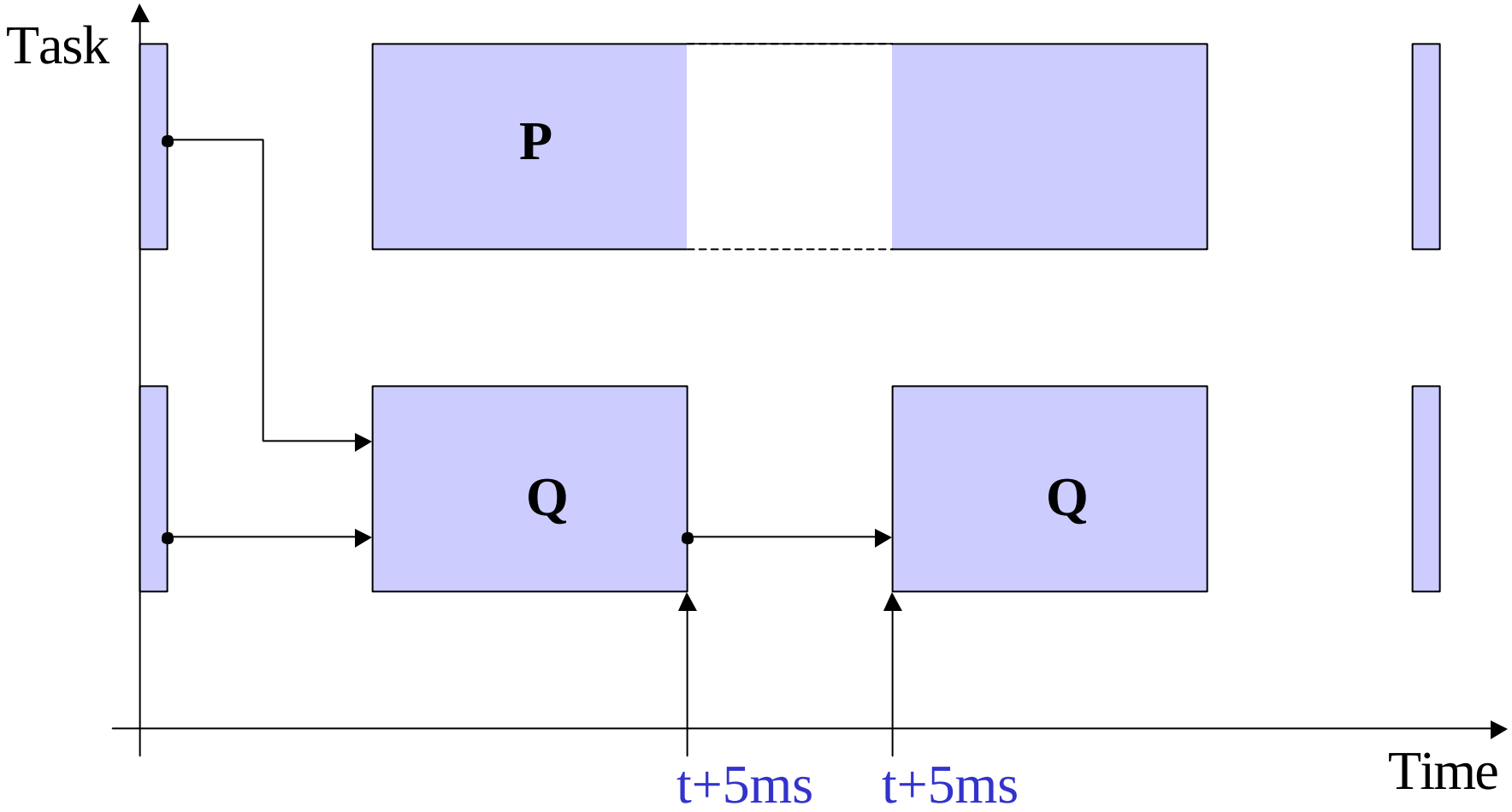

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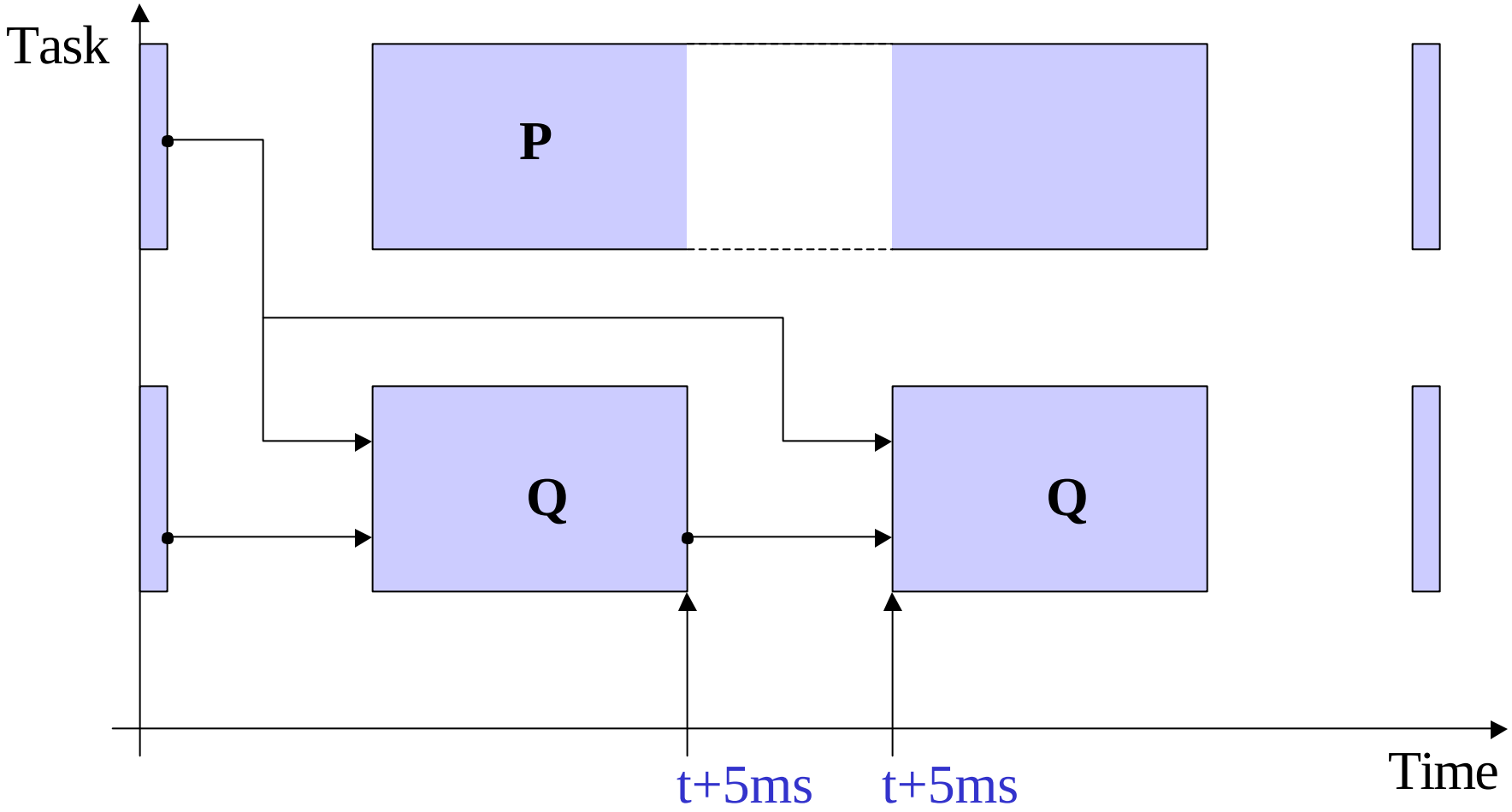

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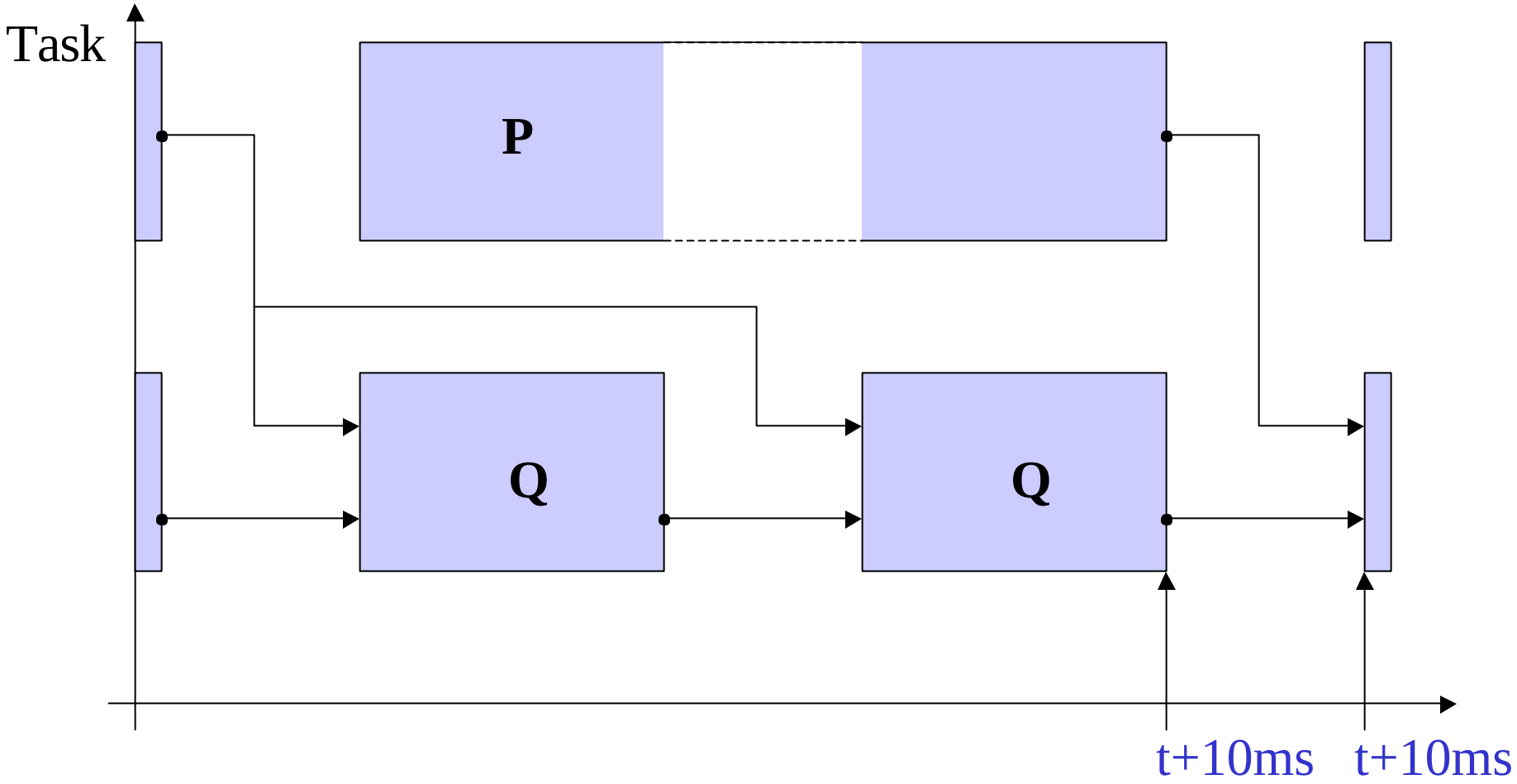
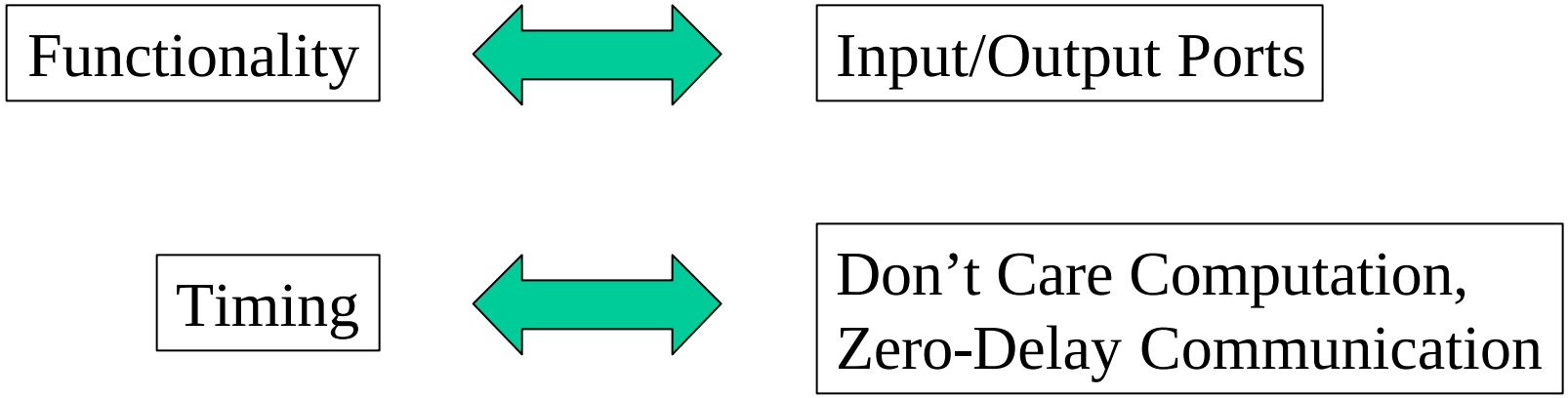


Embedded System Development

High-Level Programming

Our Approach



Decomposition: Giotto Modes

Some Motivations:

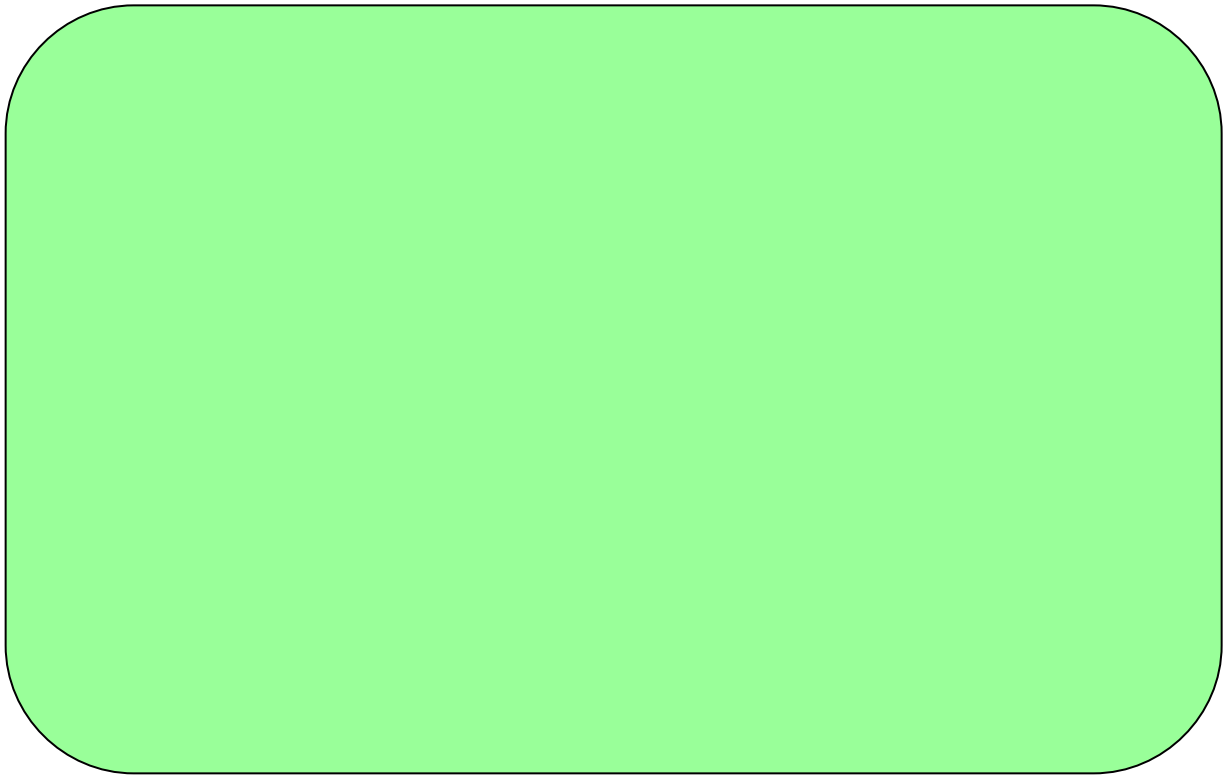
- Multi-modal control
- Fault tolerance
- Events
- Resource sharing
- Uncertain environments

Modes

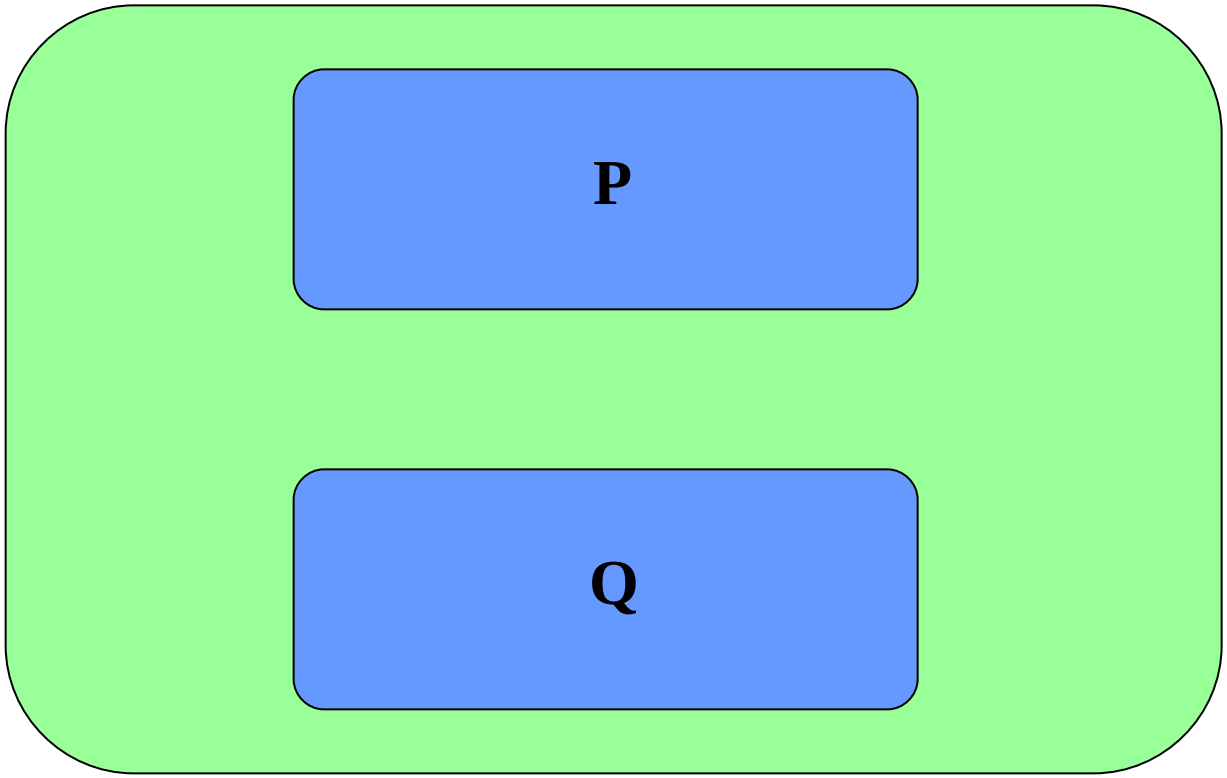
- A mode is a parameterized set of tasks
- A Giotto program consists of a set of modes and mode switches

- A Giotto system is in a single mode at the same time

A Mode



Abstract Syntax of a Mode



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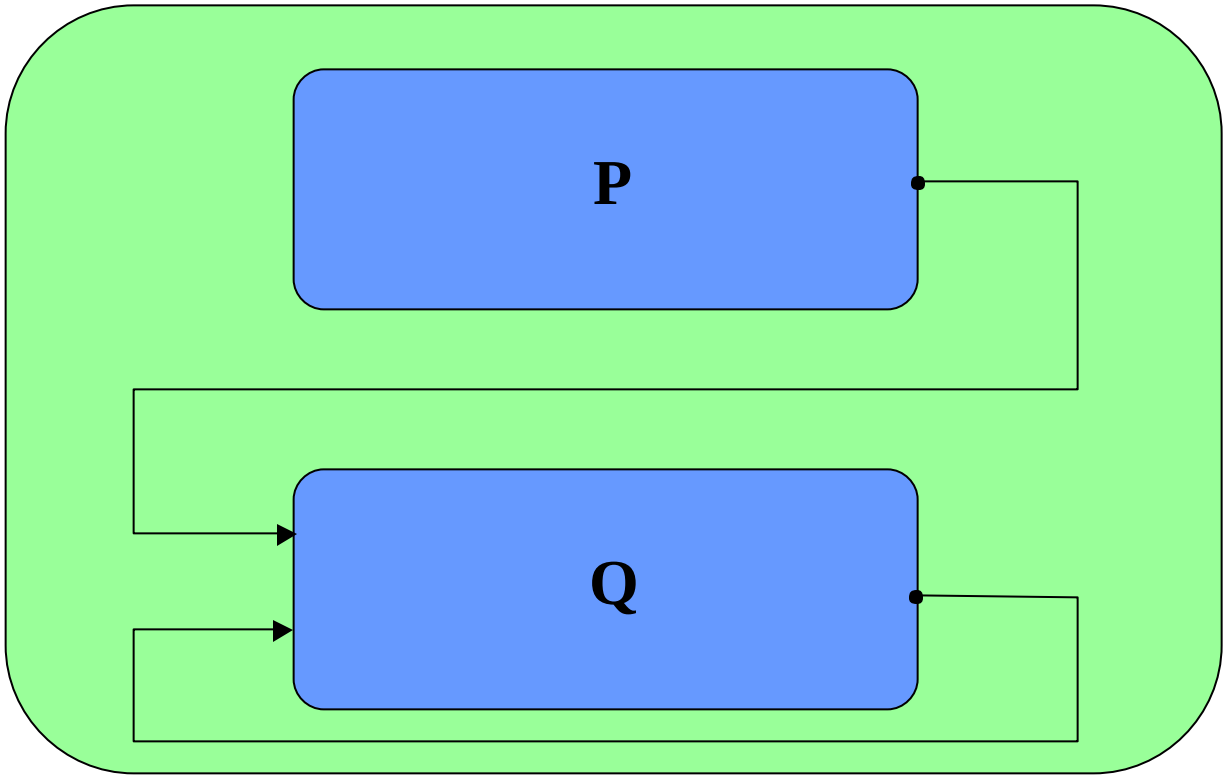

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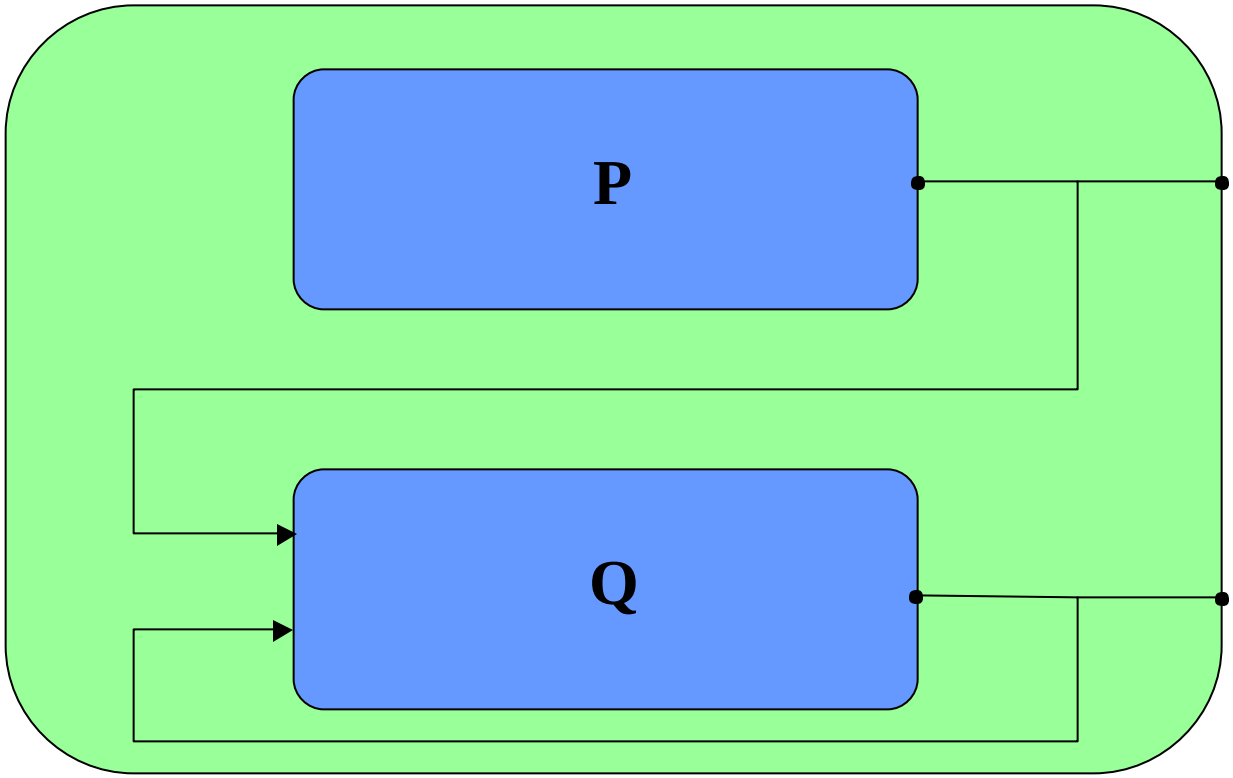

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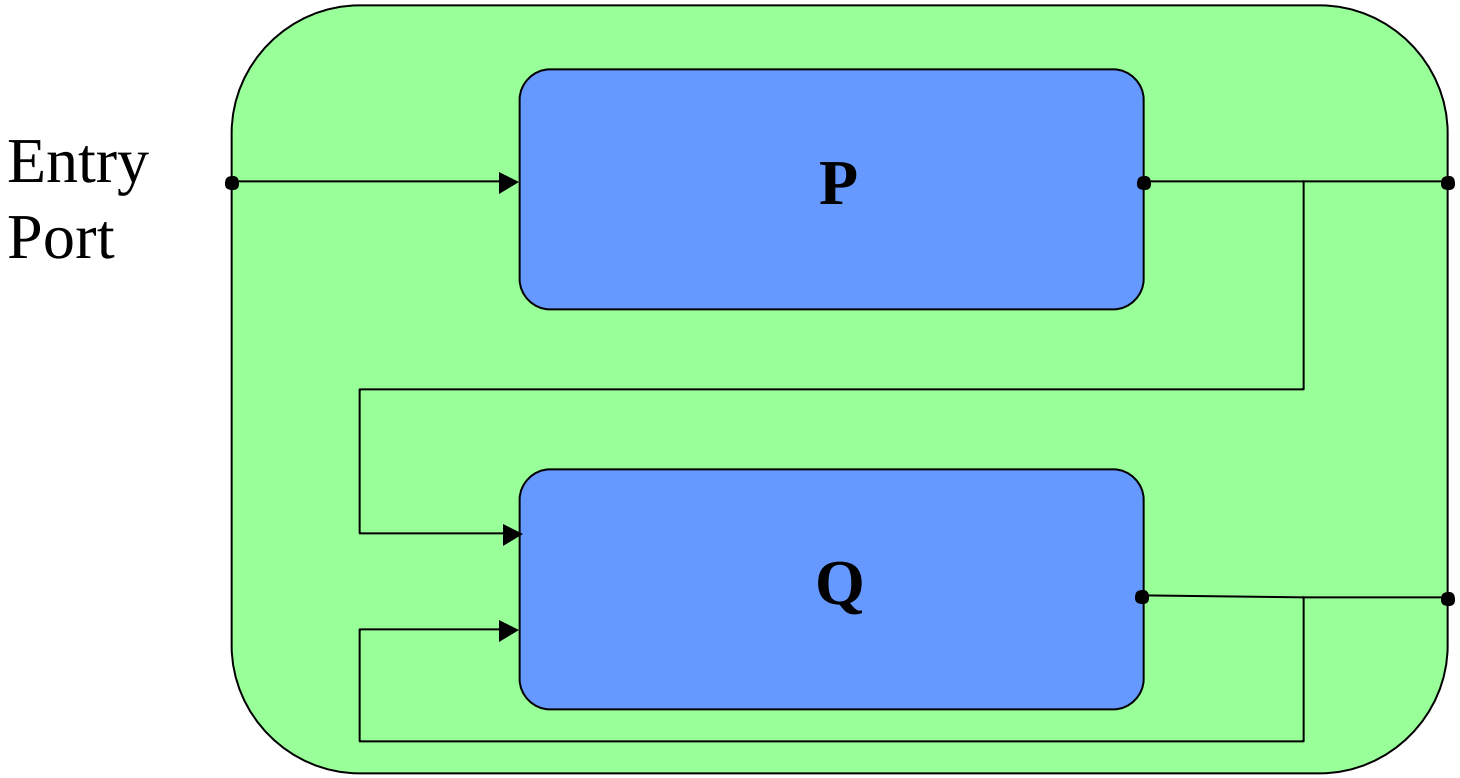

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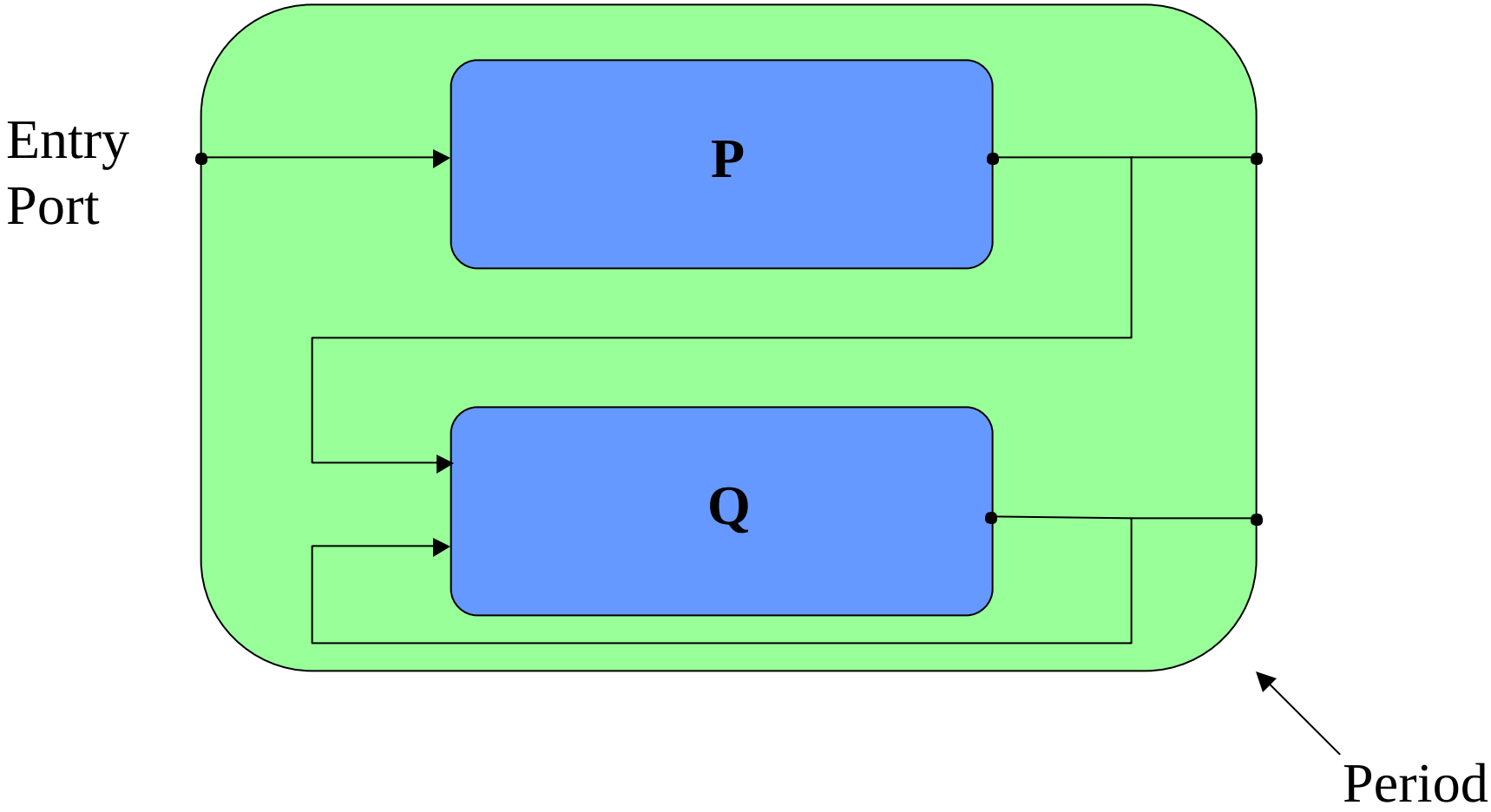
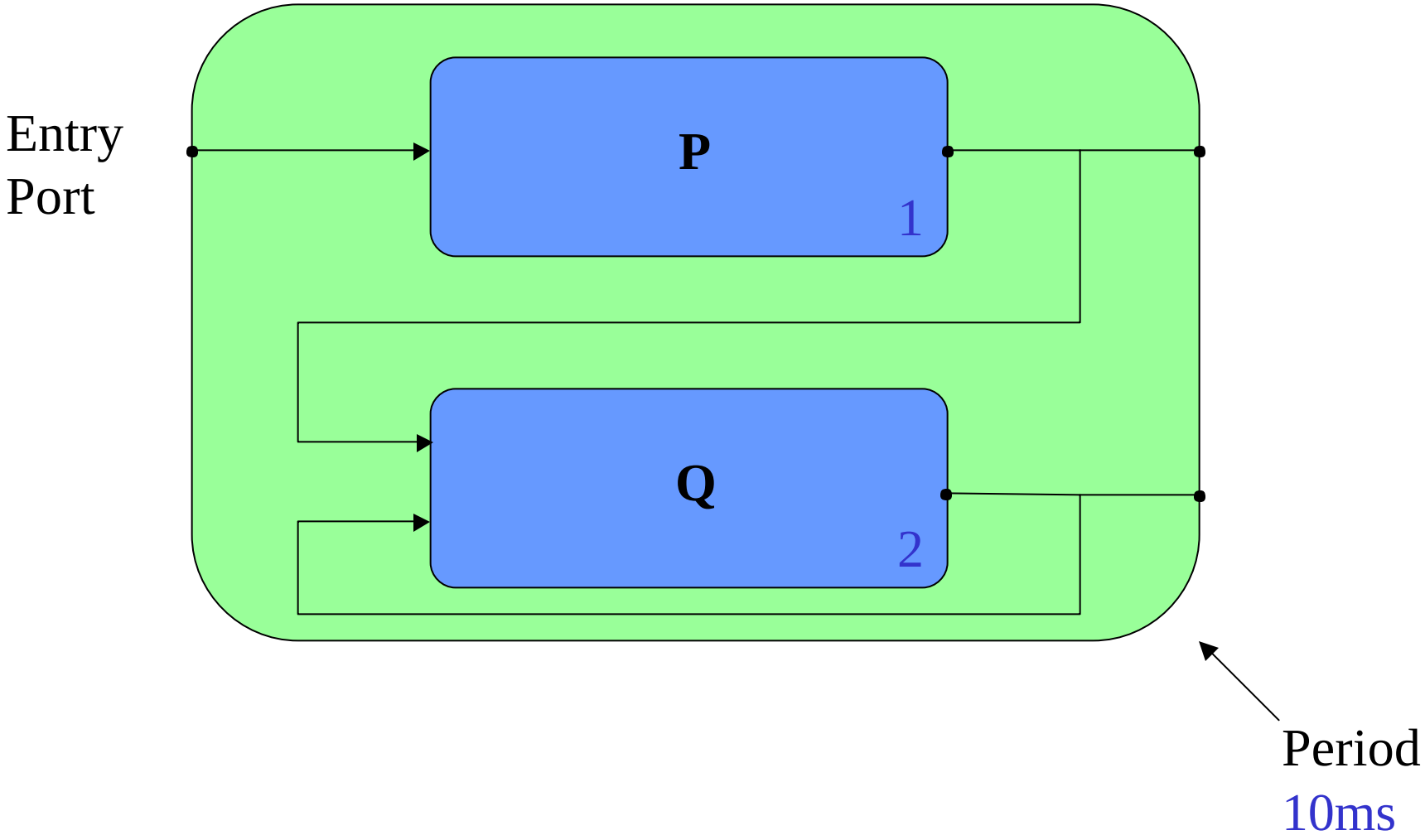


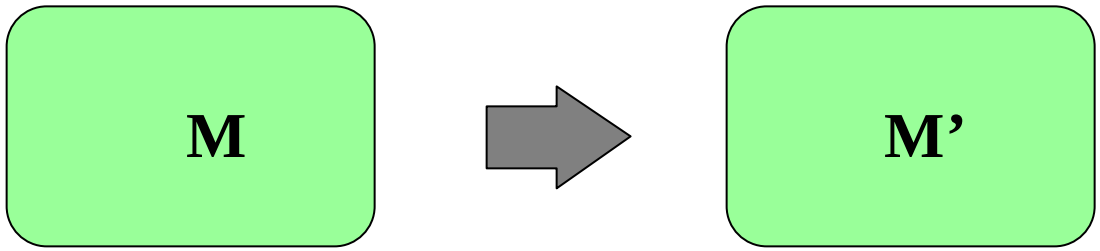
Semantics of a Mode



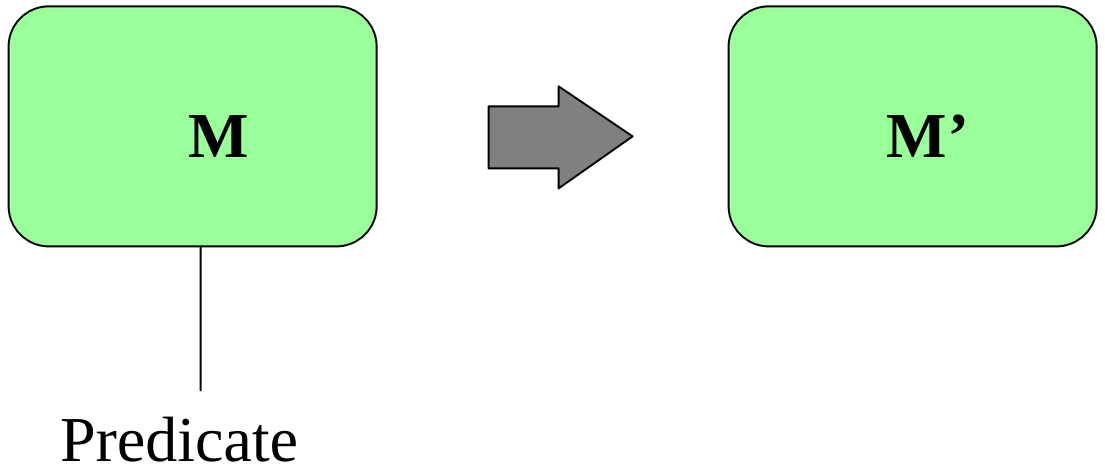
Concrete Syntax

```
mode m ( ) period 10 ms
  {
     taskfreq 1 do int x = P ( ) ;
     taskfreq 2 do int y = Q ( x, y ) ;
  }
```

A Mode Switch



Abstract Syntax of a Mode Switch



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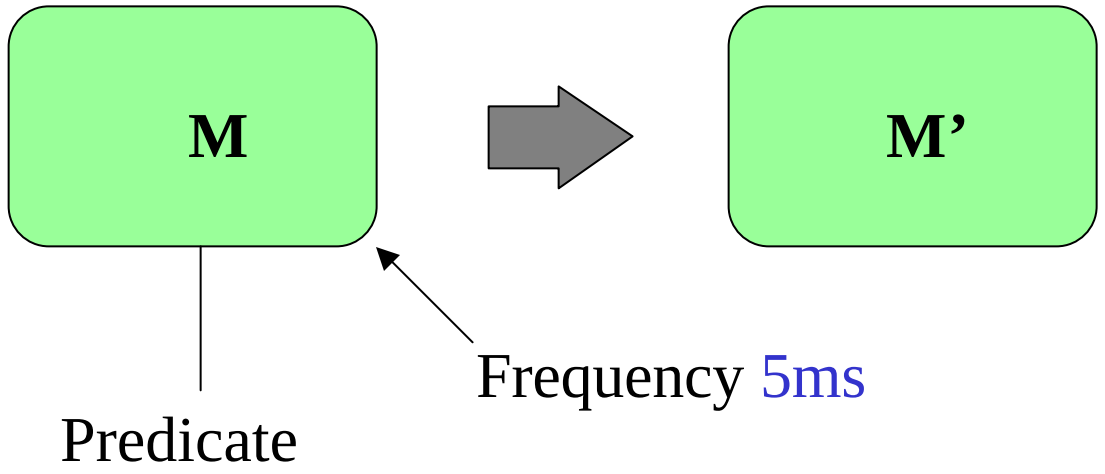

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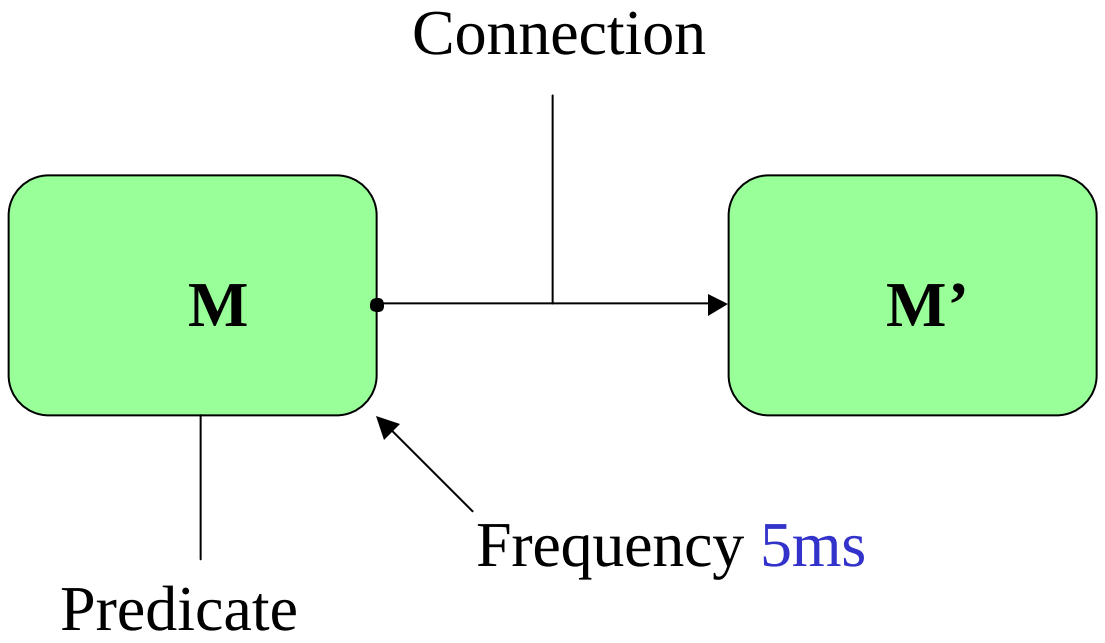
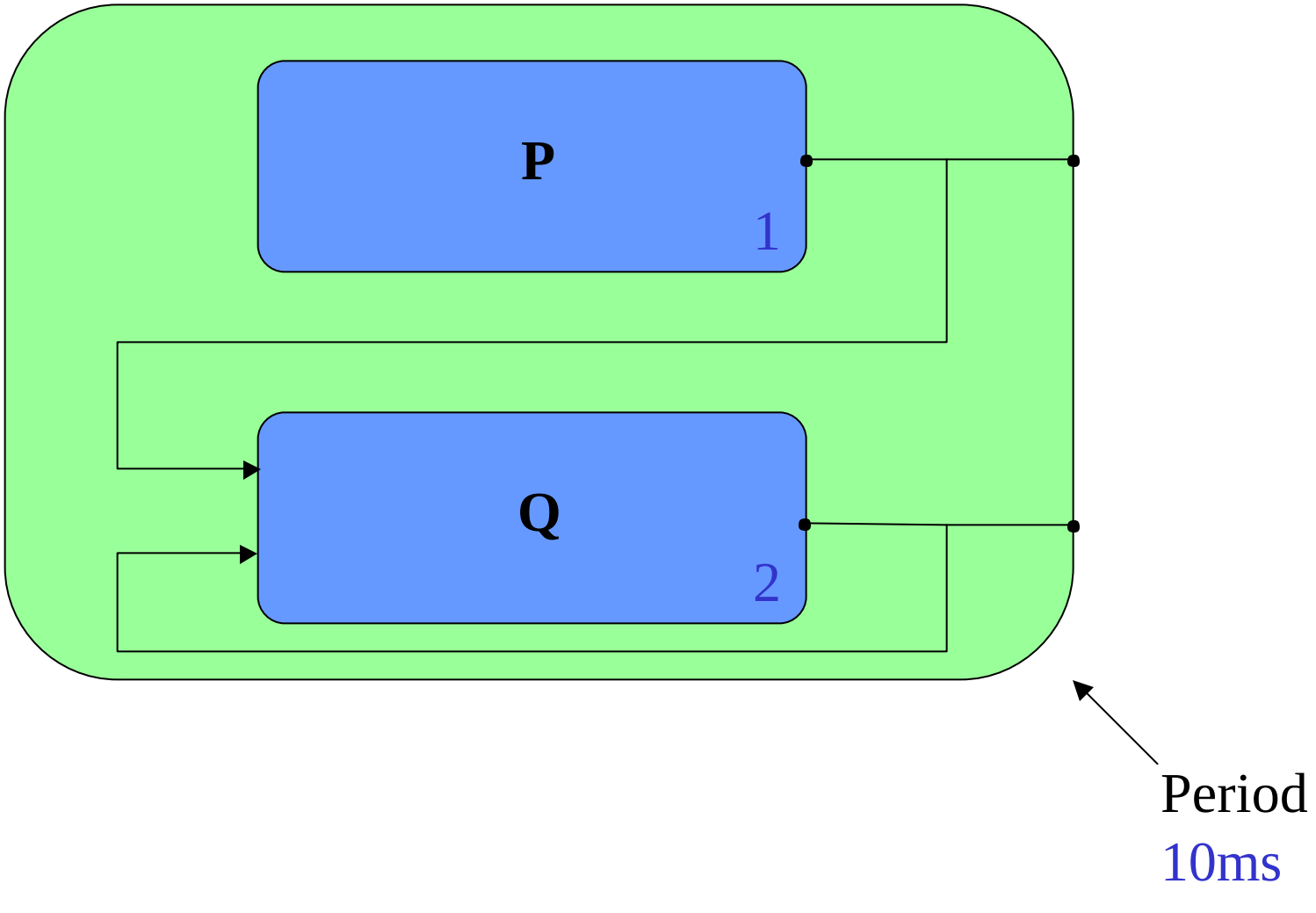
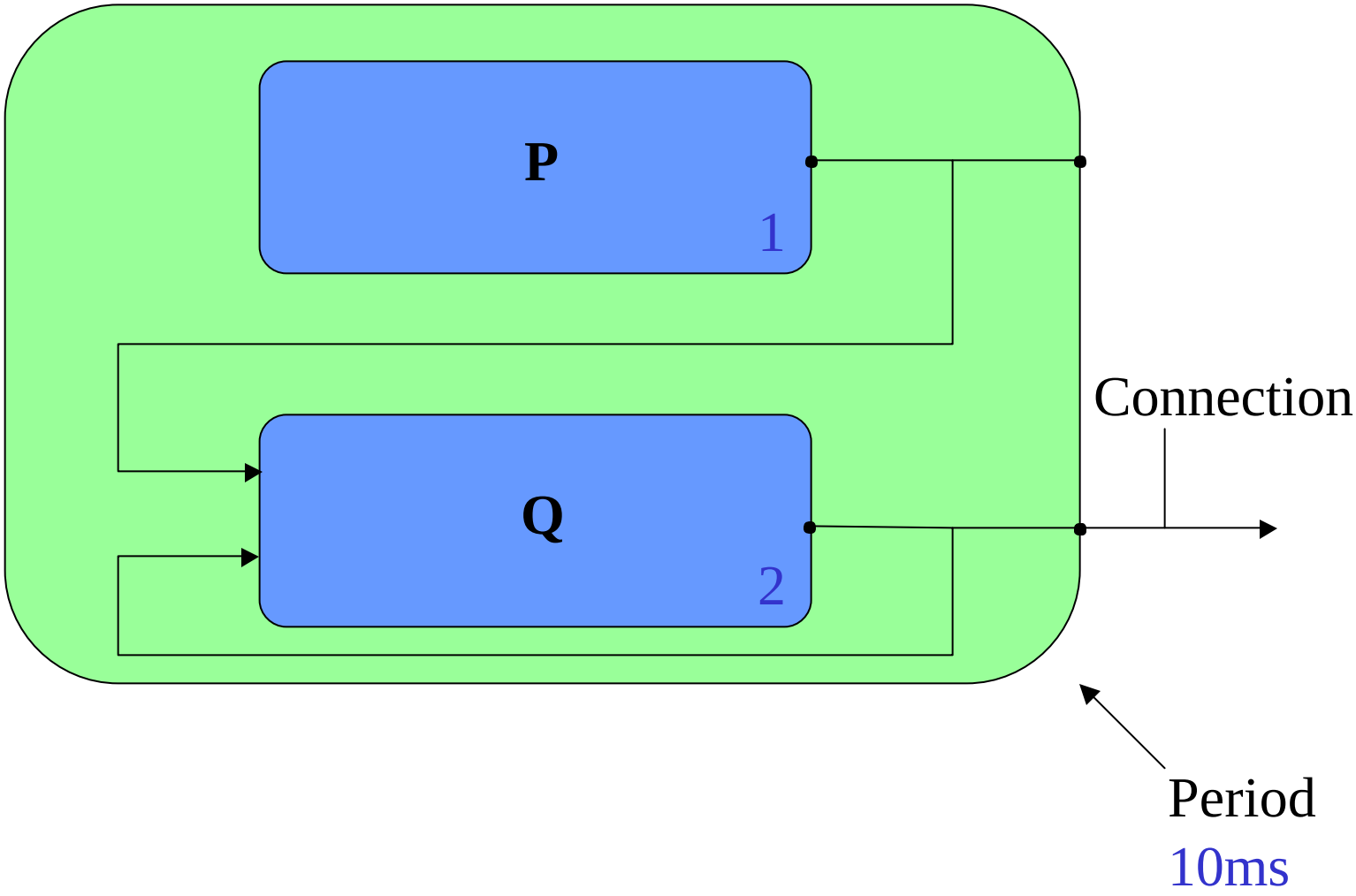


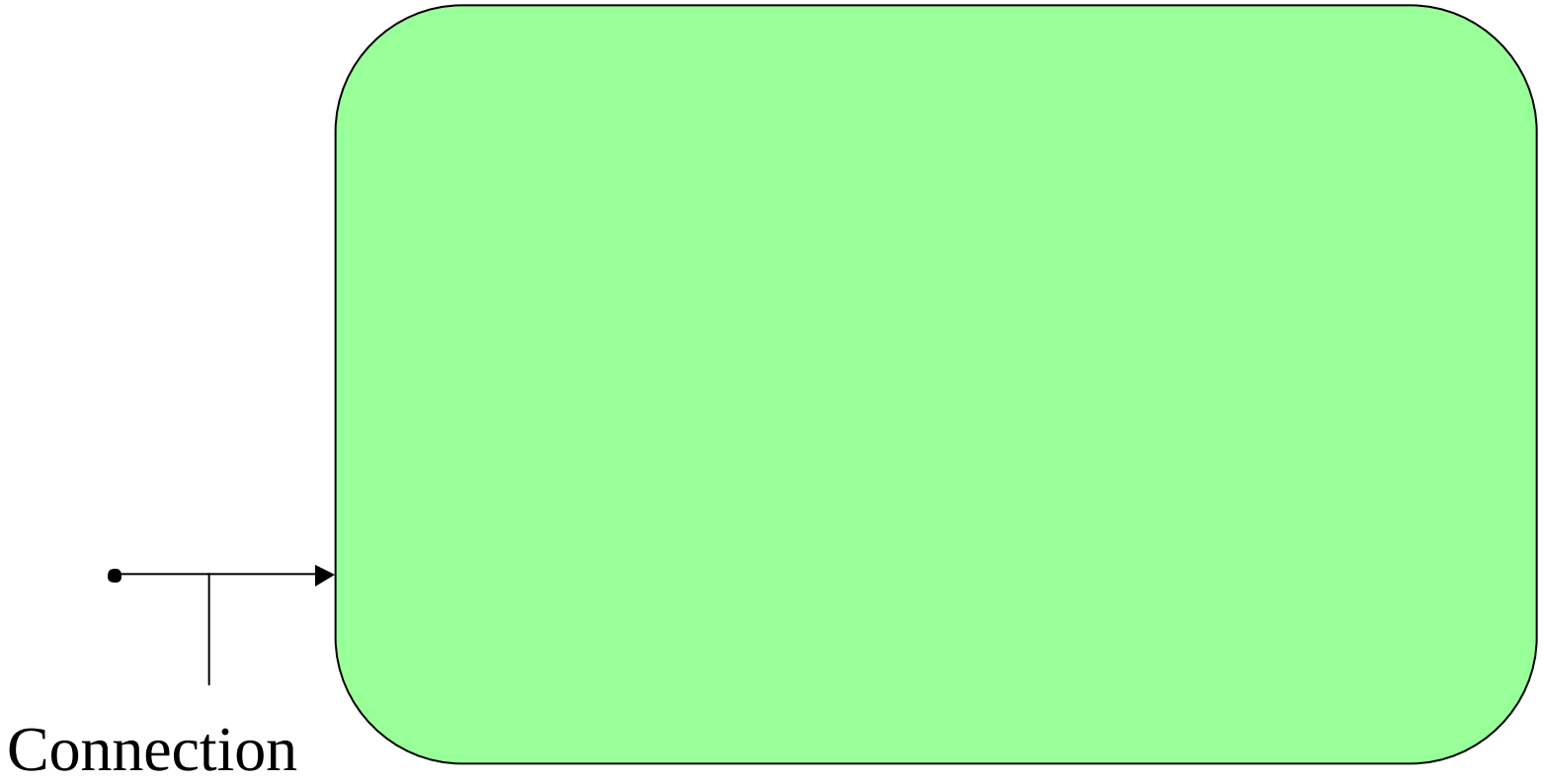
Mode M



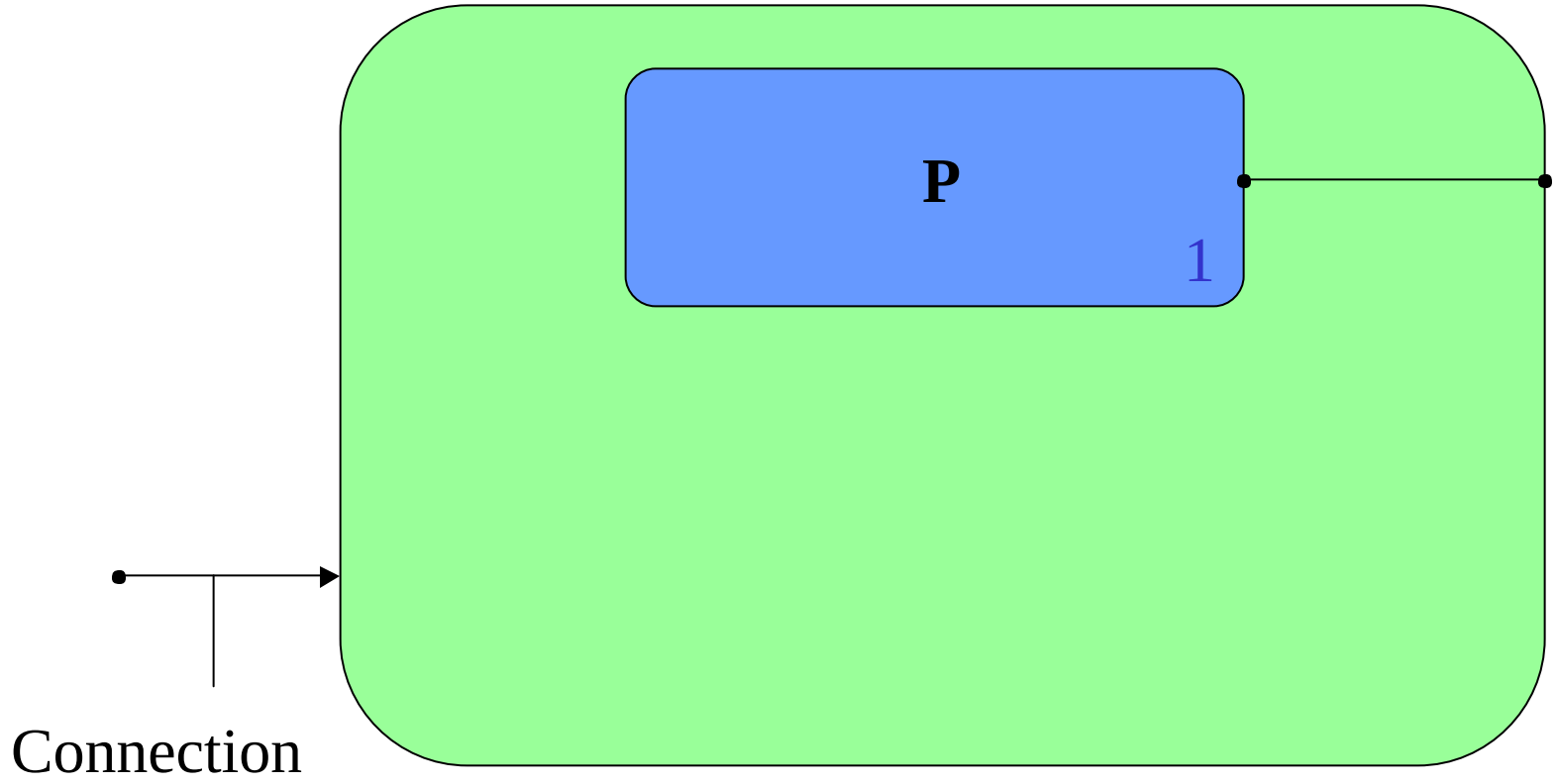
Mode M



Mode M’



Mode M’



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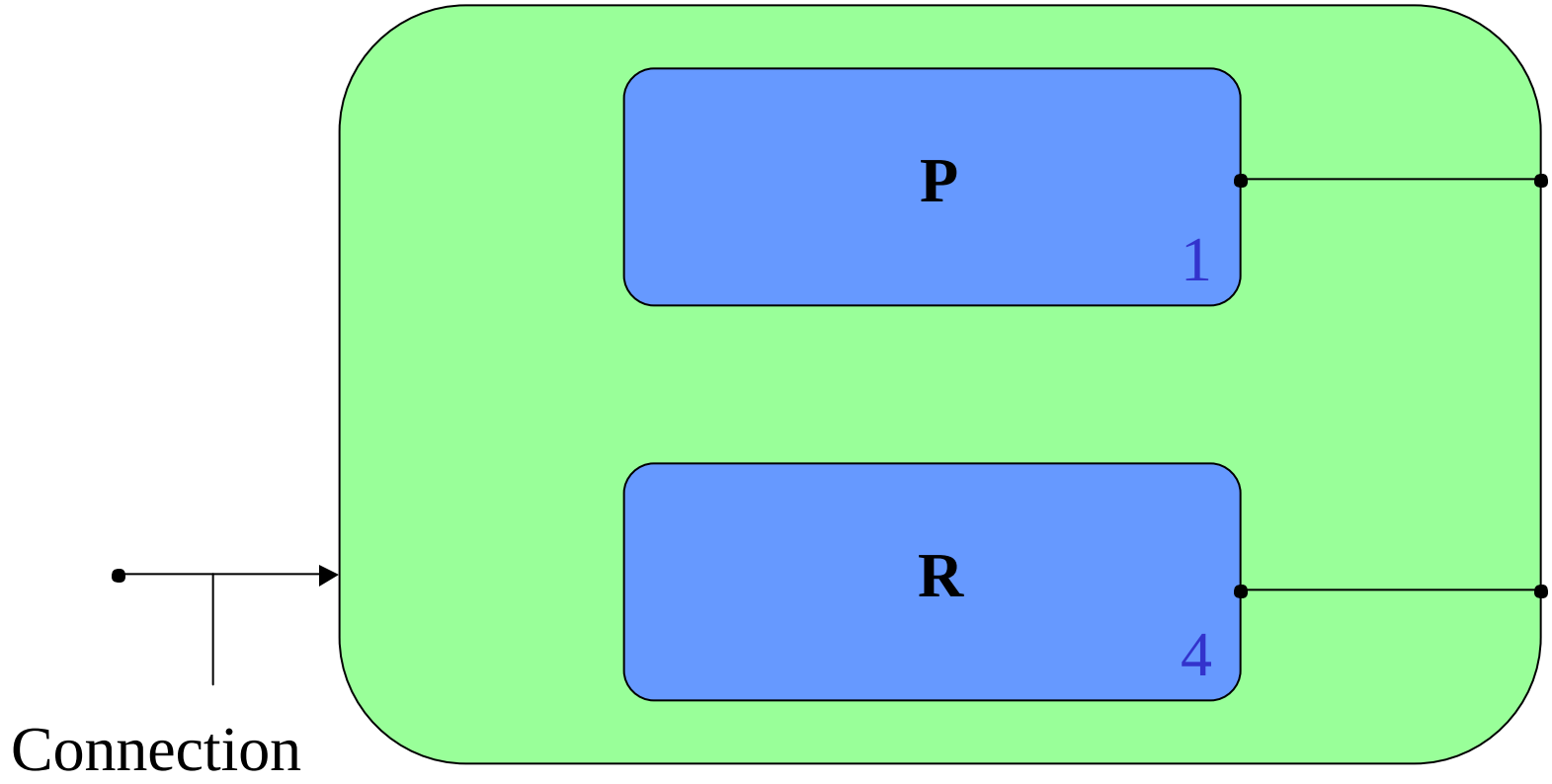
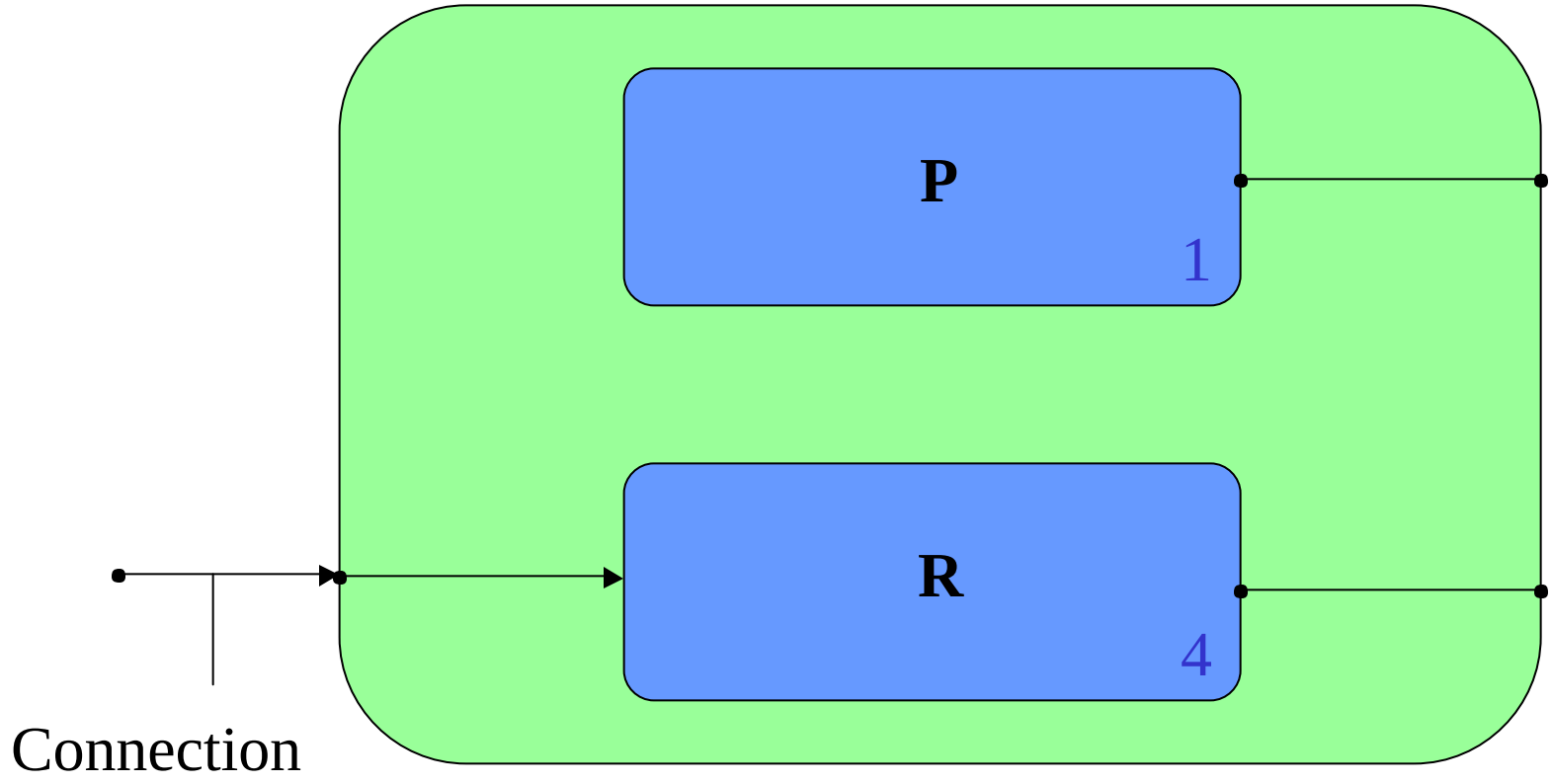


Mode M’



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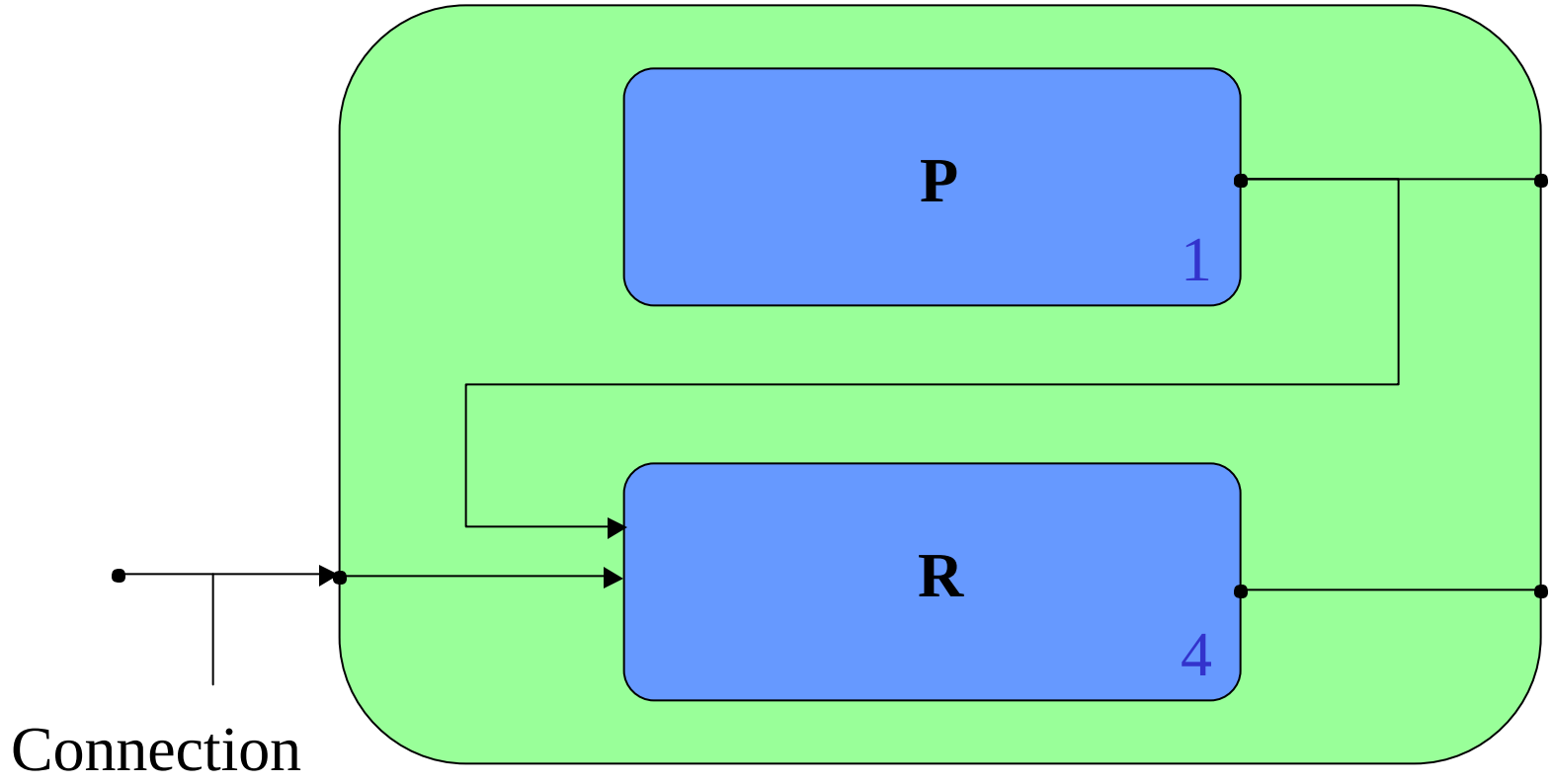

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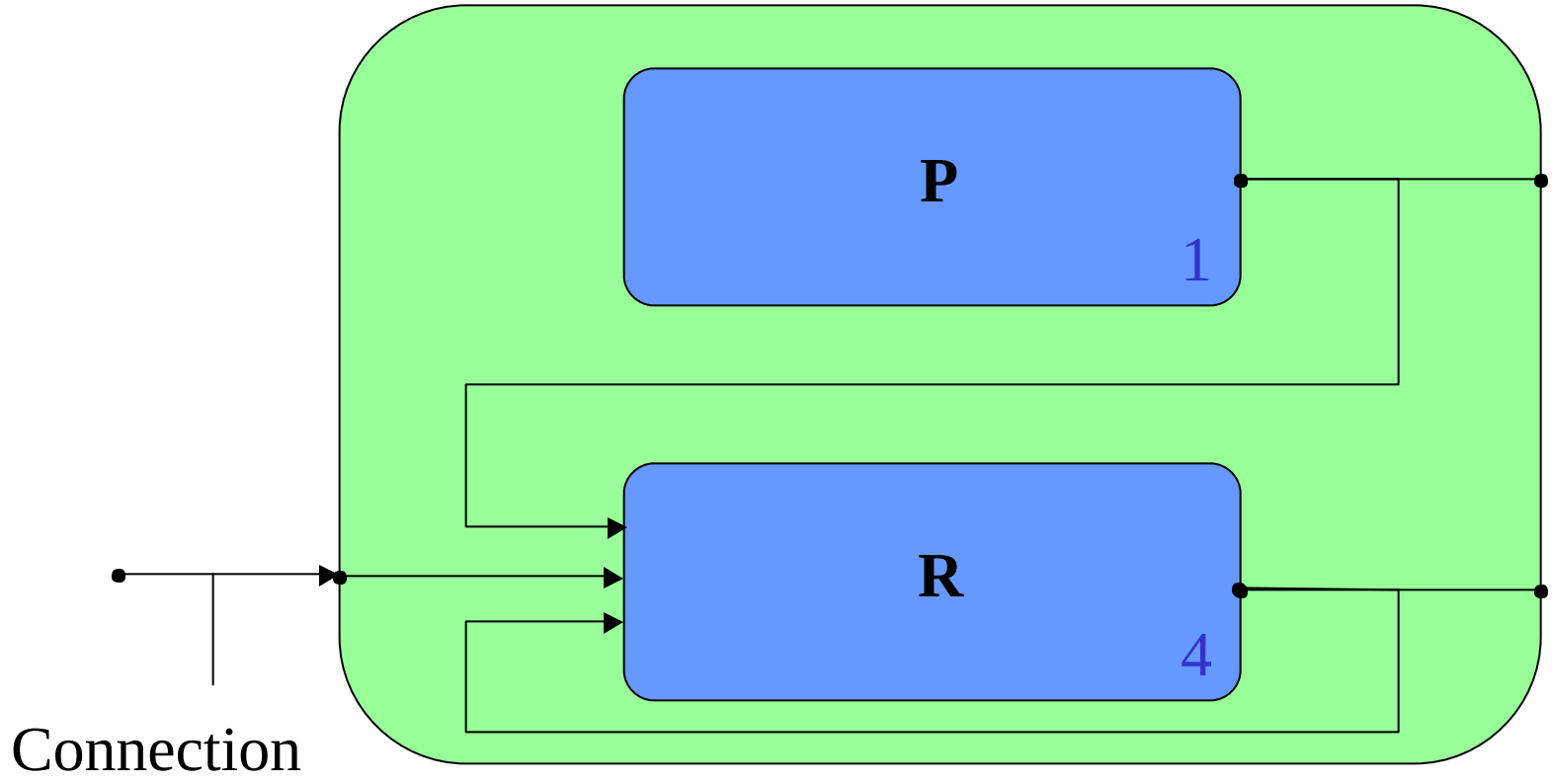

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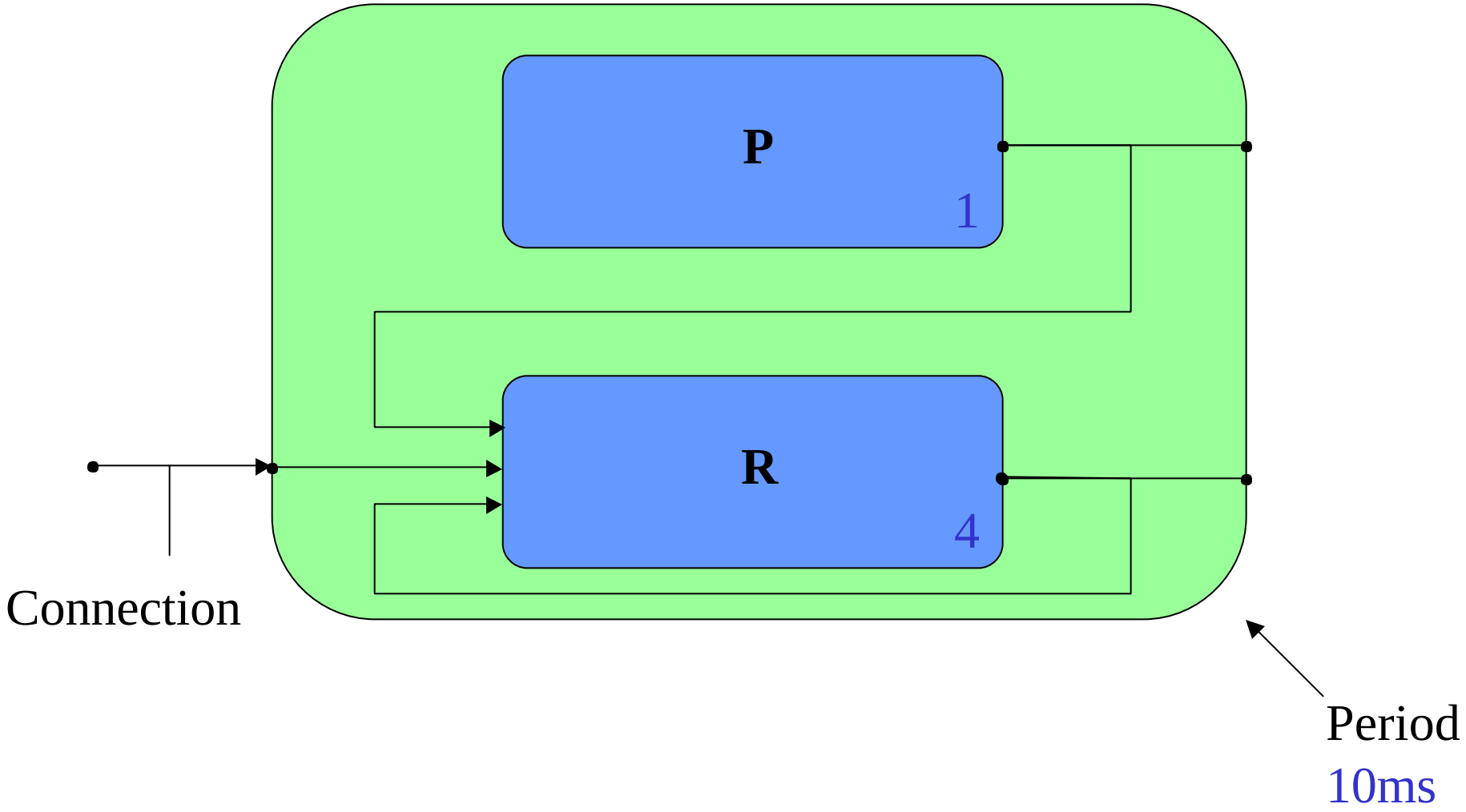
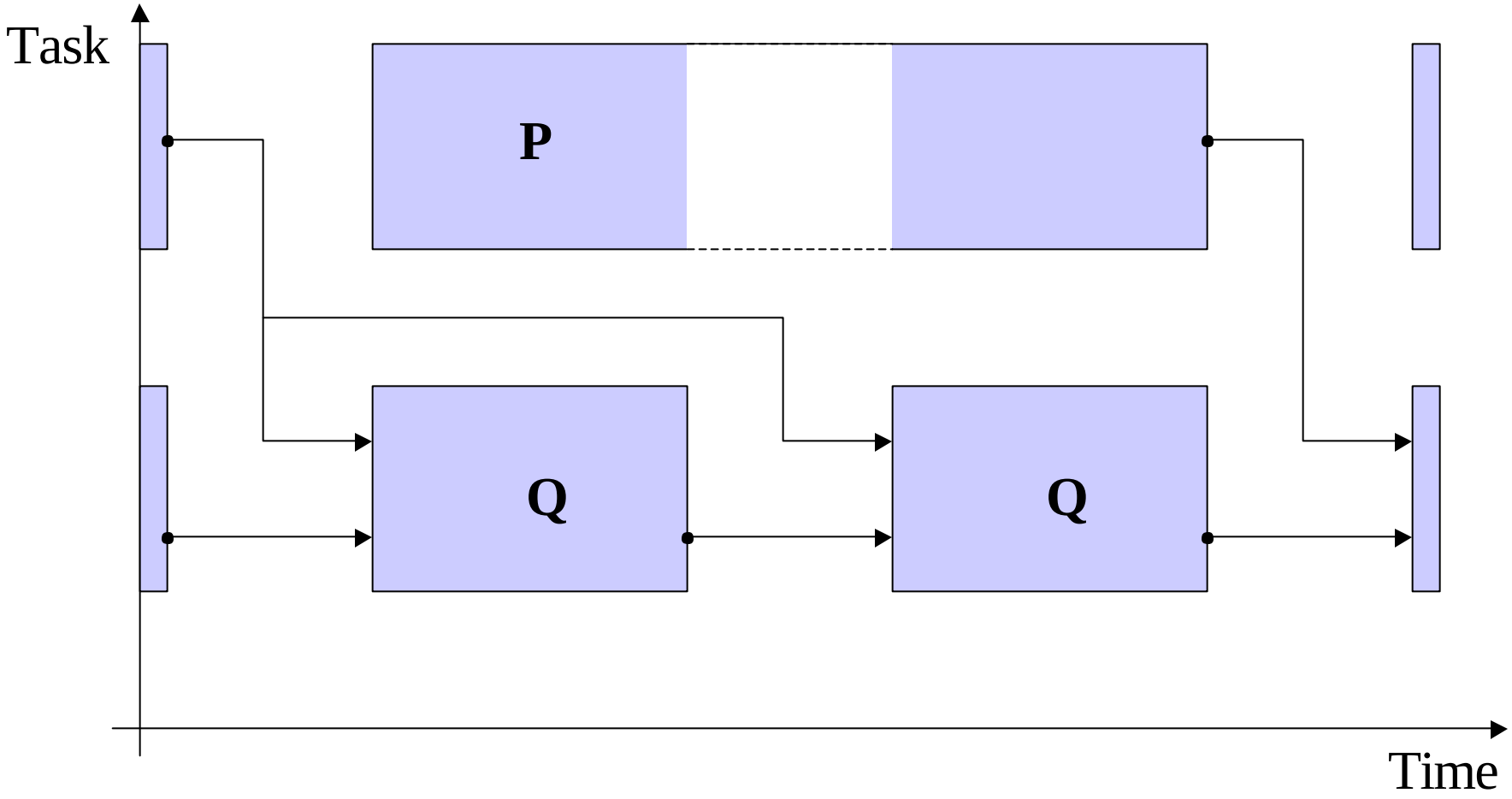


Concrete Syntax

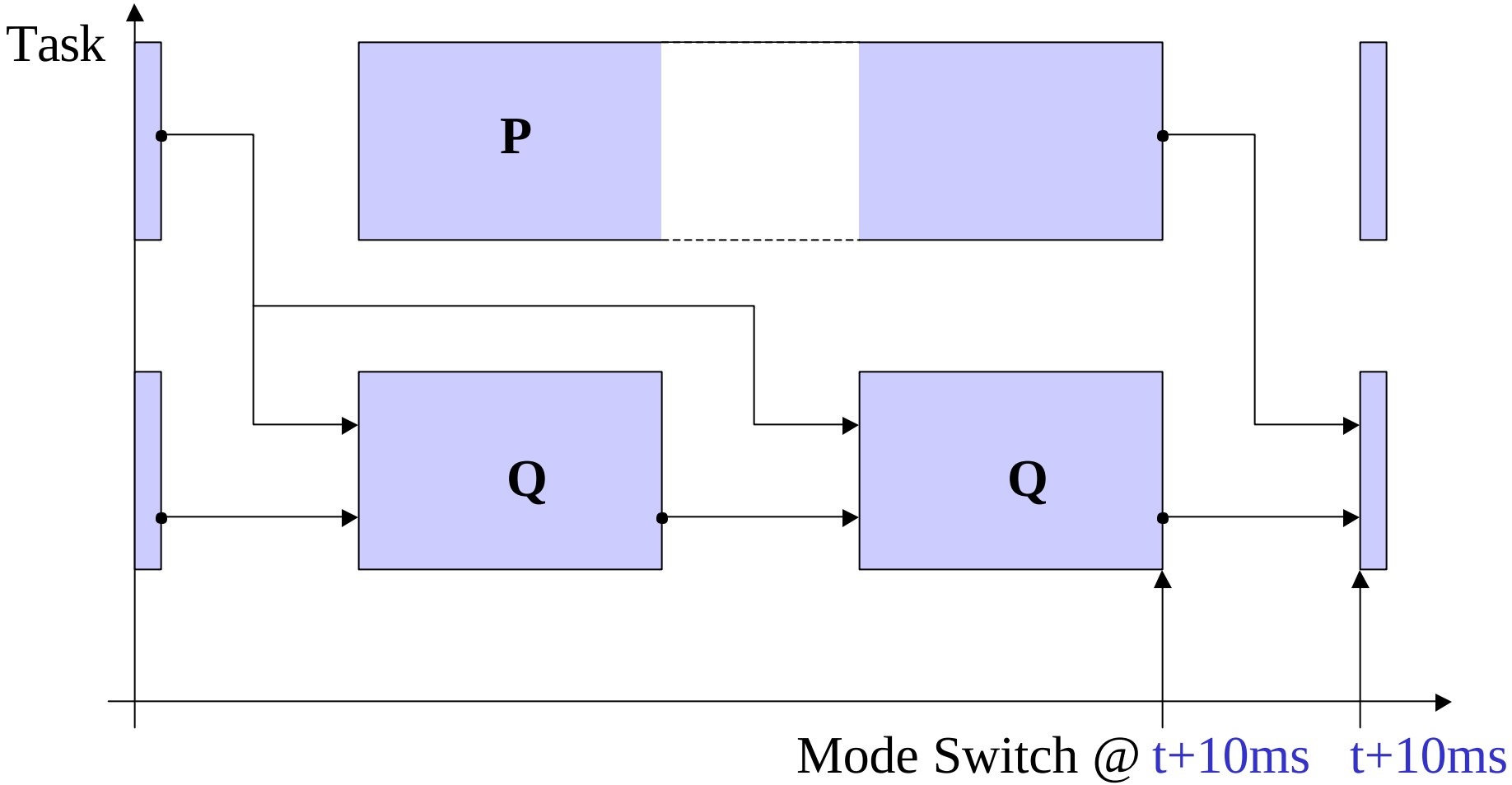
```
start m ( ) {
    mode m ( ) period 10 ms entryfreq 1 {
        taskfreq 1 do int x = P ( ) ;
        taskfreq 2 do int y = Q ( x, y ) ;

        exitfreq 2 if y = 5 then m' ( y ) ;
    }
    mode m' ( int z ) period 10 ms entryfreq 2 {
        taskfreq 1 do int x = P ( ) ;
        taskfreq 4 do int u = R ( x, z ) ;
    }
}
```

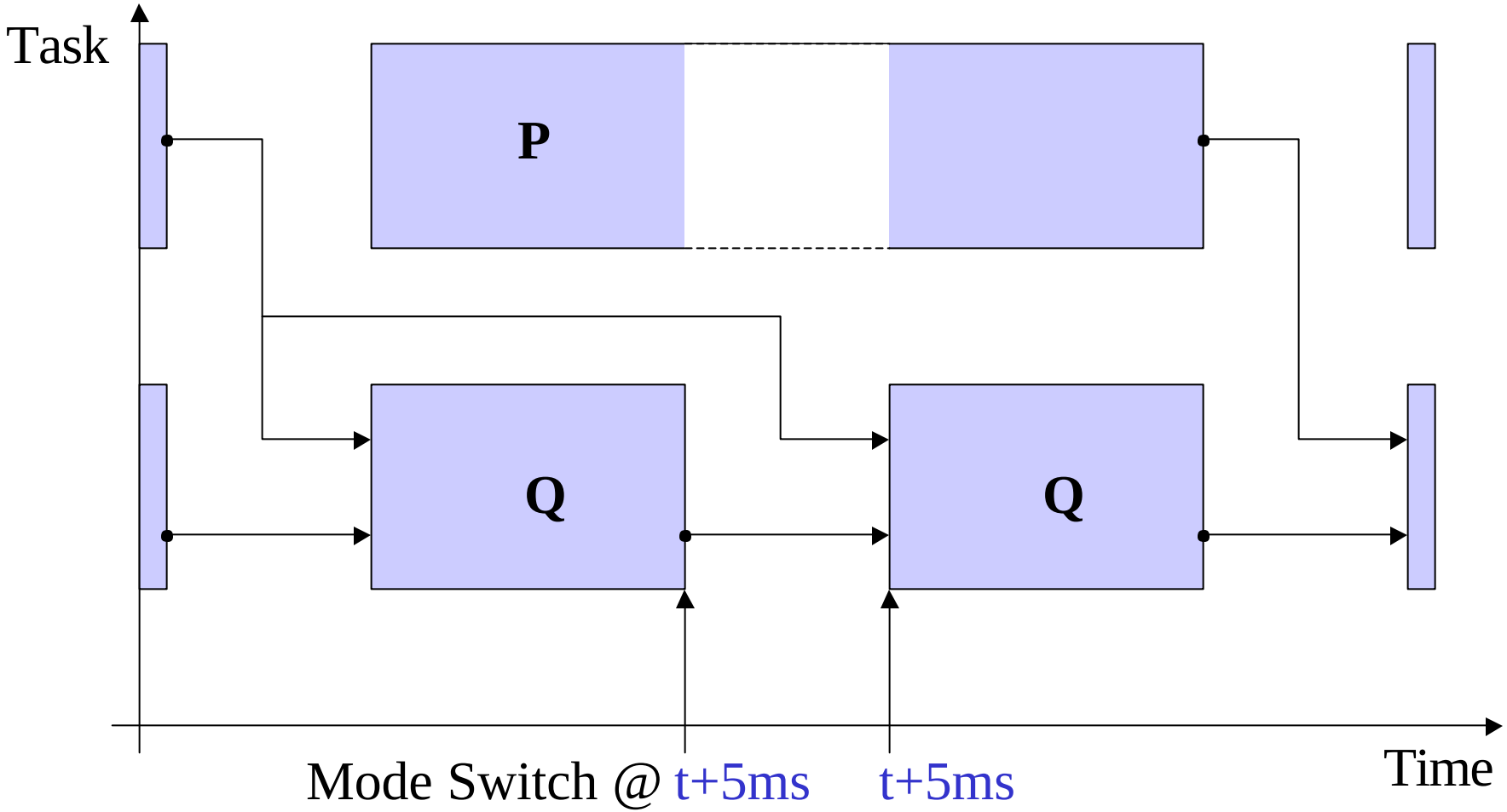
Semantics of a Mode Switch



Semantics of a Mode Switch



Semantics of a Mode Switch



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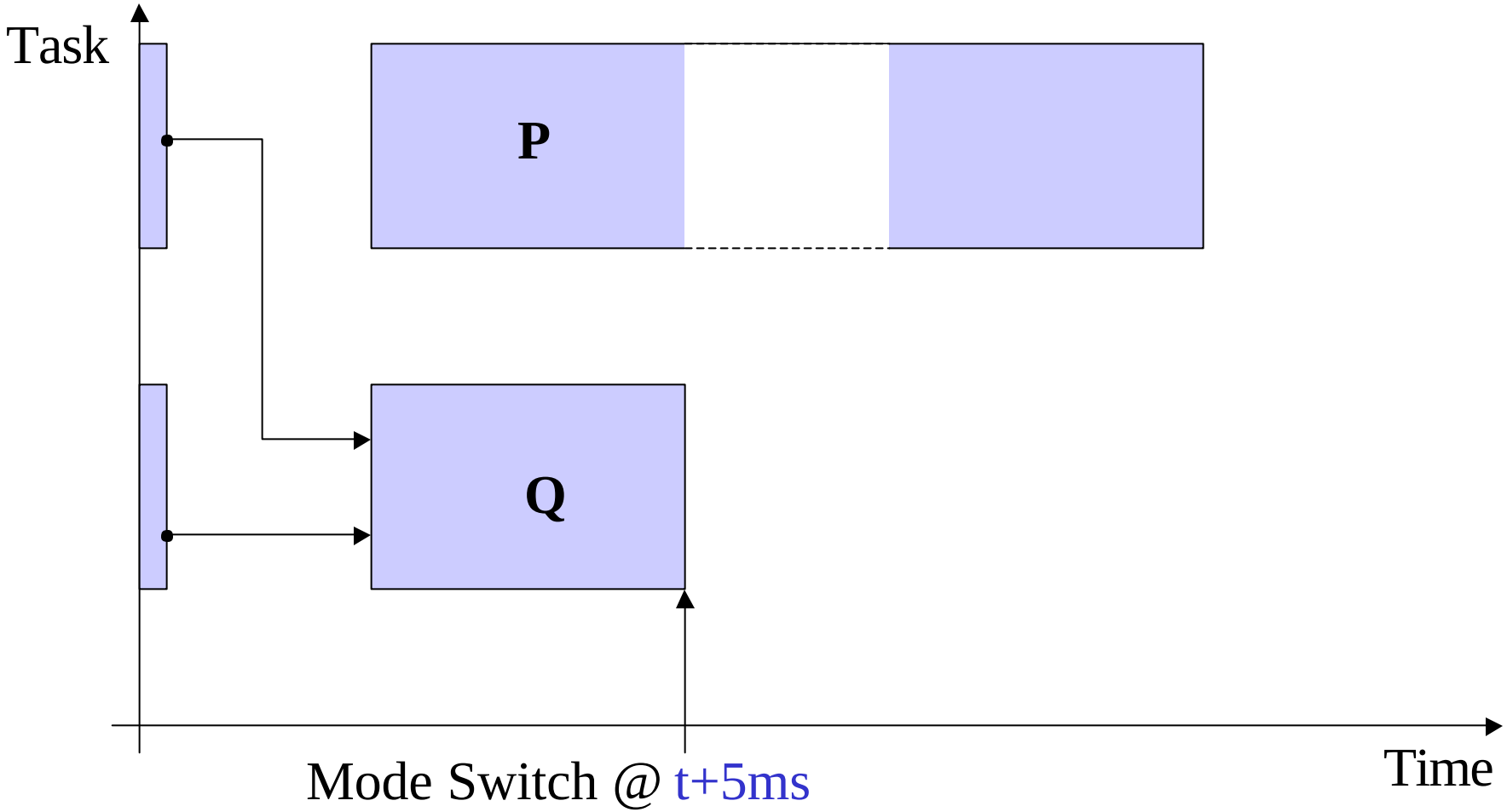

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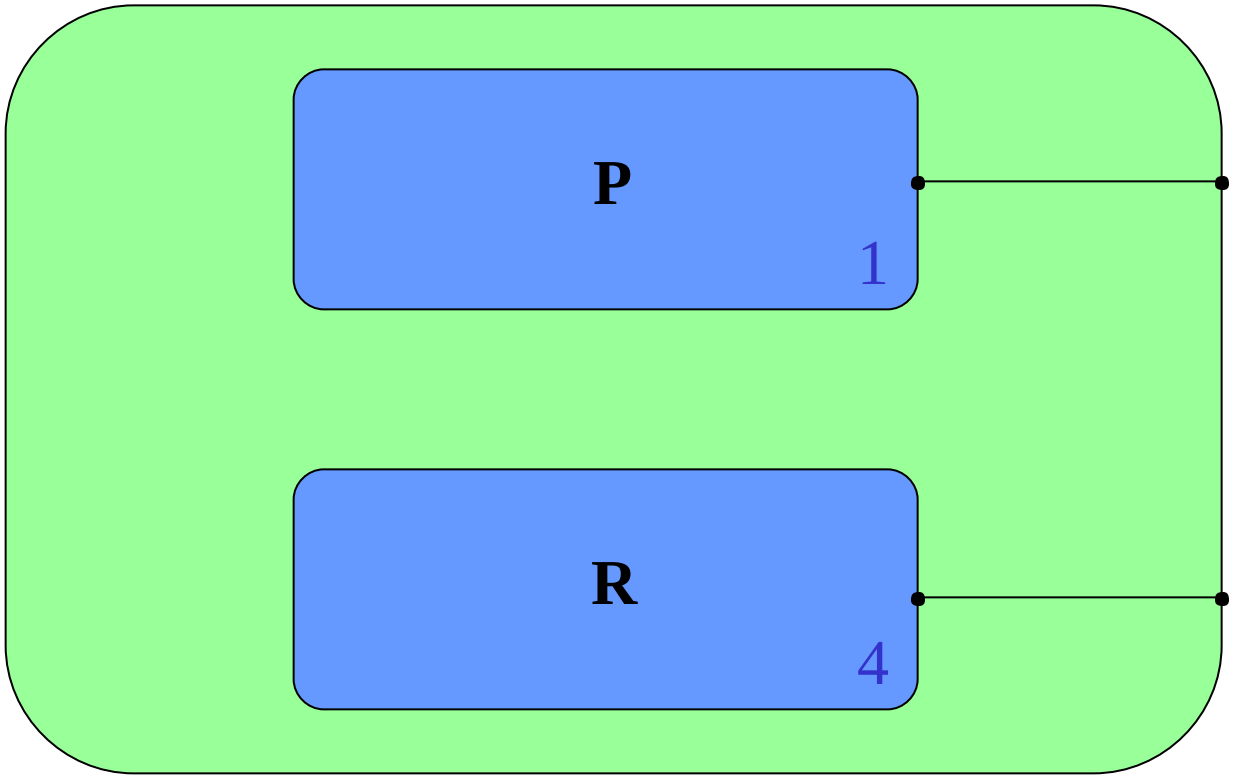
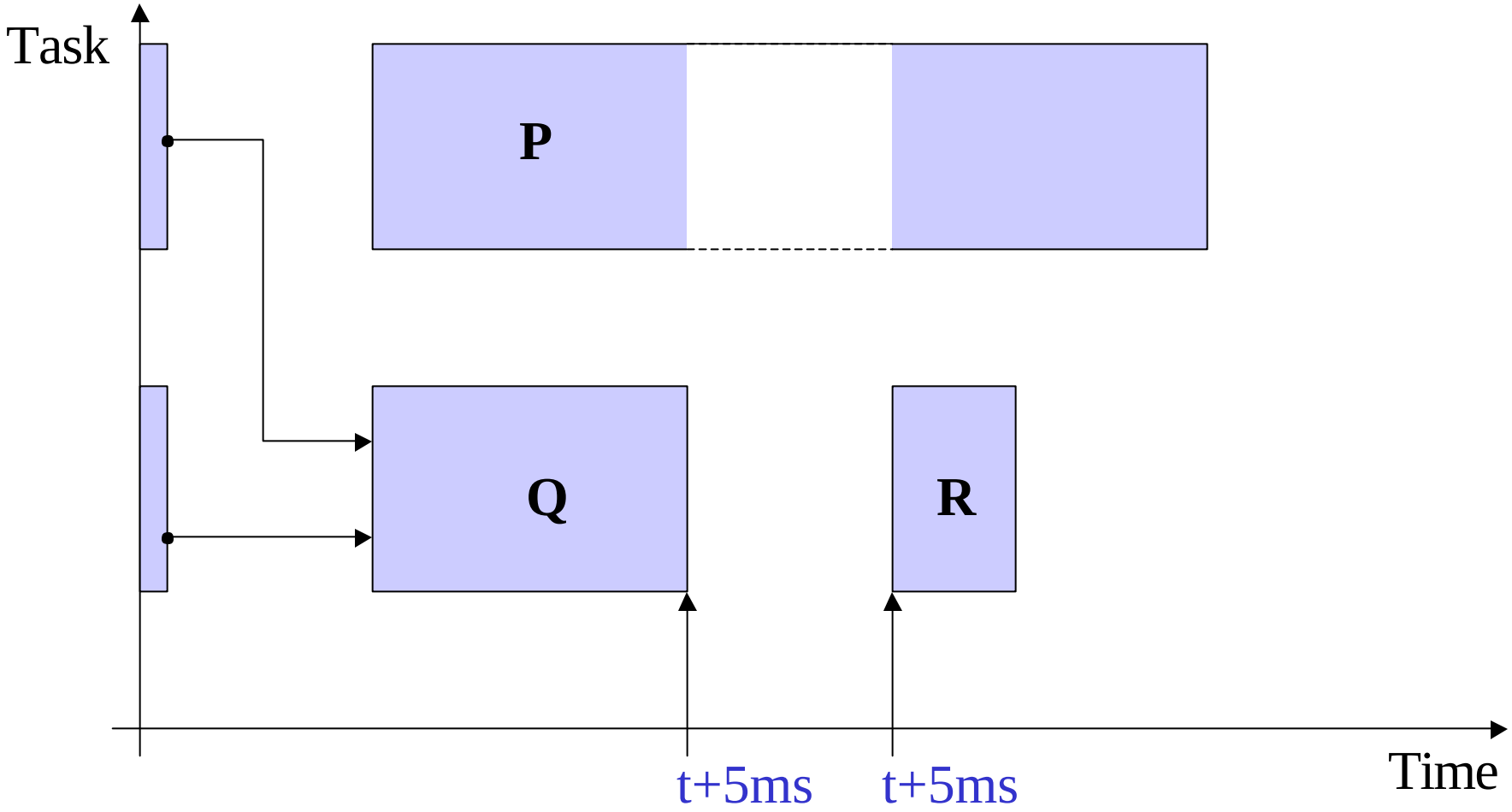


Semantics of a Mode Switch



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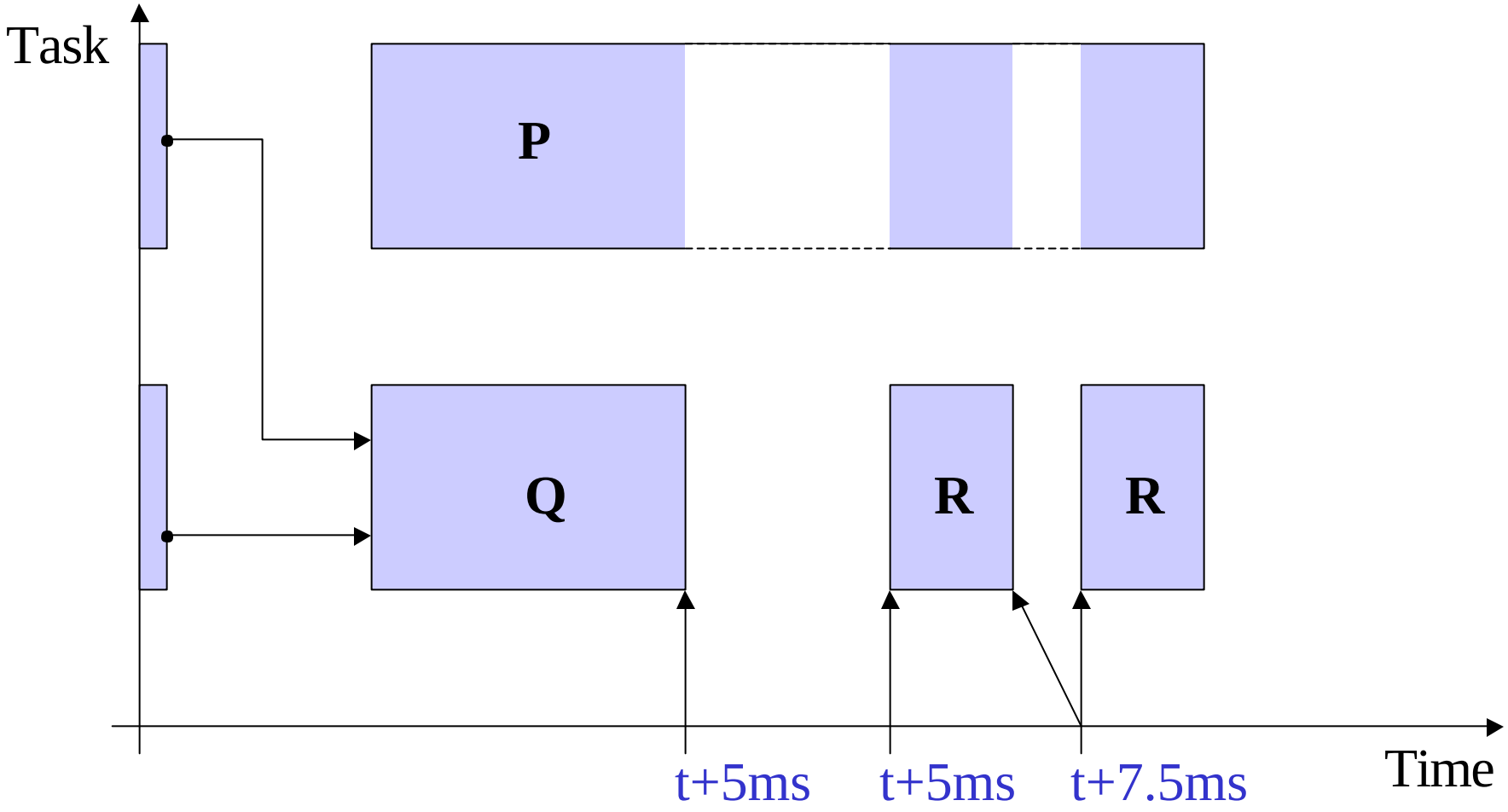
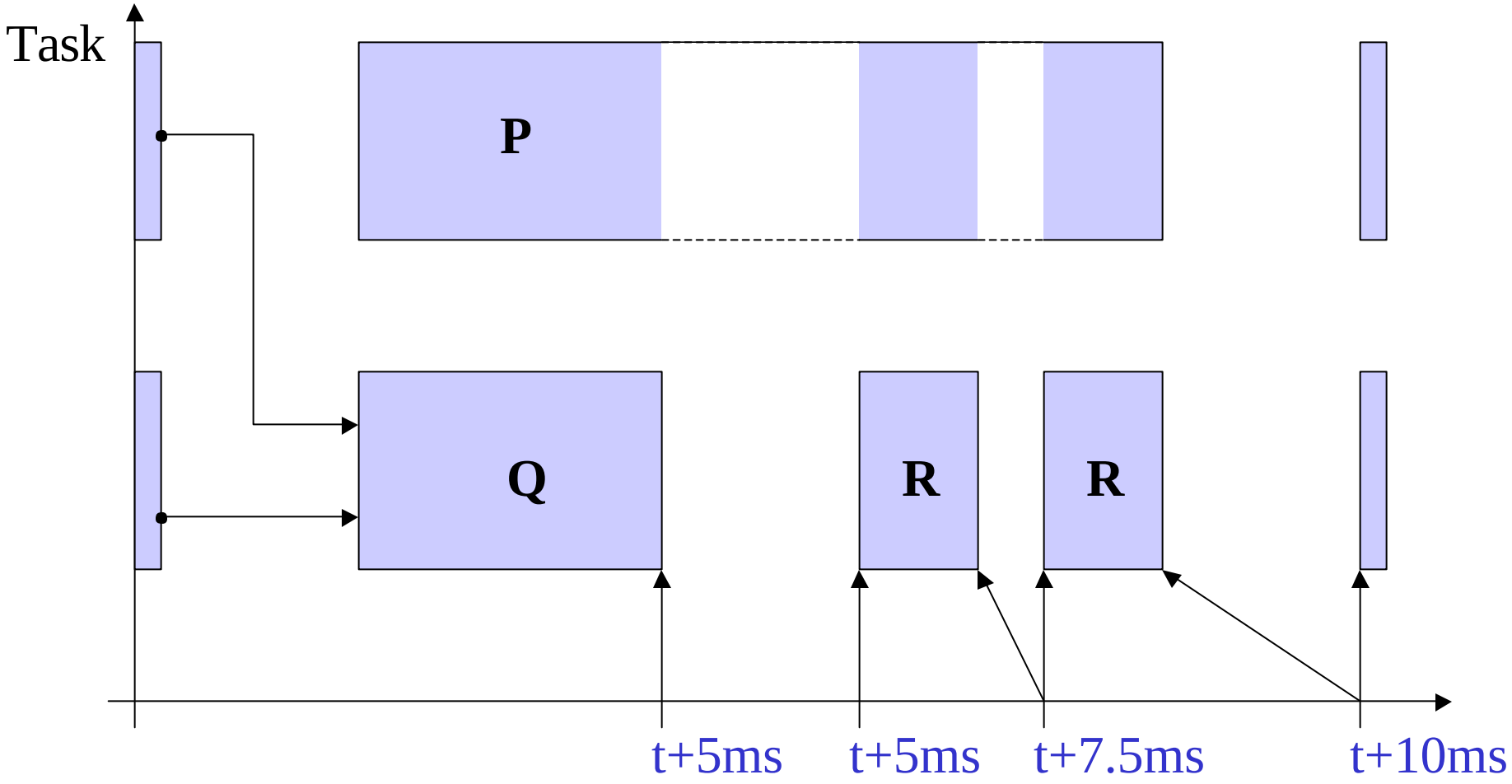


Semantics of a Mode Switch



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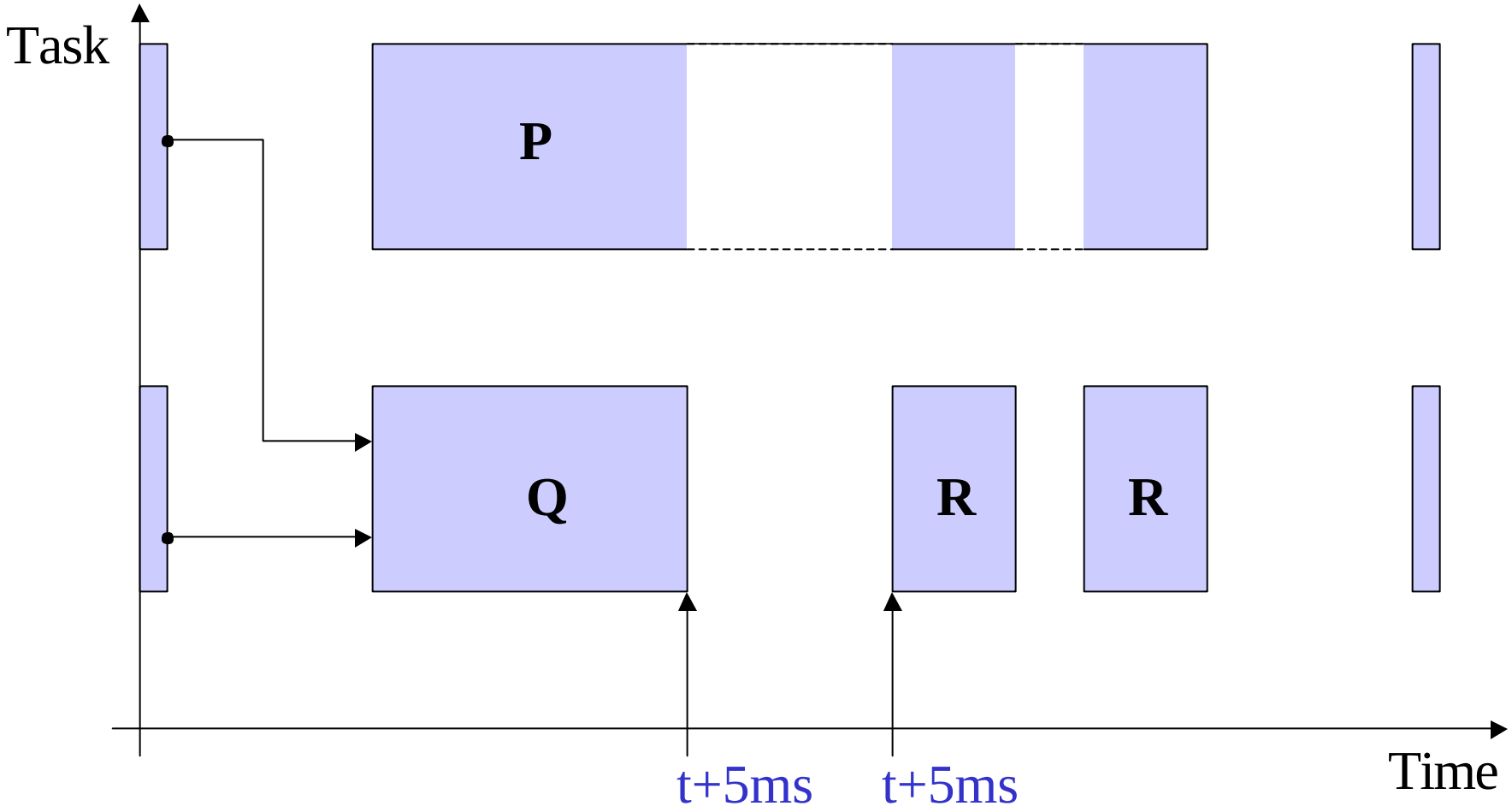
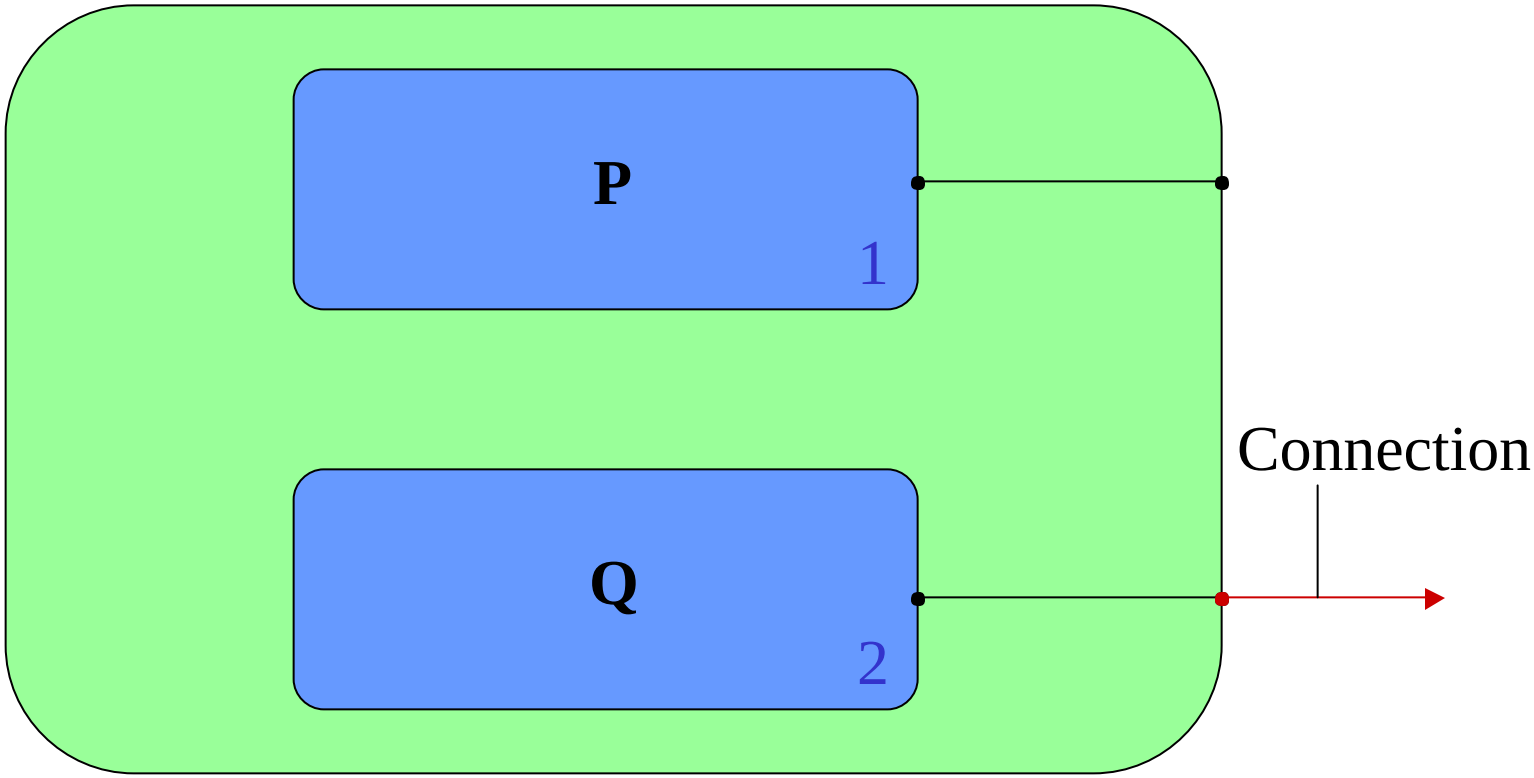
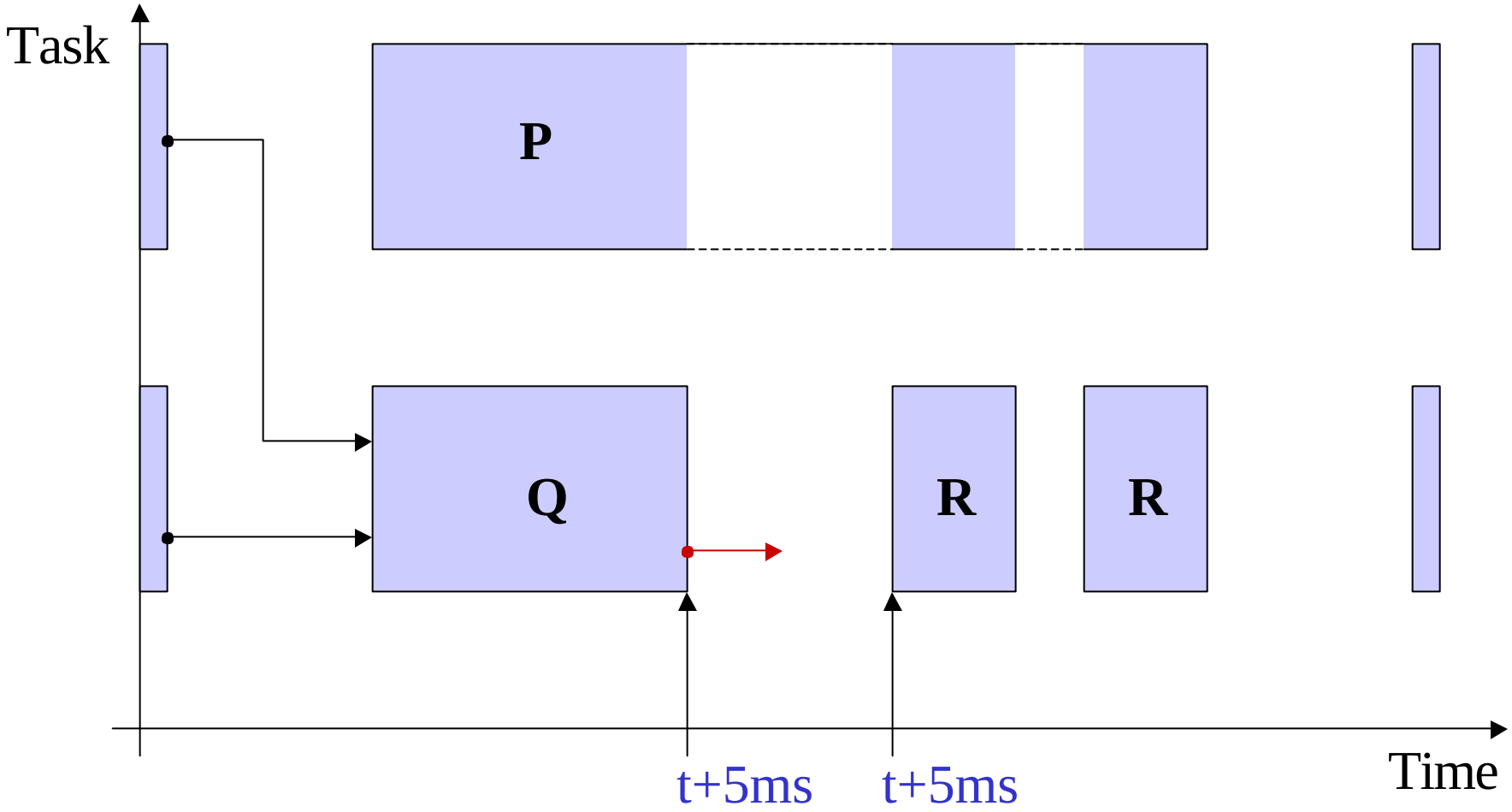


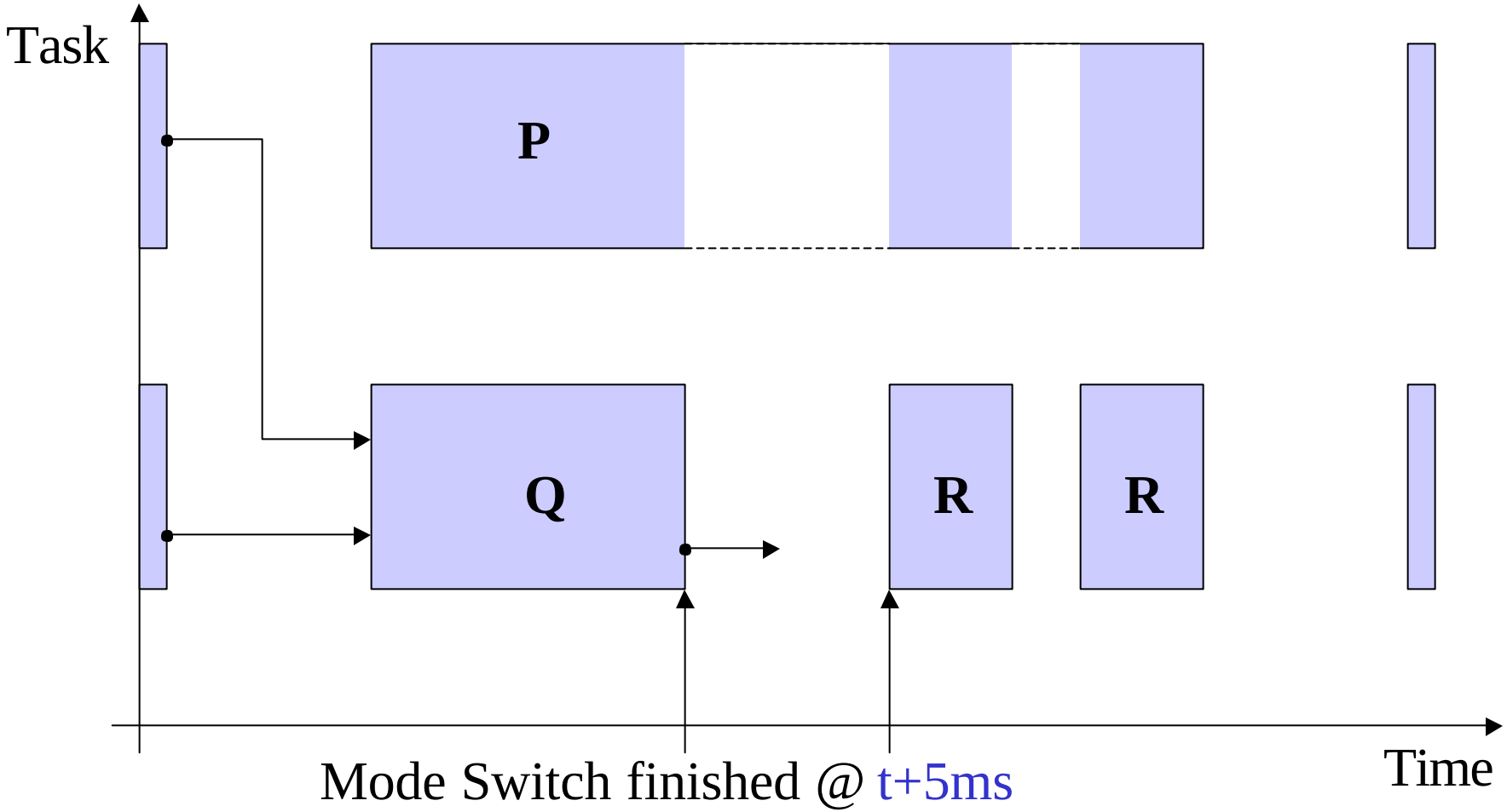
Mode M



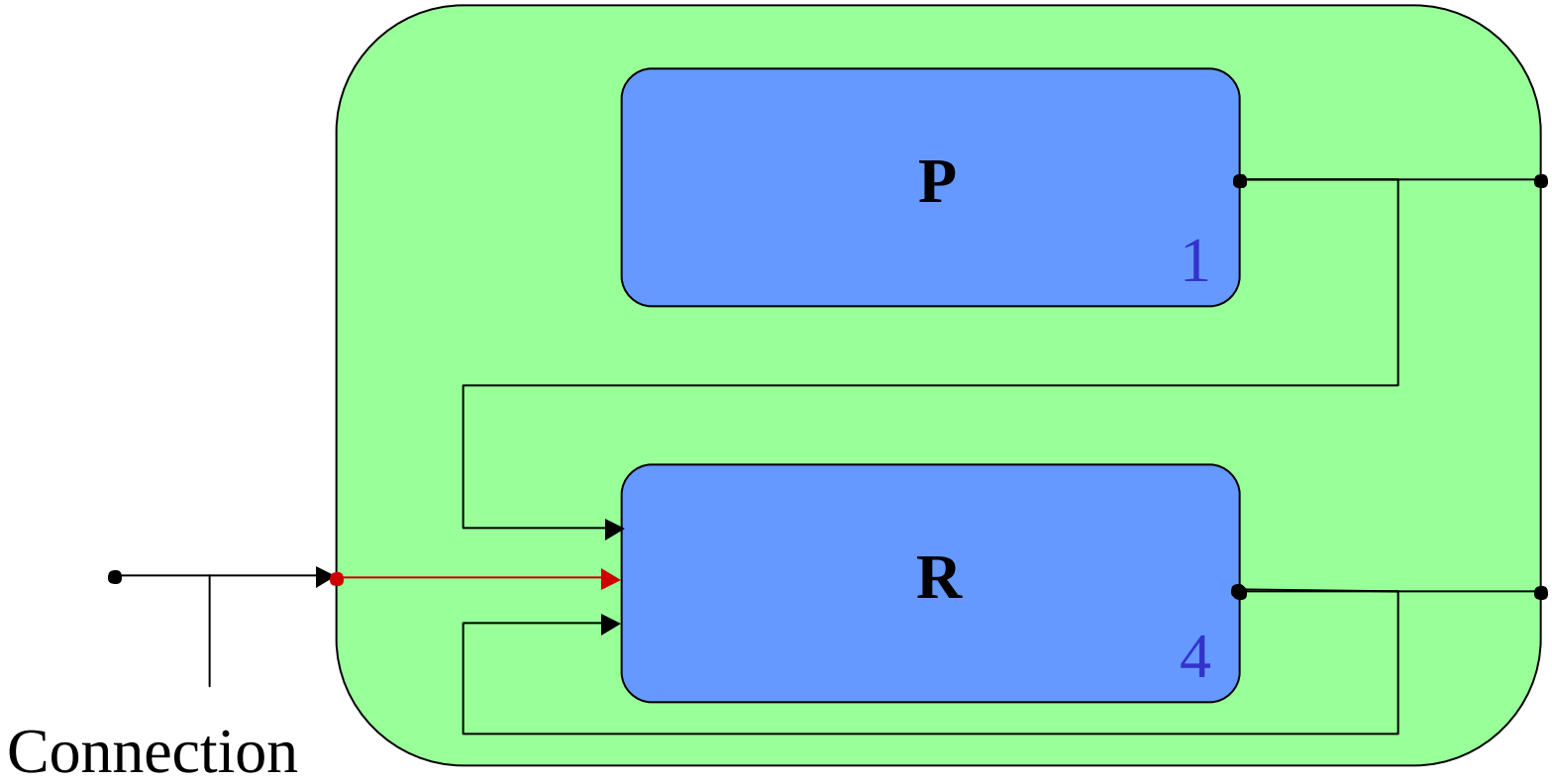
Semantics of a Mode Switch



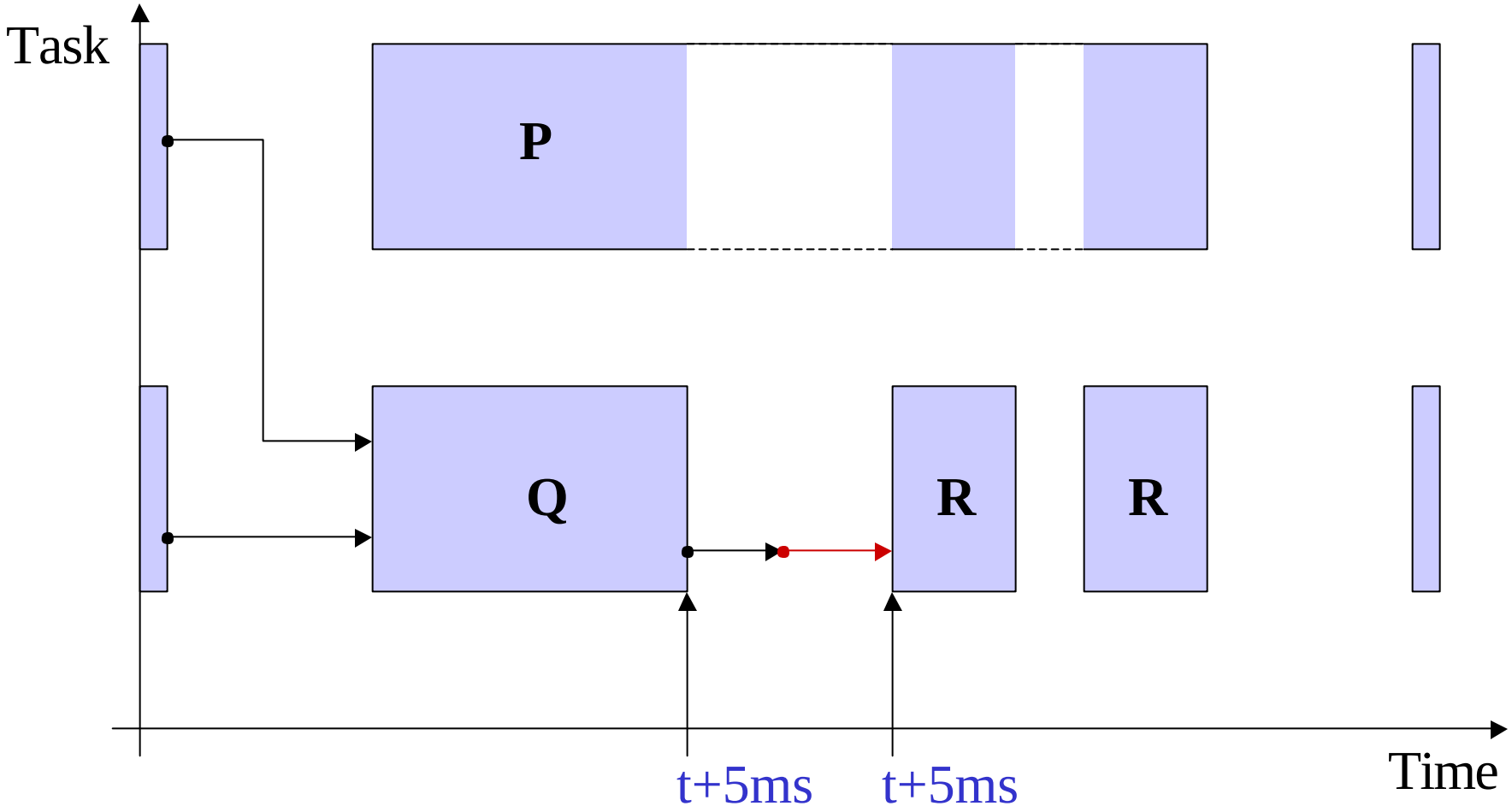
Semantics of a Mode Switch



Mode M’



Semantics of a Mode Switch



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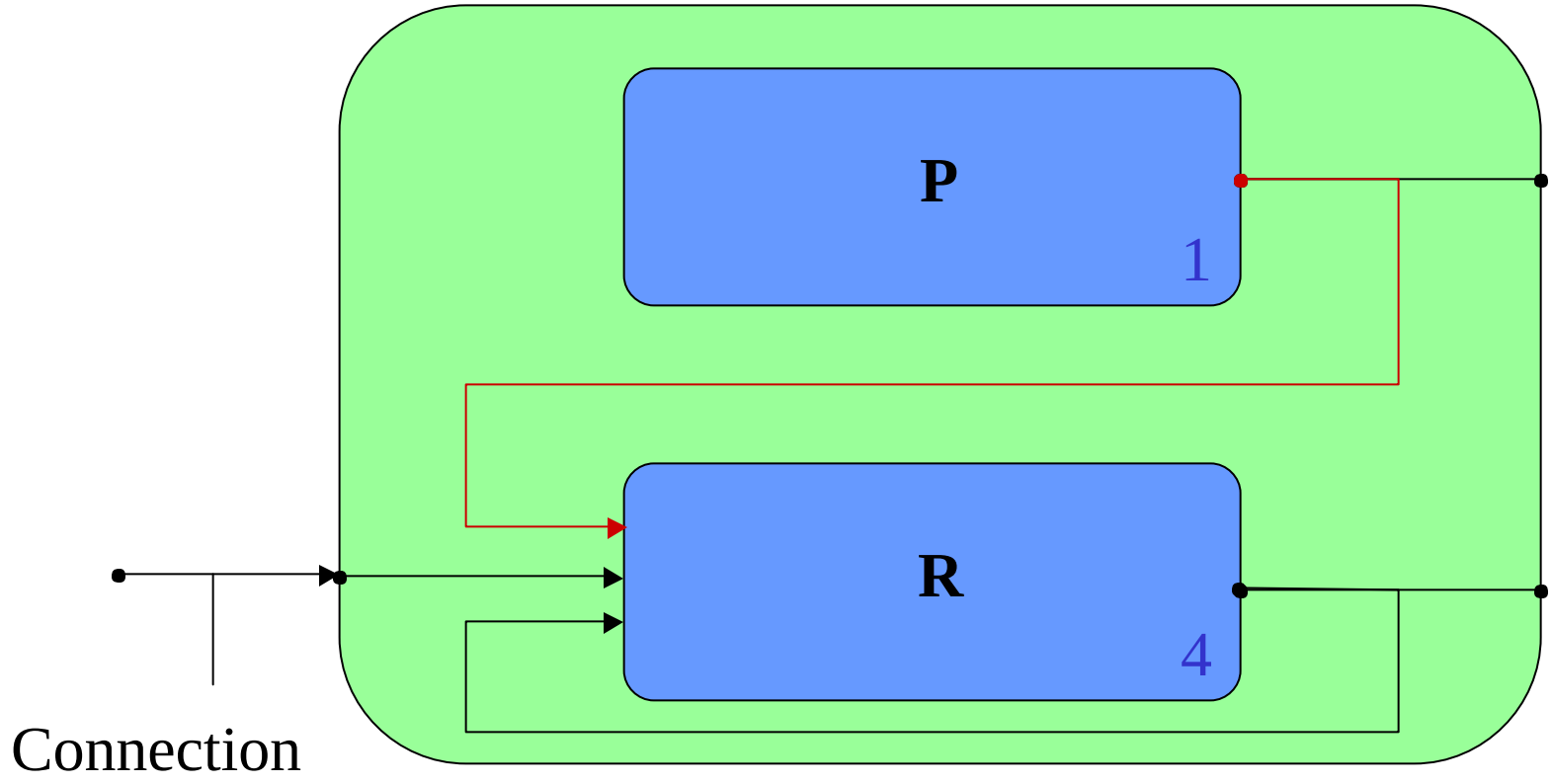

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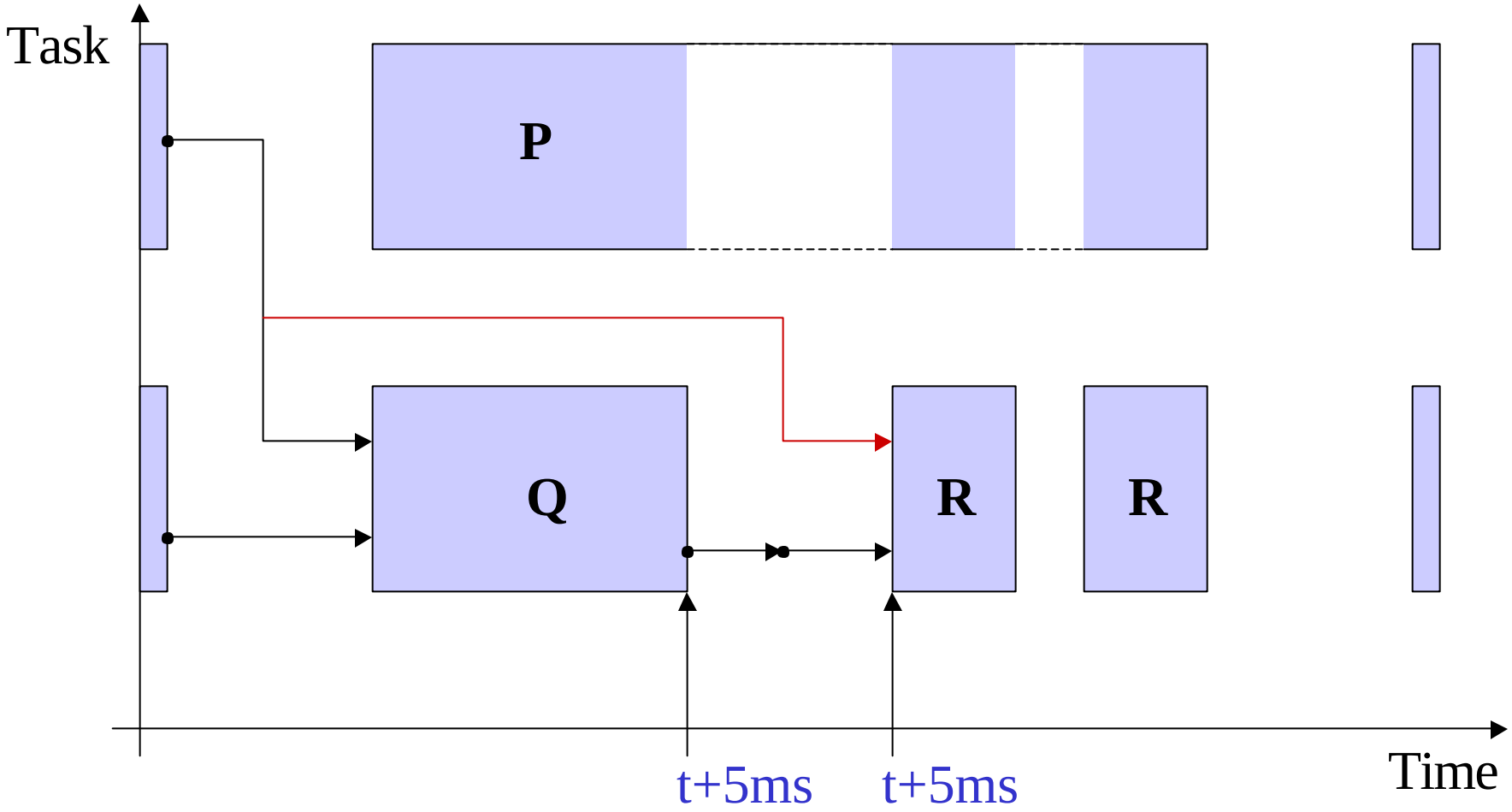

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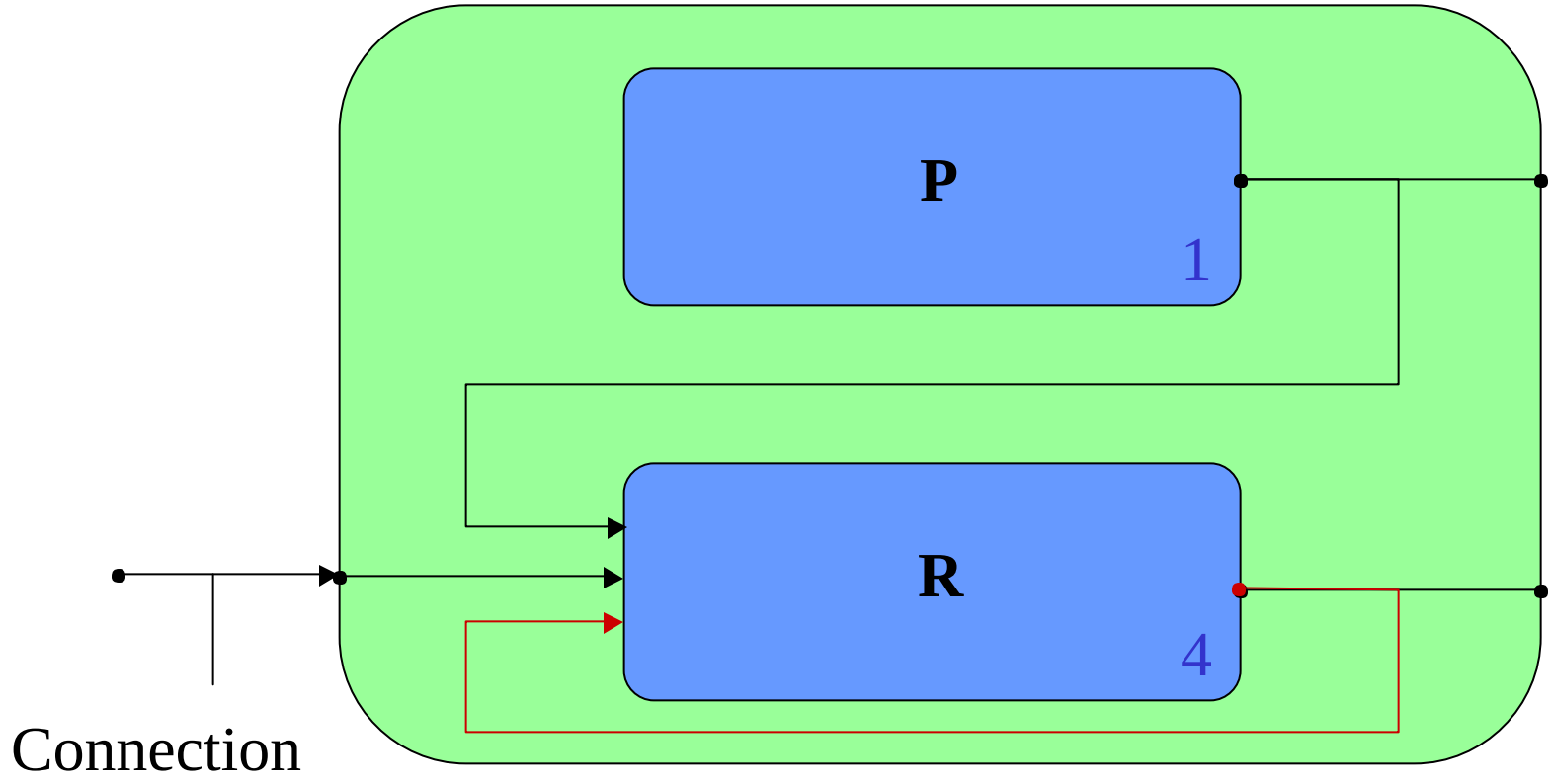
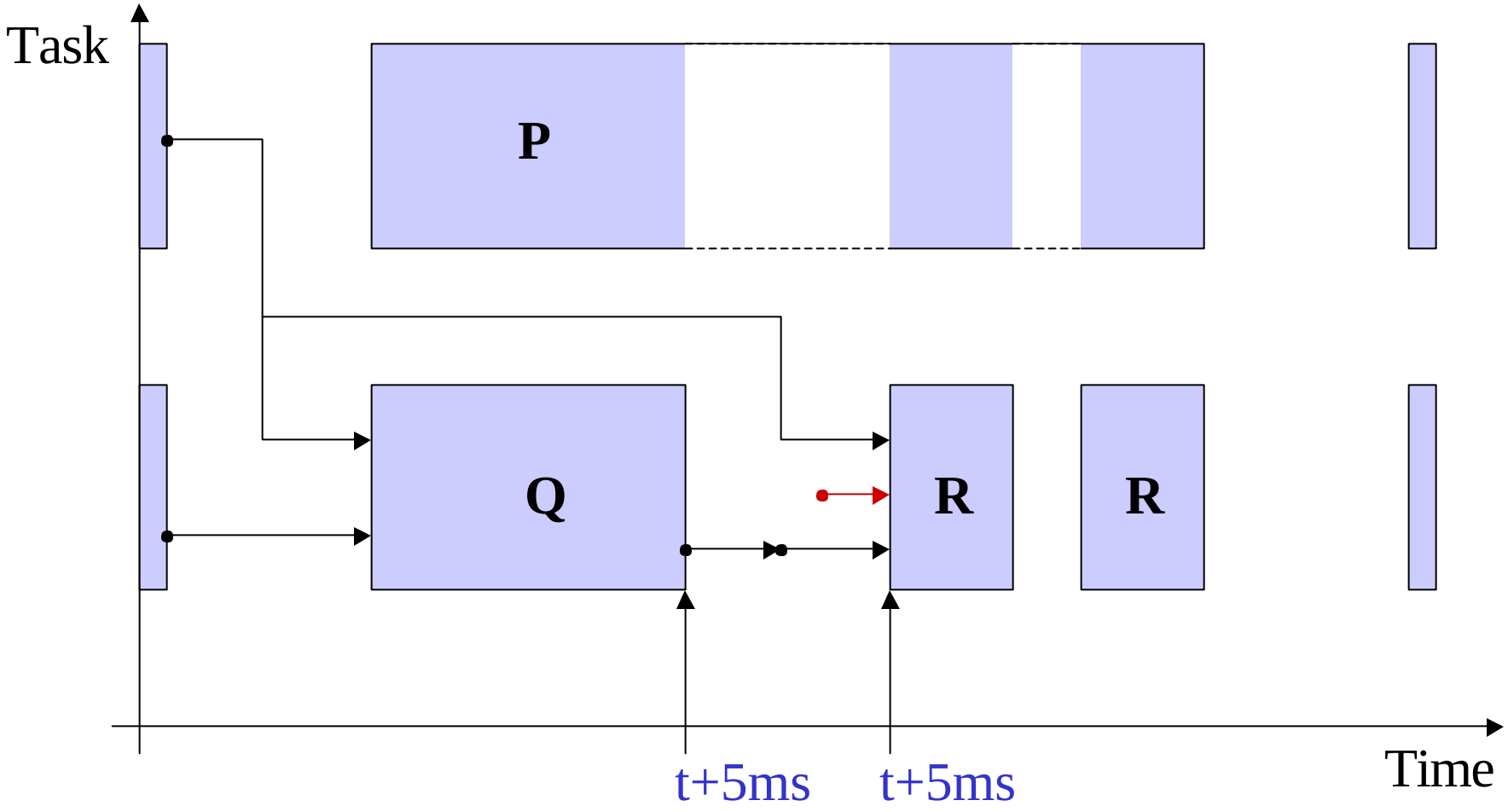
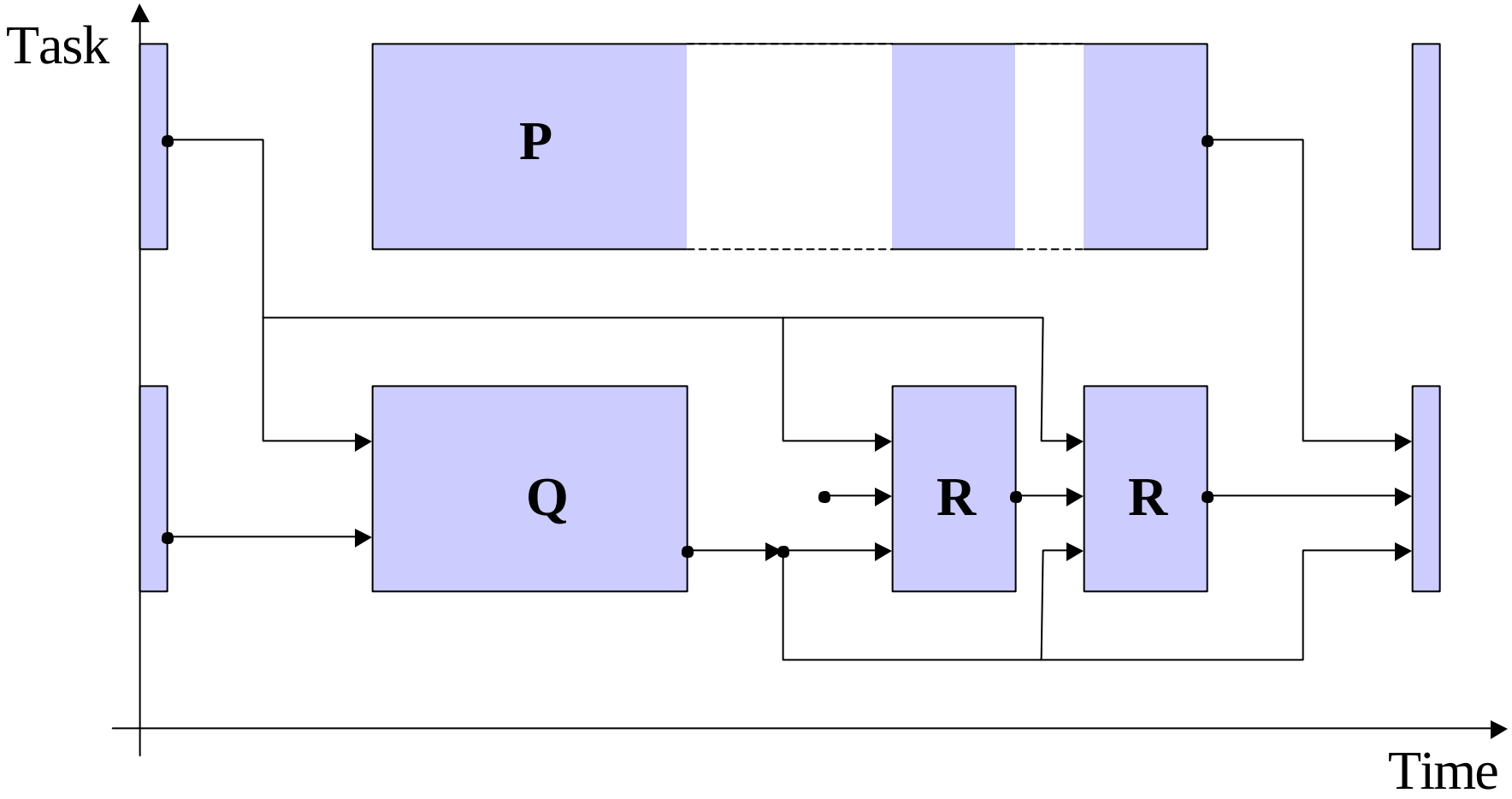


Semantics of a Mode Switch



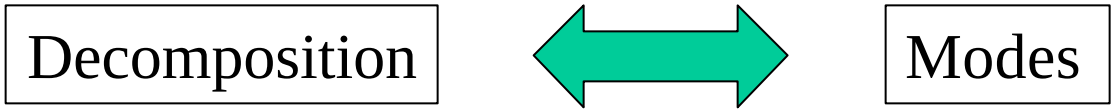
Semantics of a Mode Switch



Decomposition: Giotto Modes

Preserving Structure

Our Approach

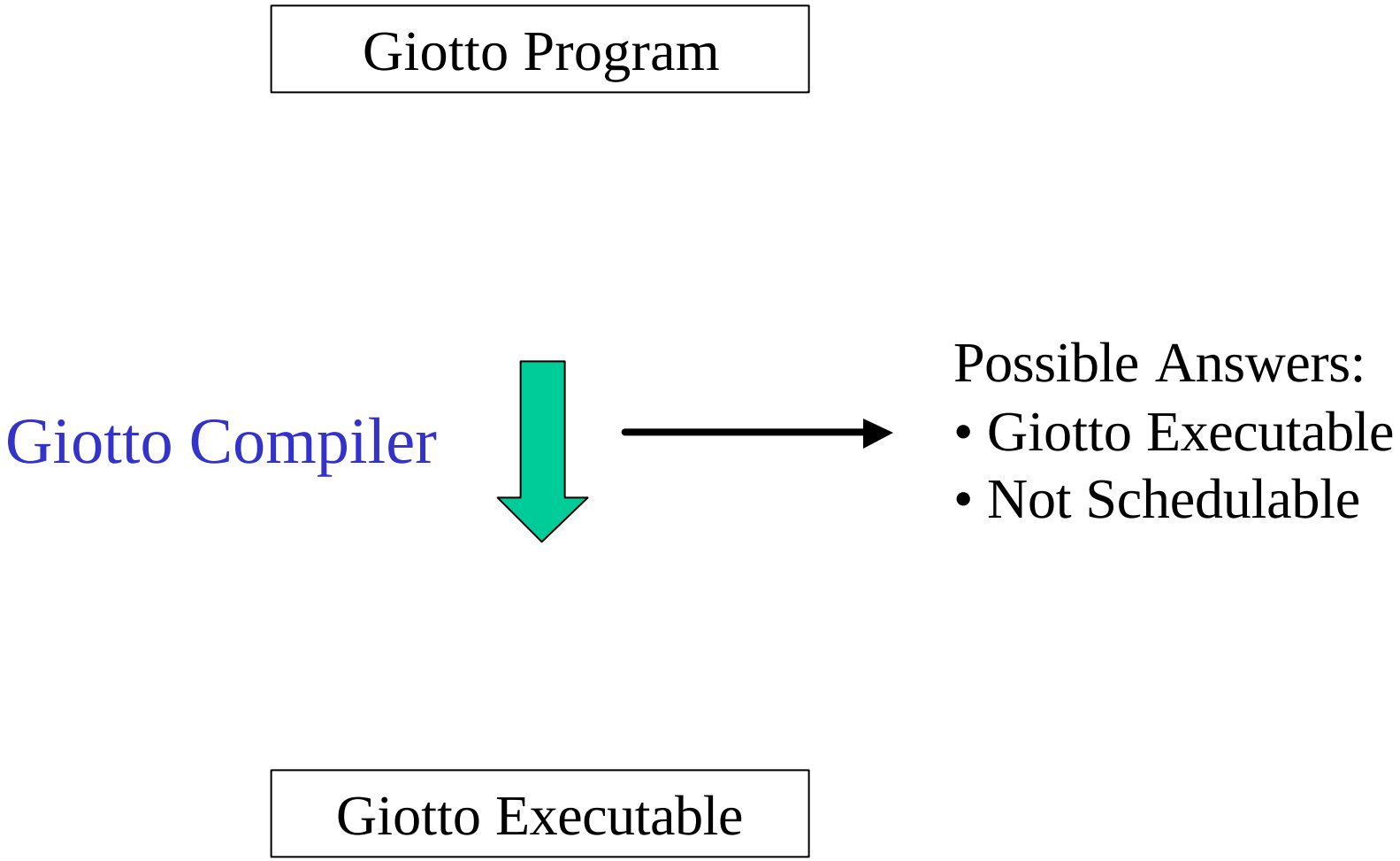


Compilation

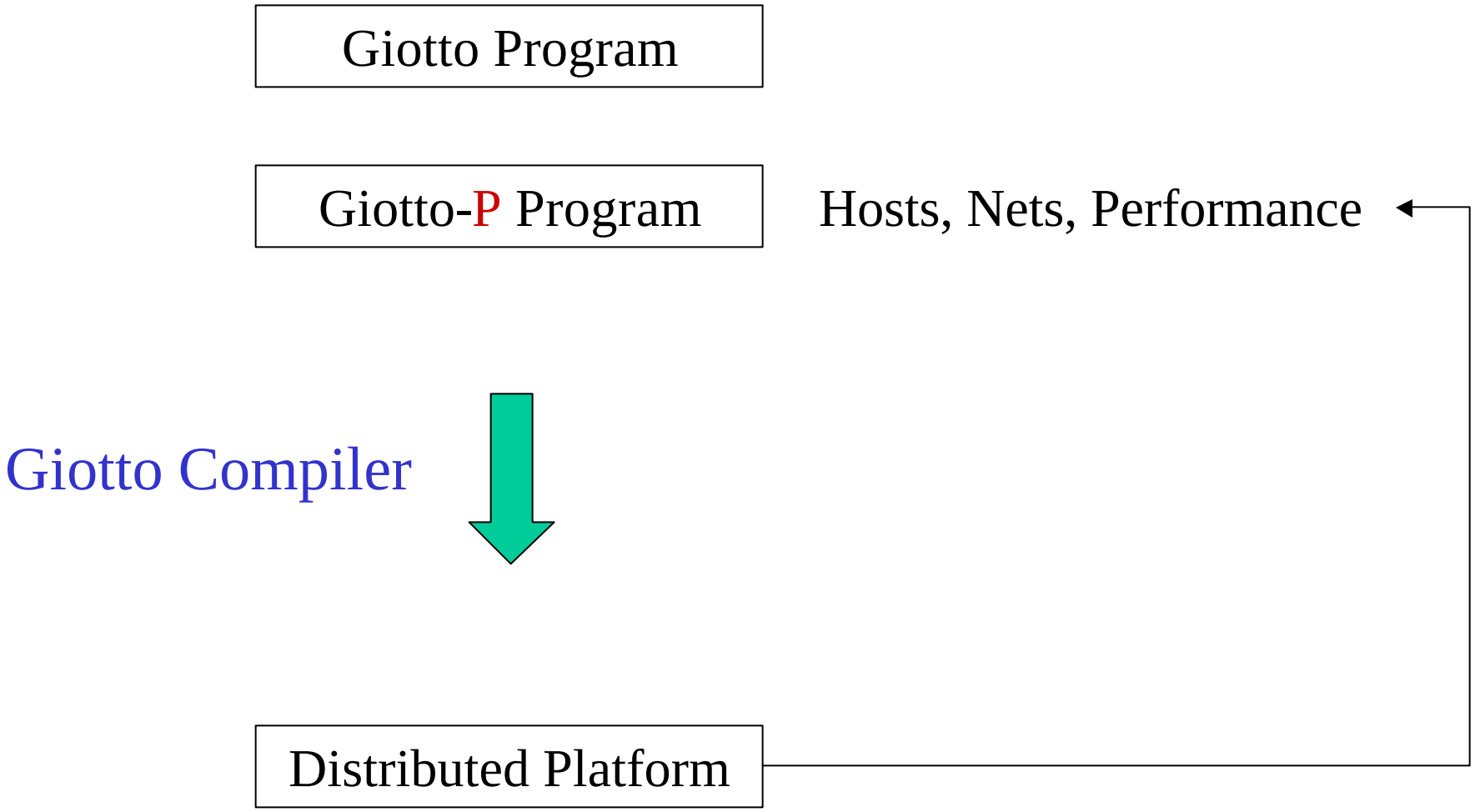
The Giotto Compiler:

- Automatic code generation
- Stepwise program refinement with annotated Giotto for distributed platforms

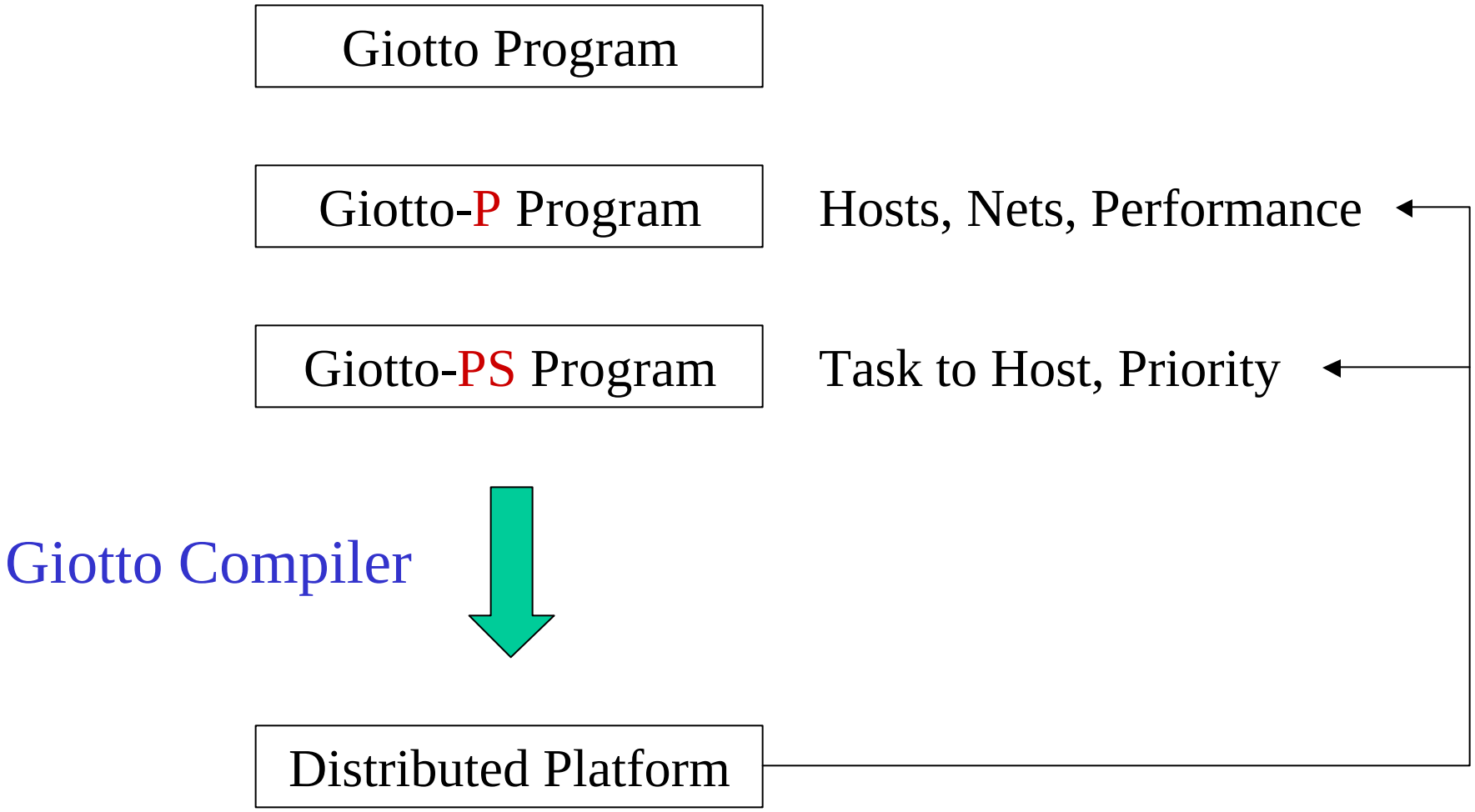
The Giotto Compiler



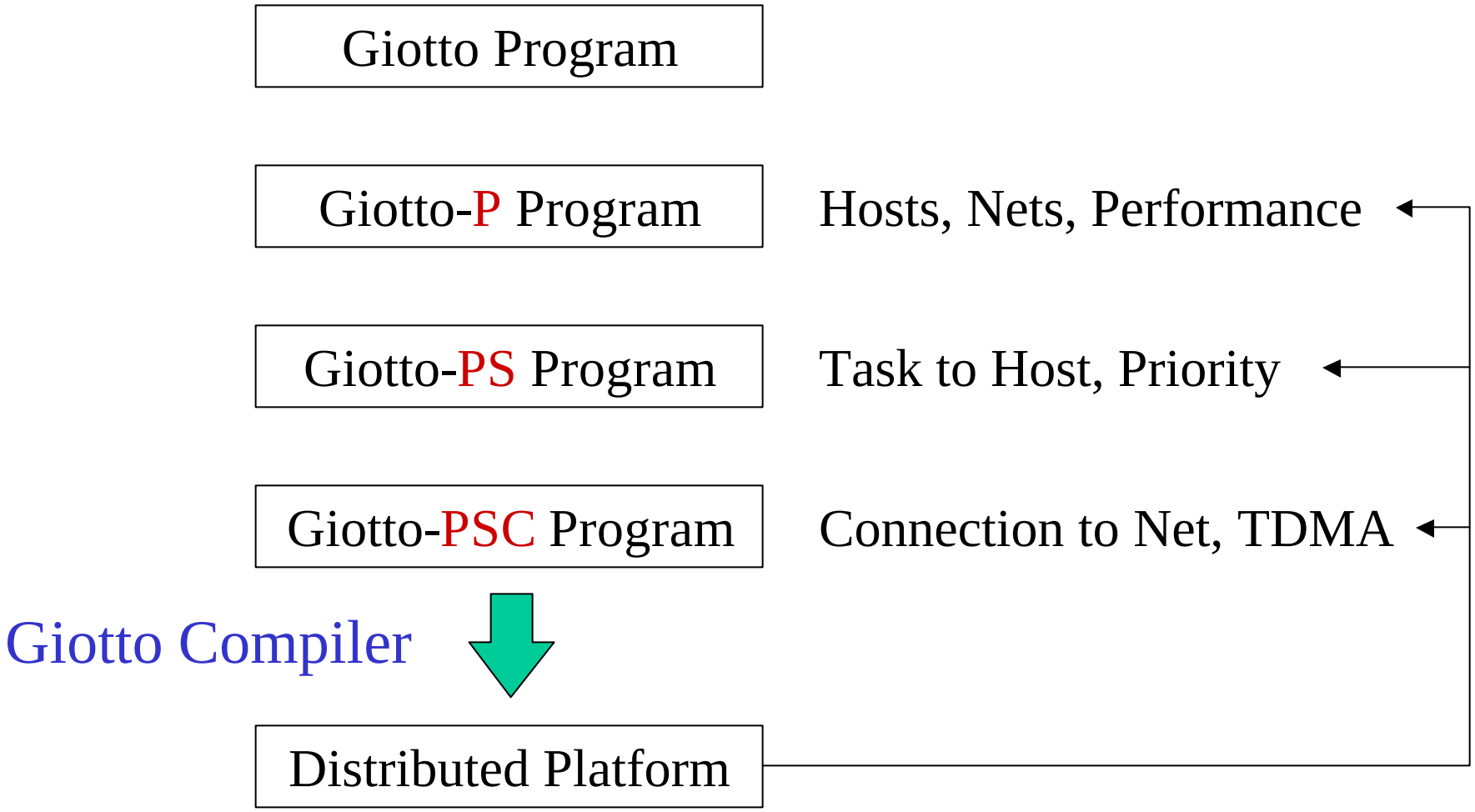
Giotto-Platform



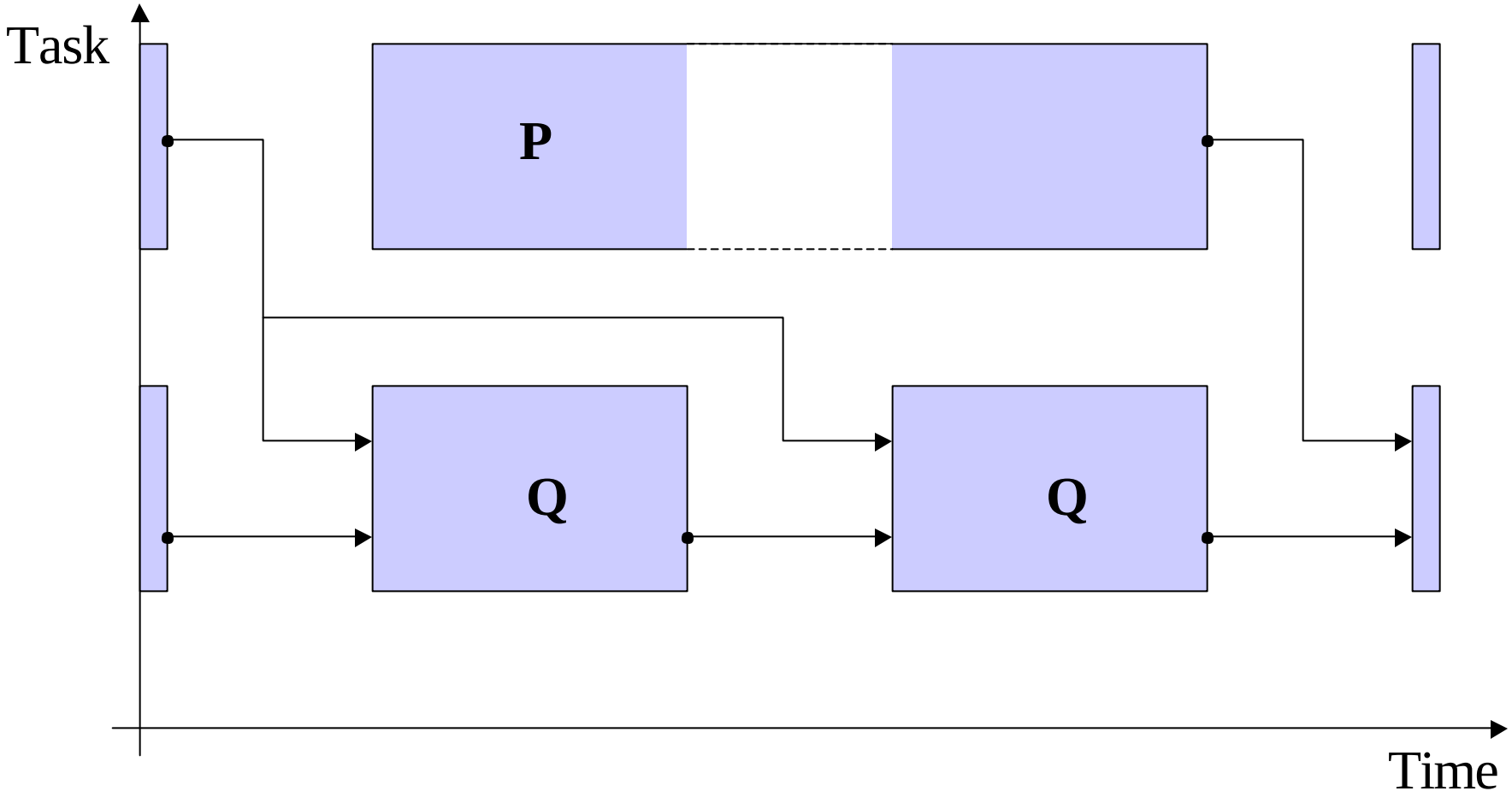
Giotto-Scheduler



Giotto-Communication



Platform Dependency



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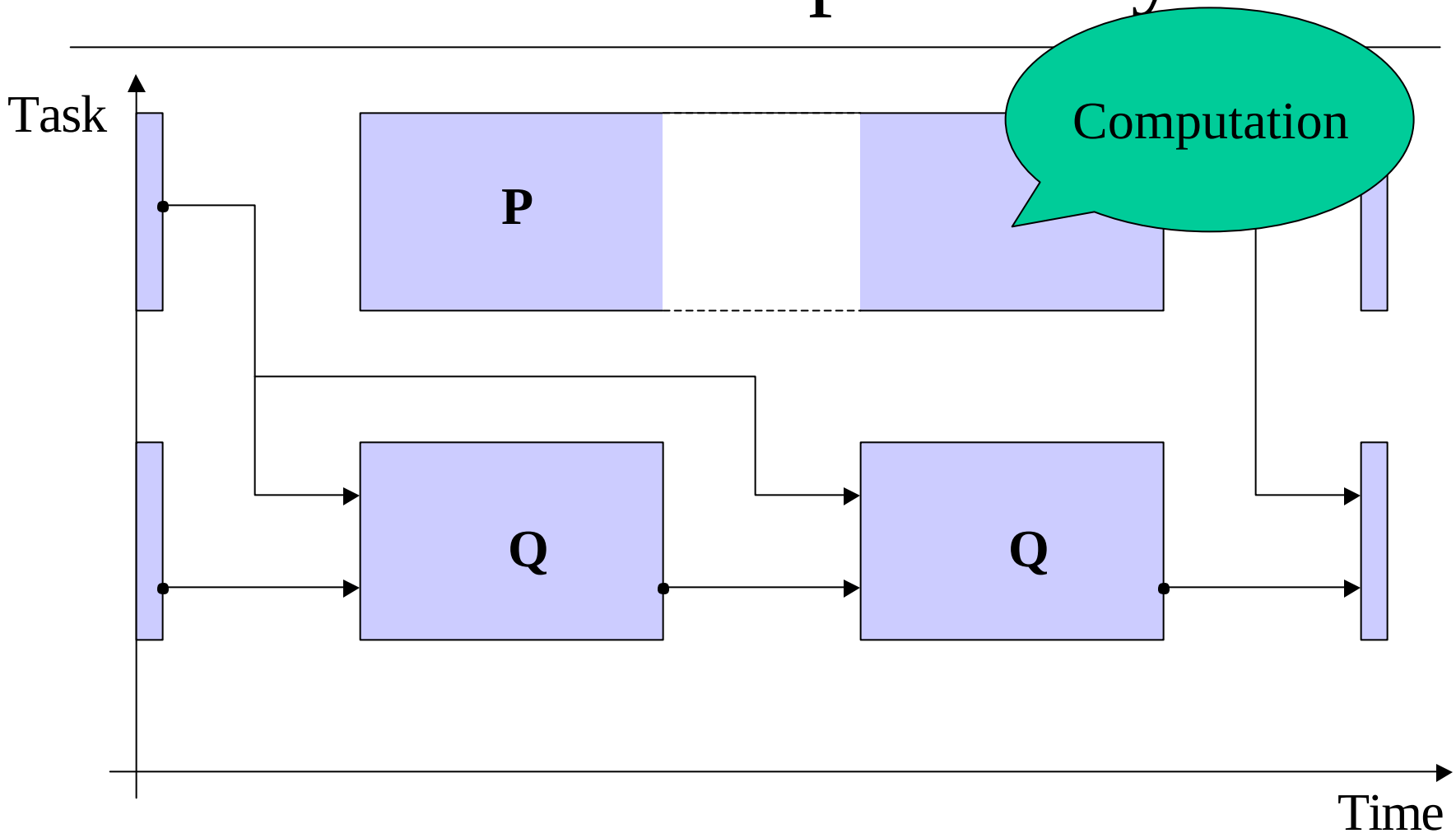
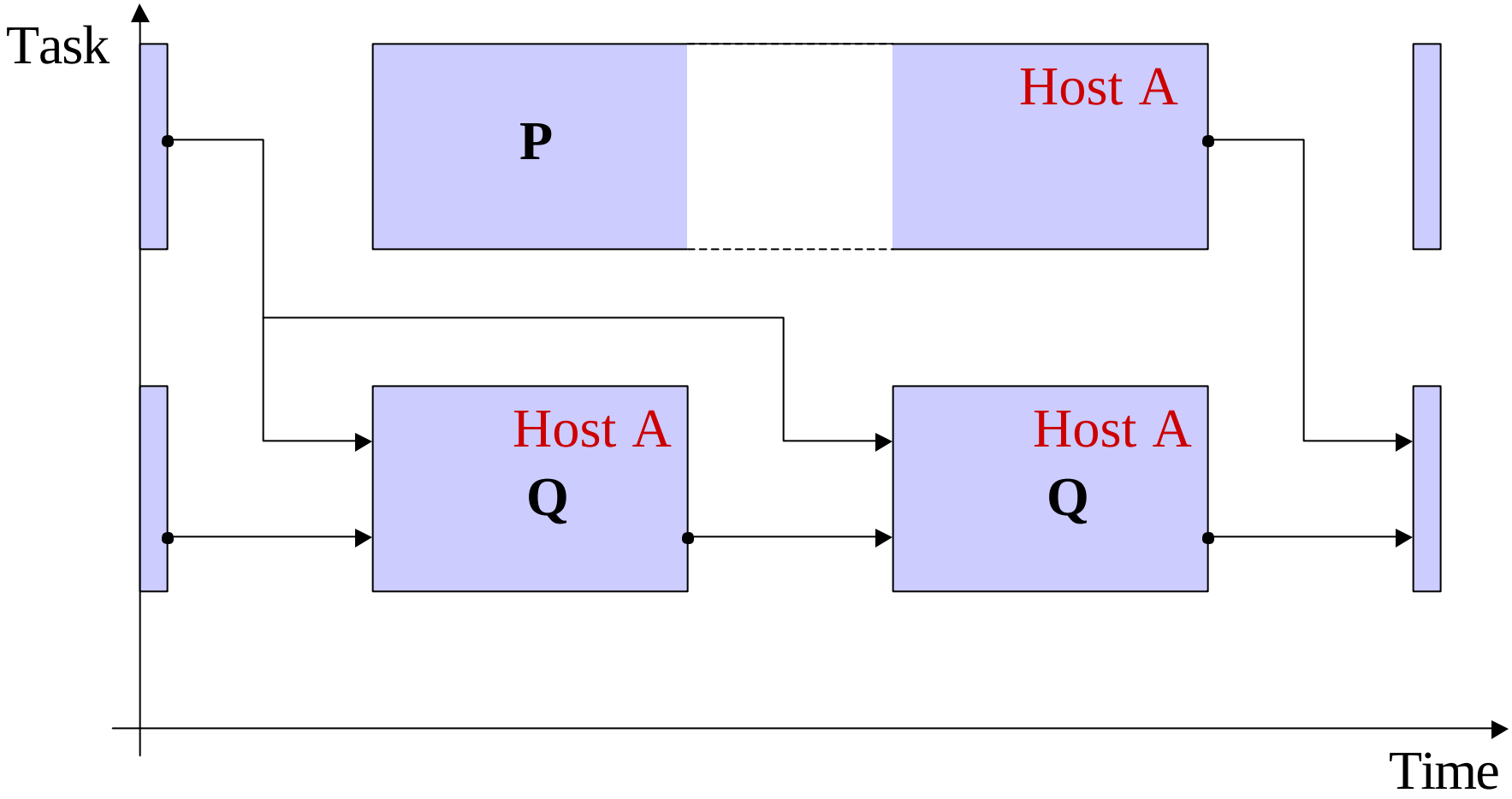
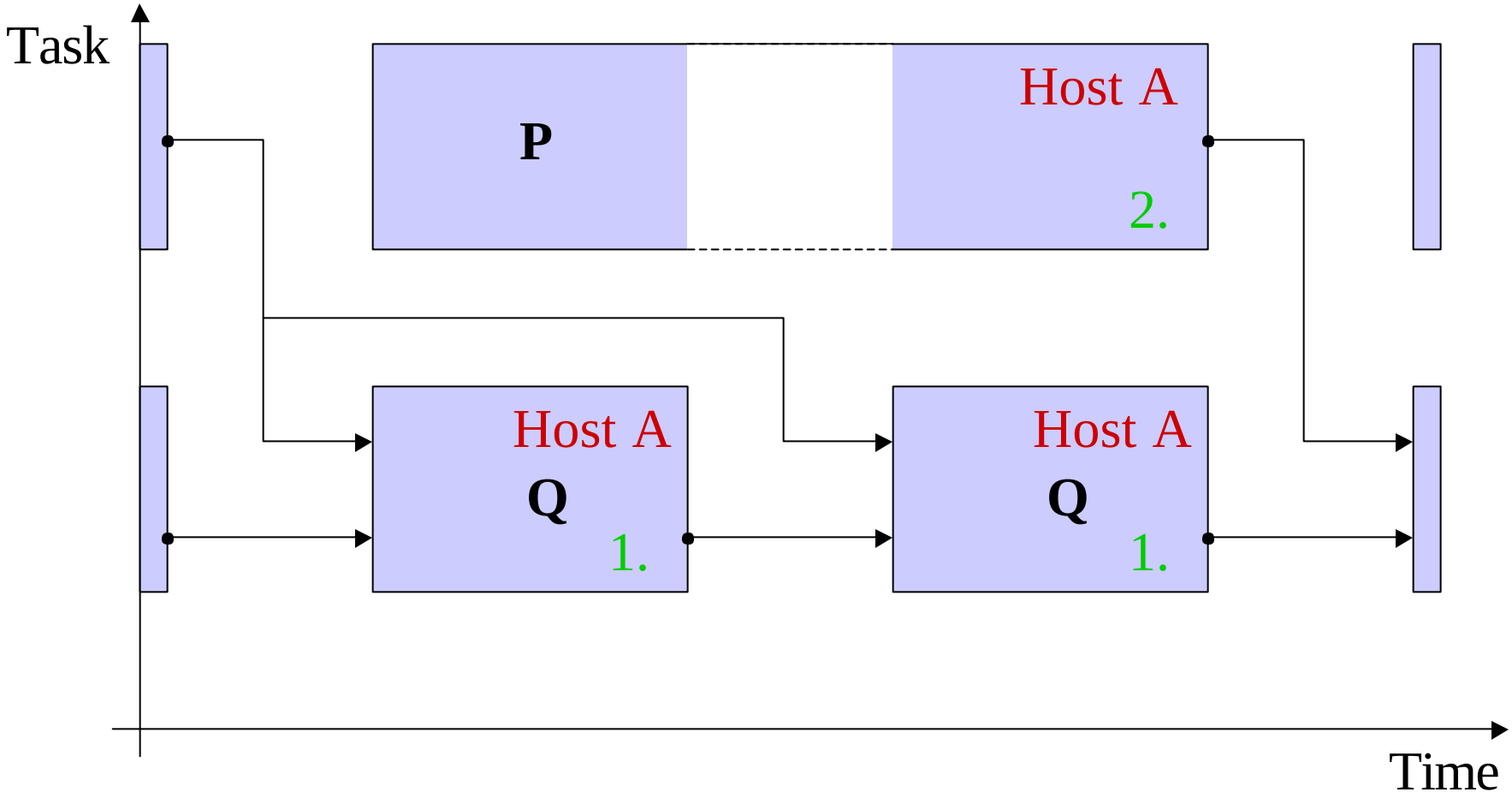


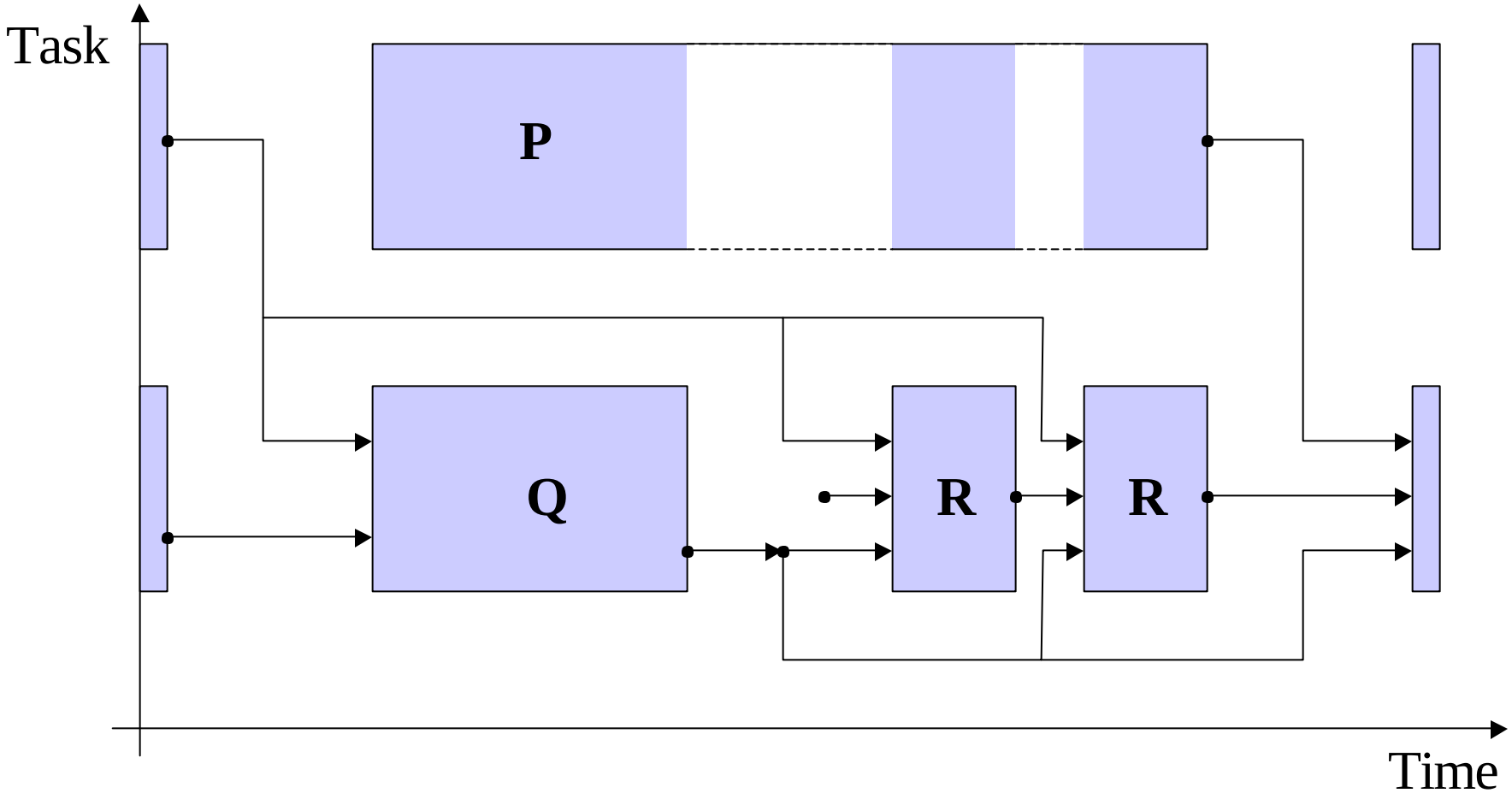
Giotto-PS



Giotto-PS



Platform Dependency



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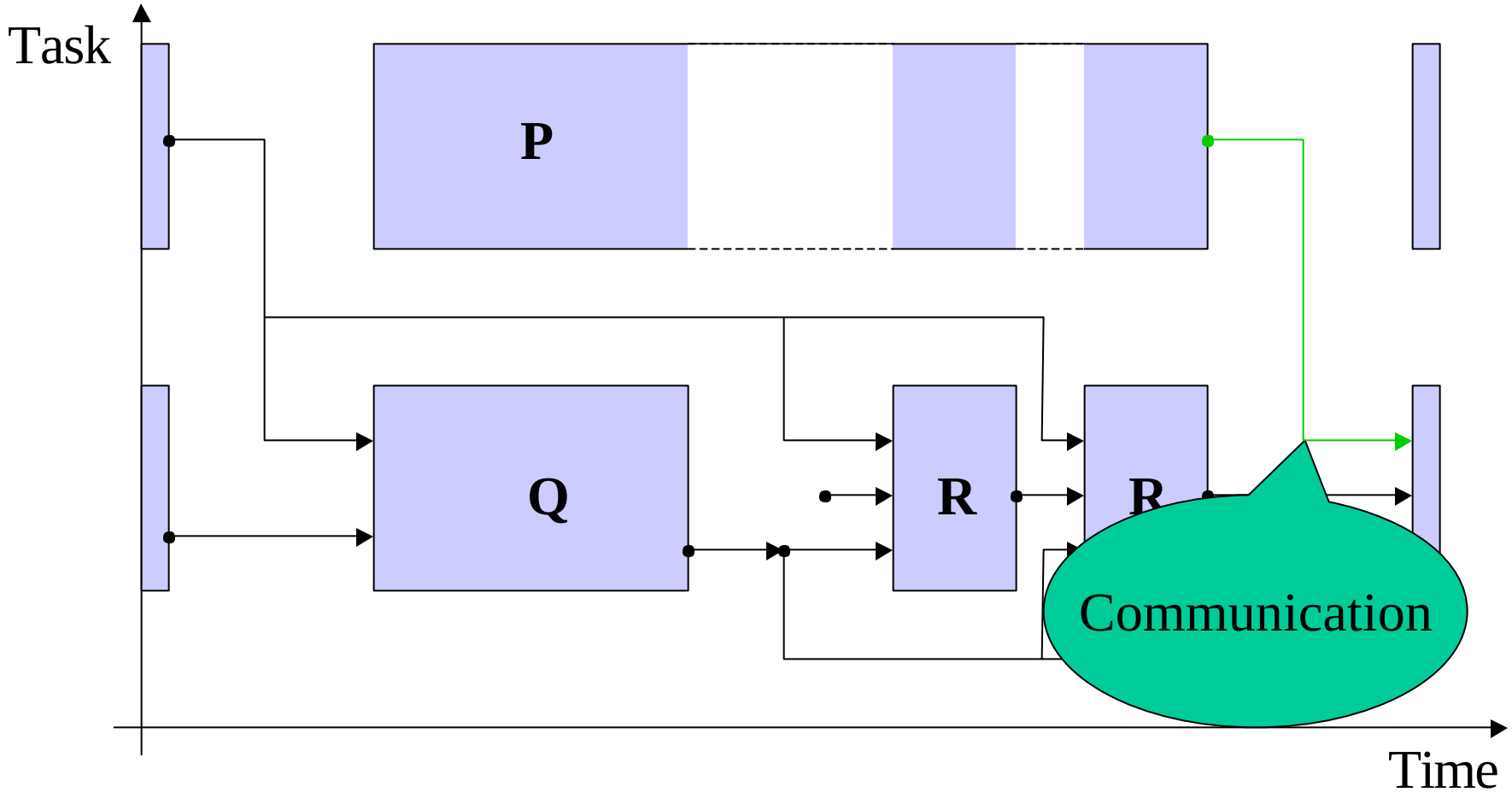
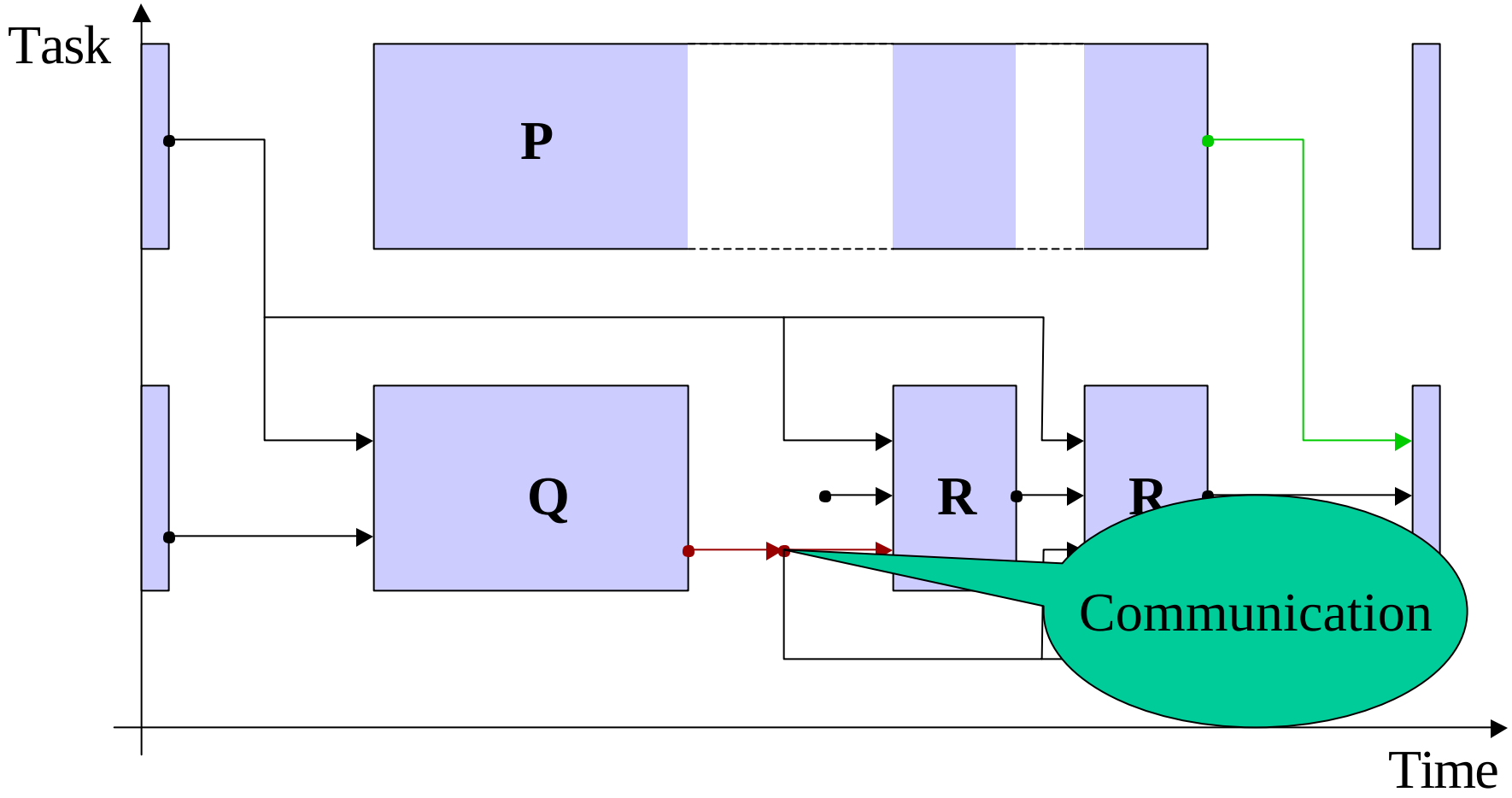
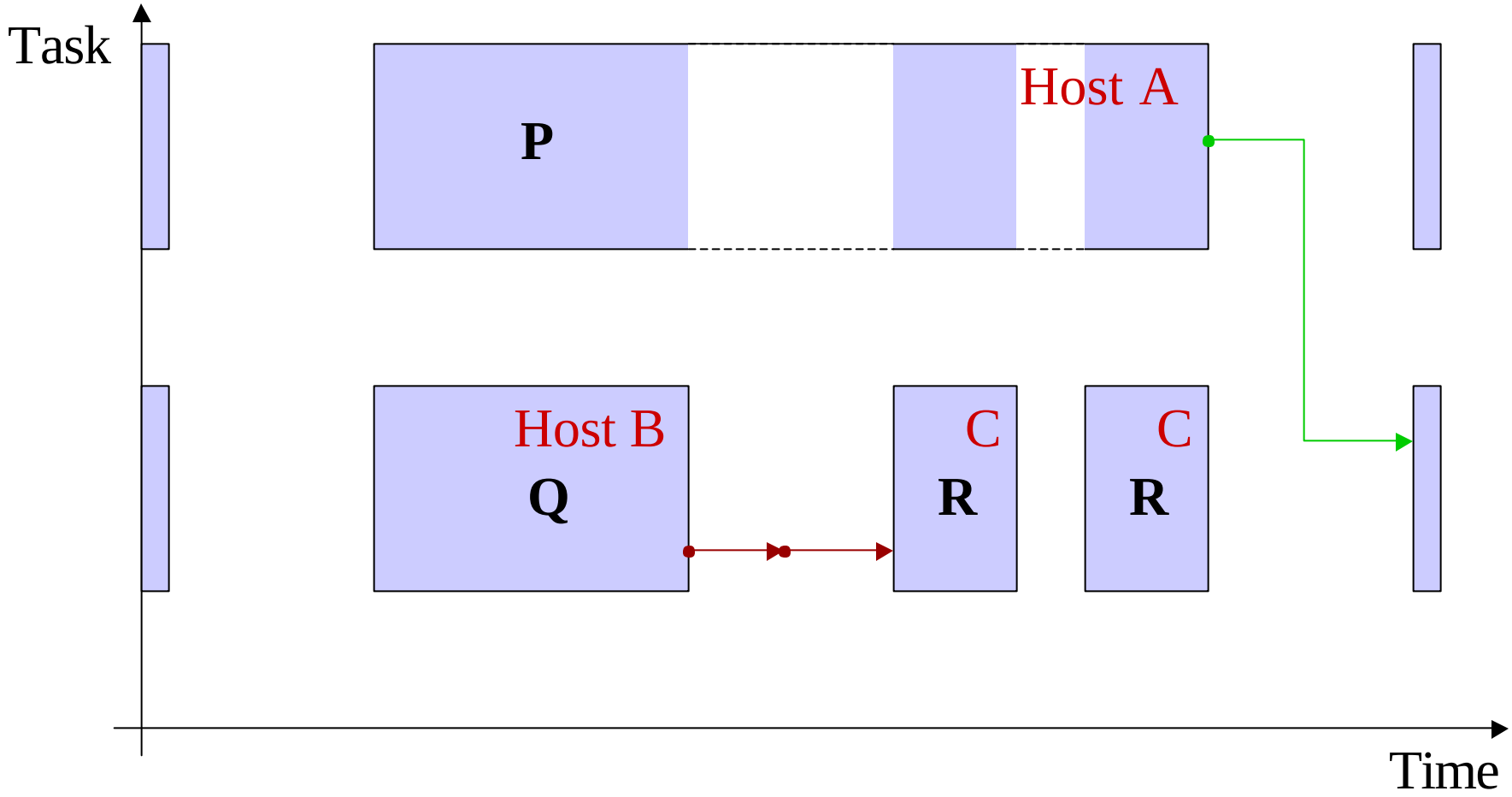


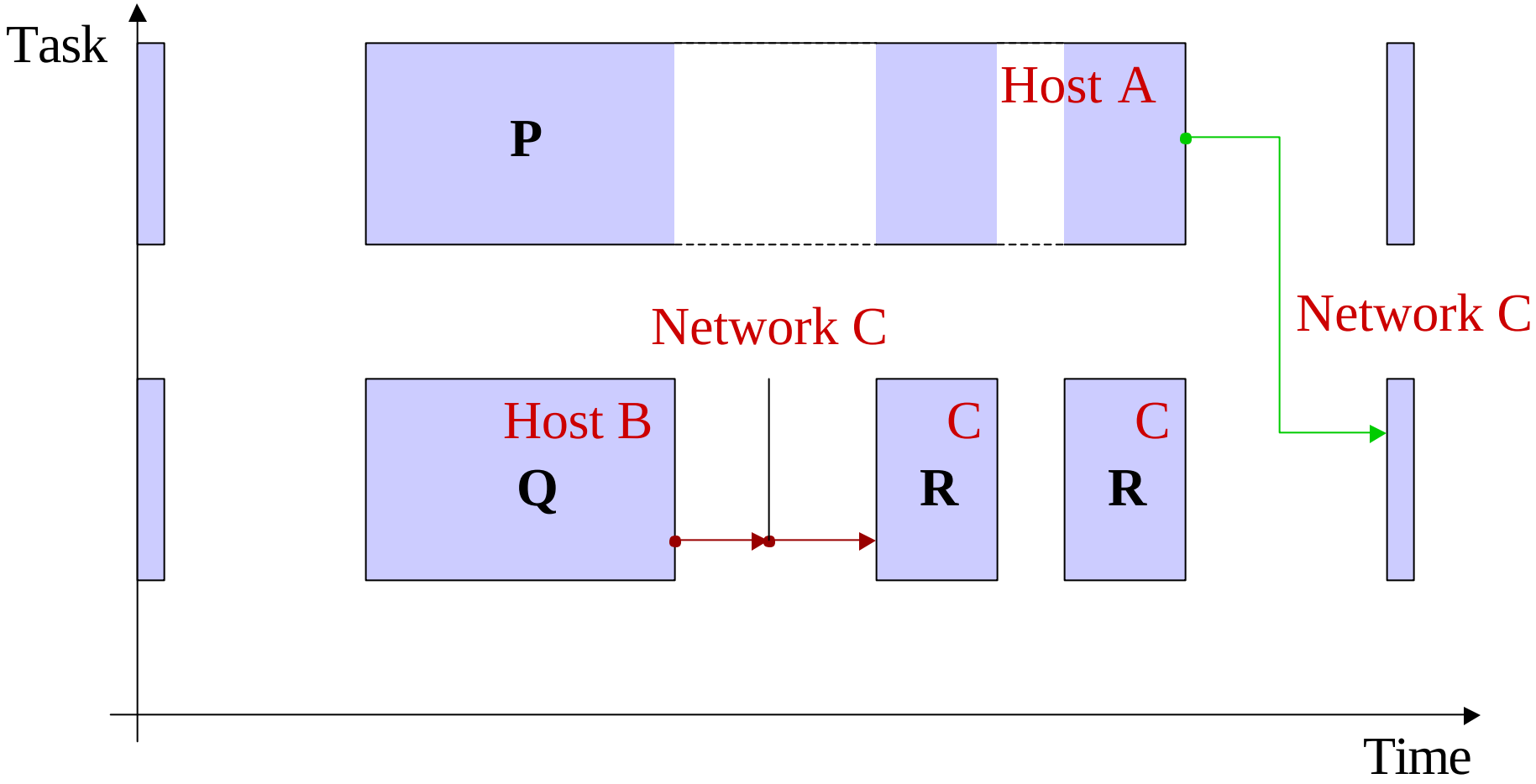
Platform Dependency



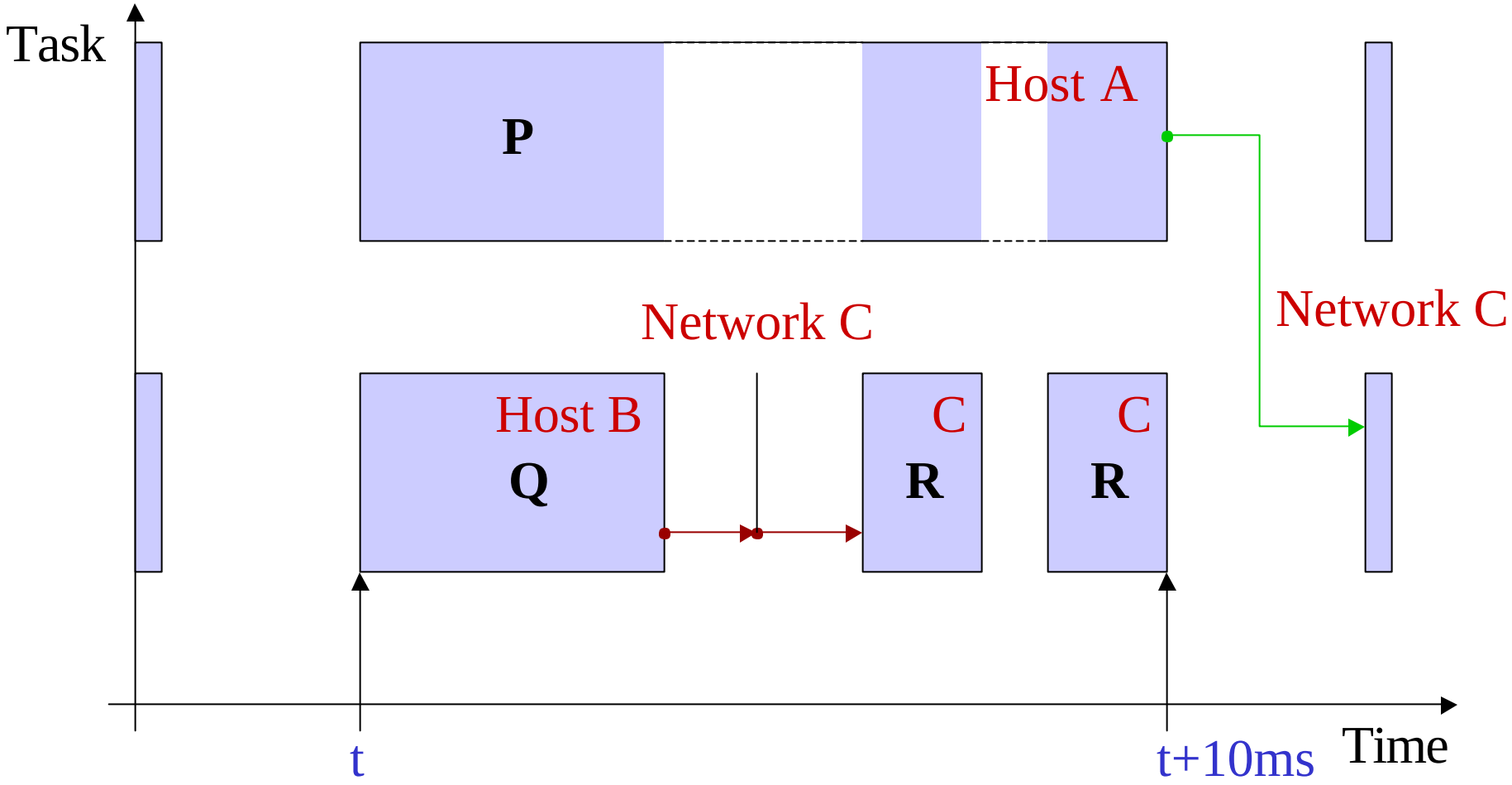
Giotto-PSC



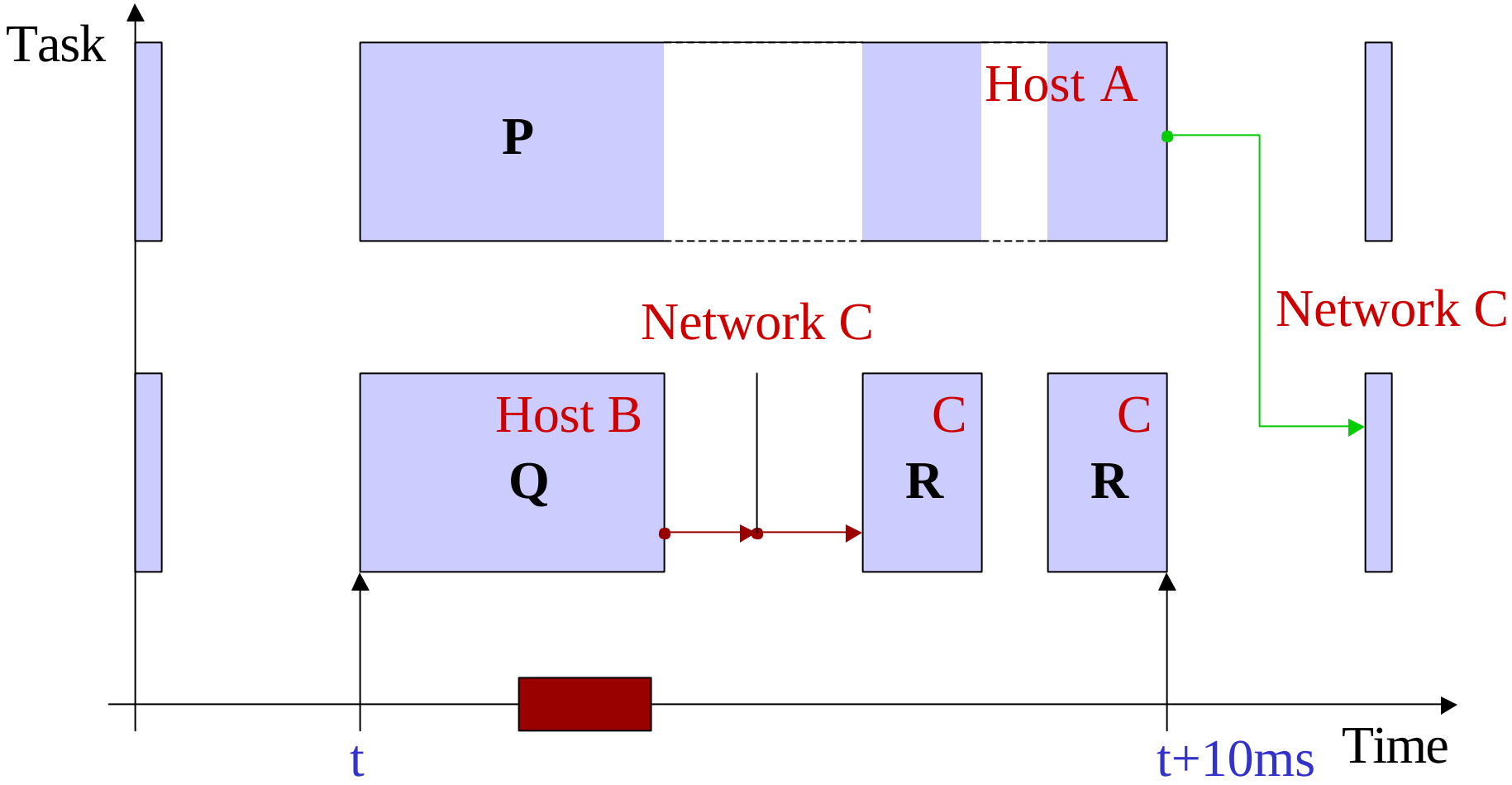
Giotto-PSC



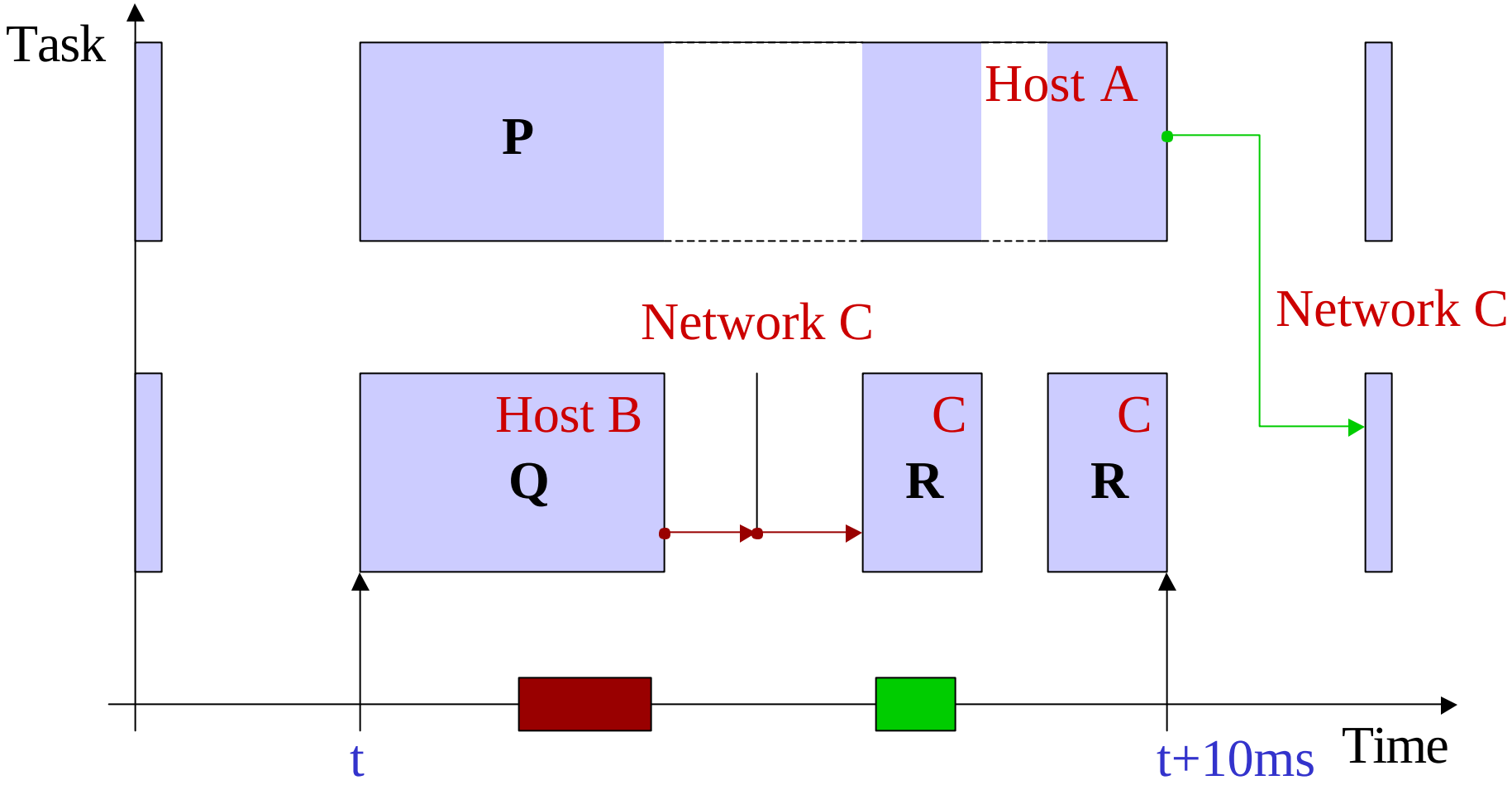
Giotto-PSC



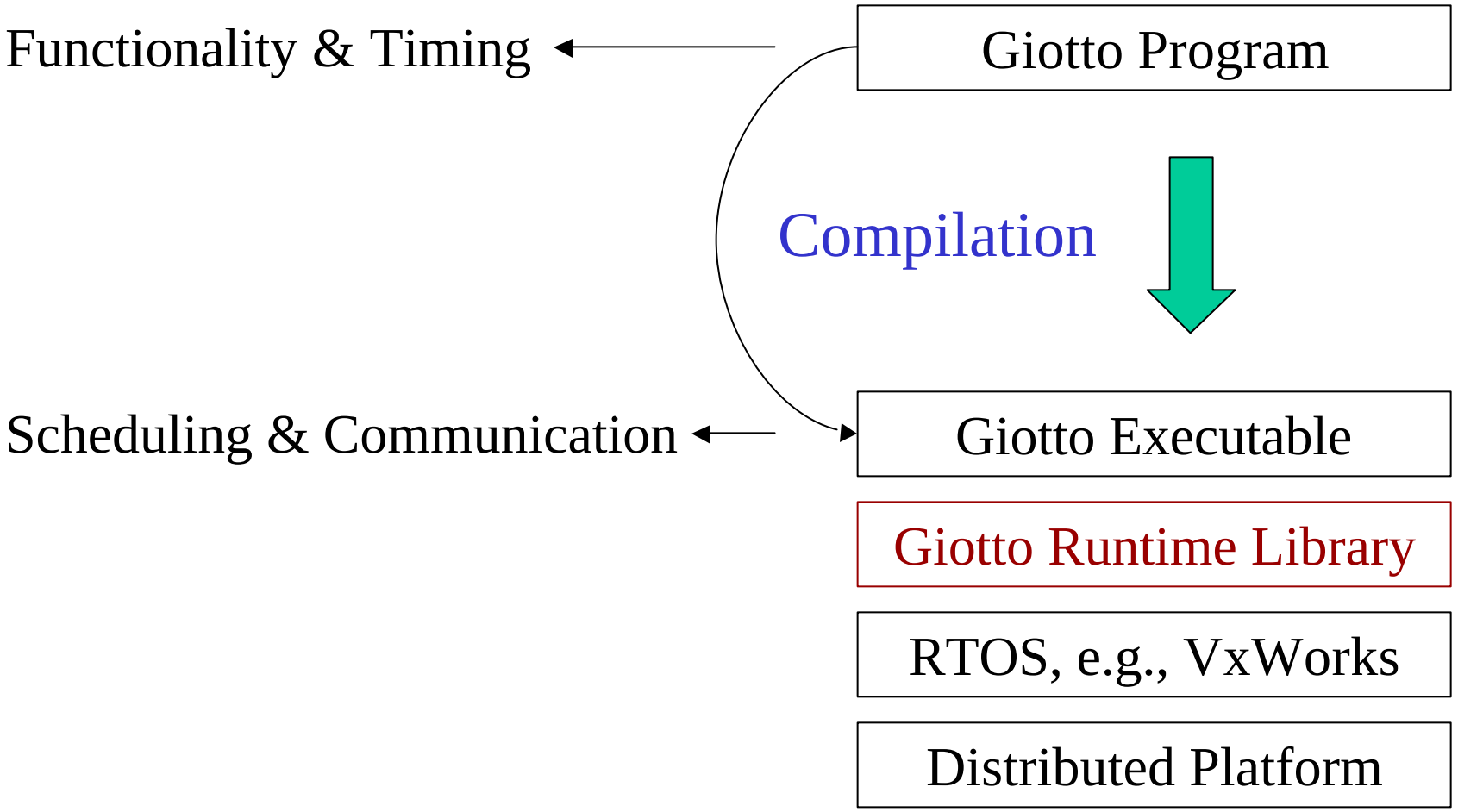
Giotto-PSC



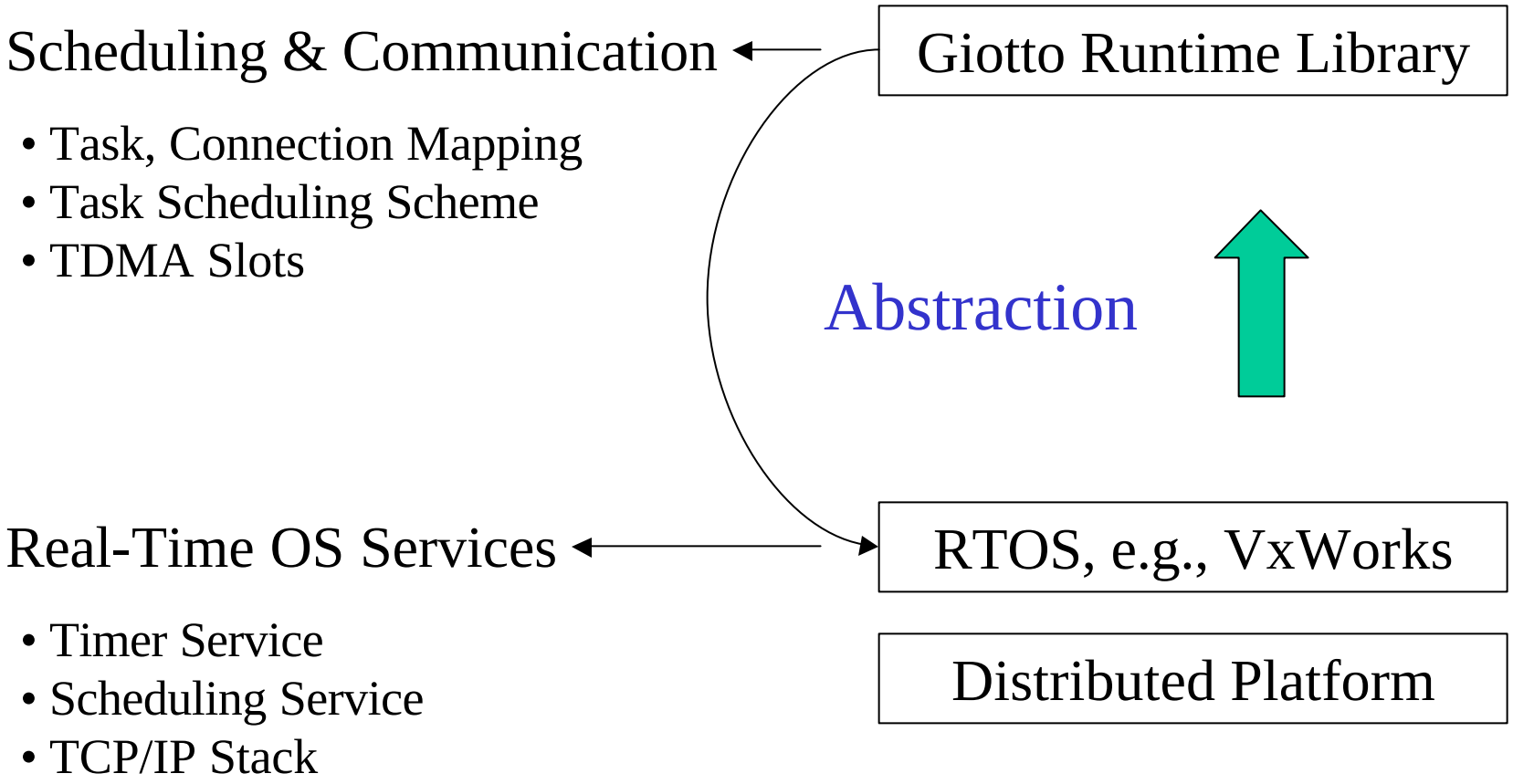
Giotto-PSC



The Giotto Runtime Library



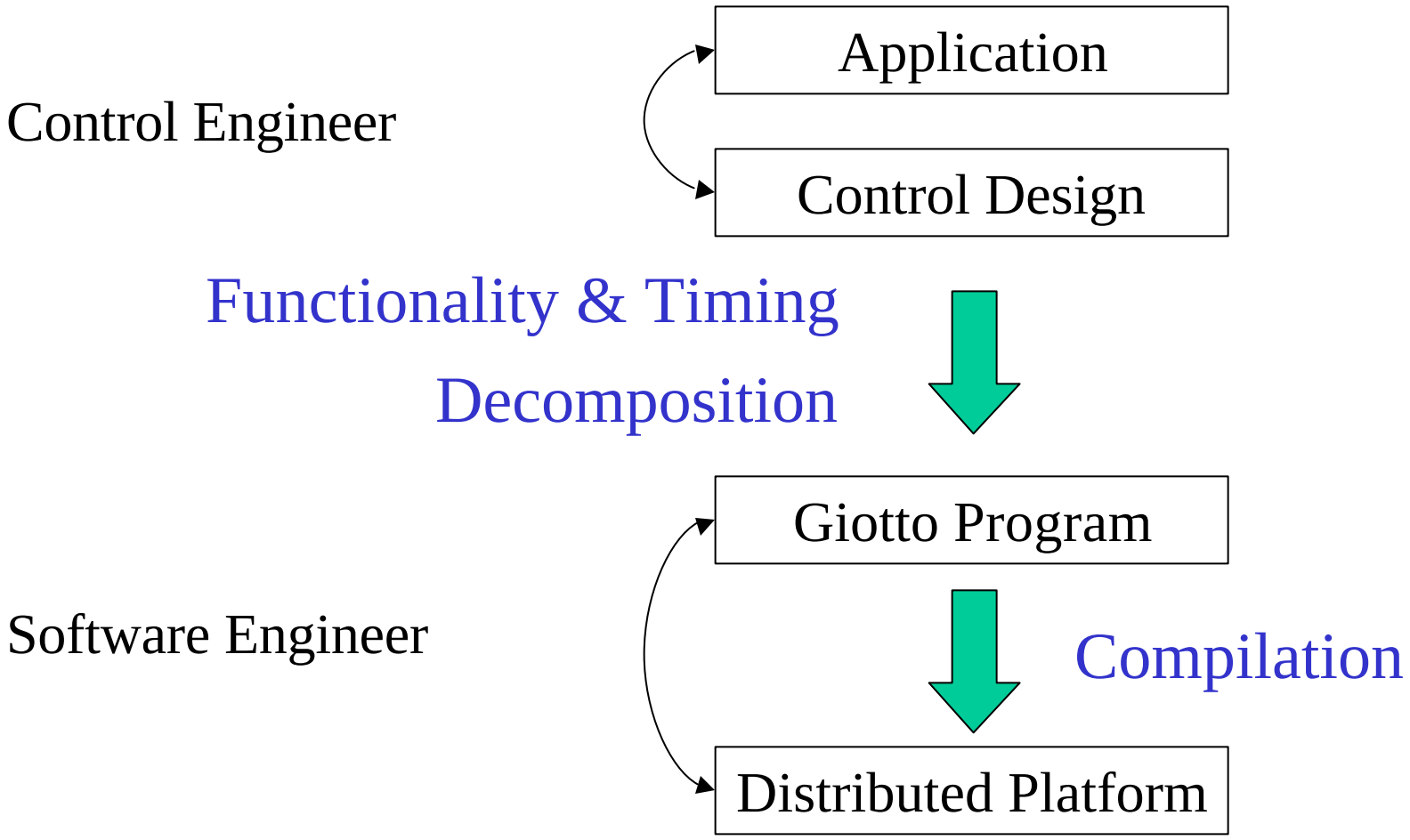
The Giotto Runtime Library



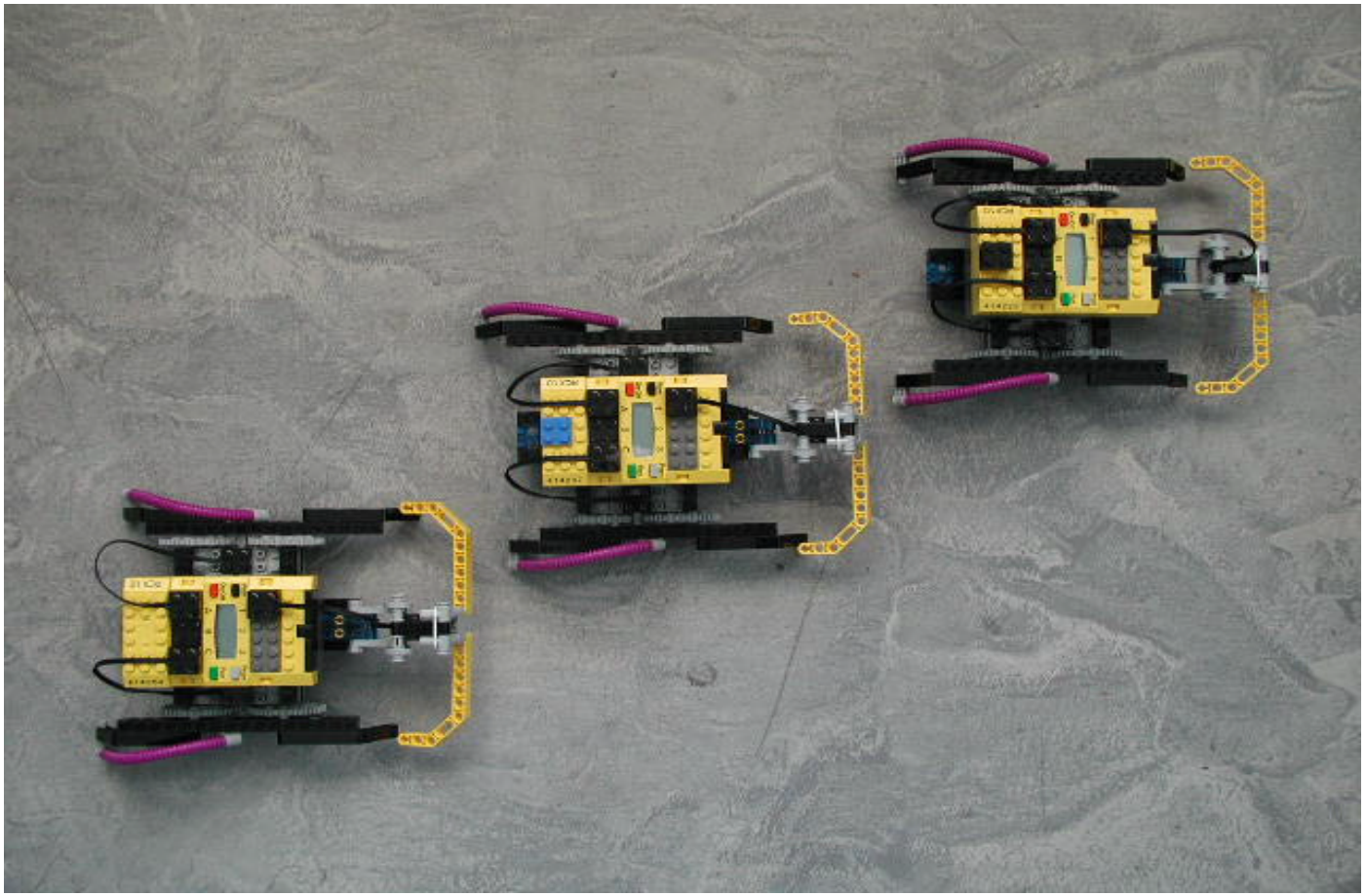
The Giotto Runtime Library

- Available on VxWorks and x86 targets
- Current Experimental Robots:
  - credit card size x86 single board computer running VxWorks
  - wireless Ethernet
  - Lego motors, sensors
- Next Experimental Platform:
  - unmanned Yamaha helicopters
  - PC 104 single board computer running VxWorks
  - wireless Ethernet, GPS, inertial navigation sensor, …

Summary


Control Engineer
Application
Control Design
Functionality & Timing
Decomposition
Software Engineer
Giotto Program
Compilation
Distributed Platform

Demo



Demo

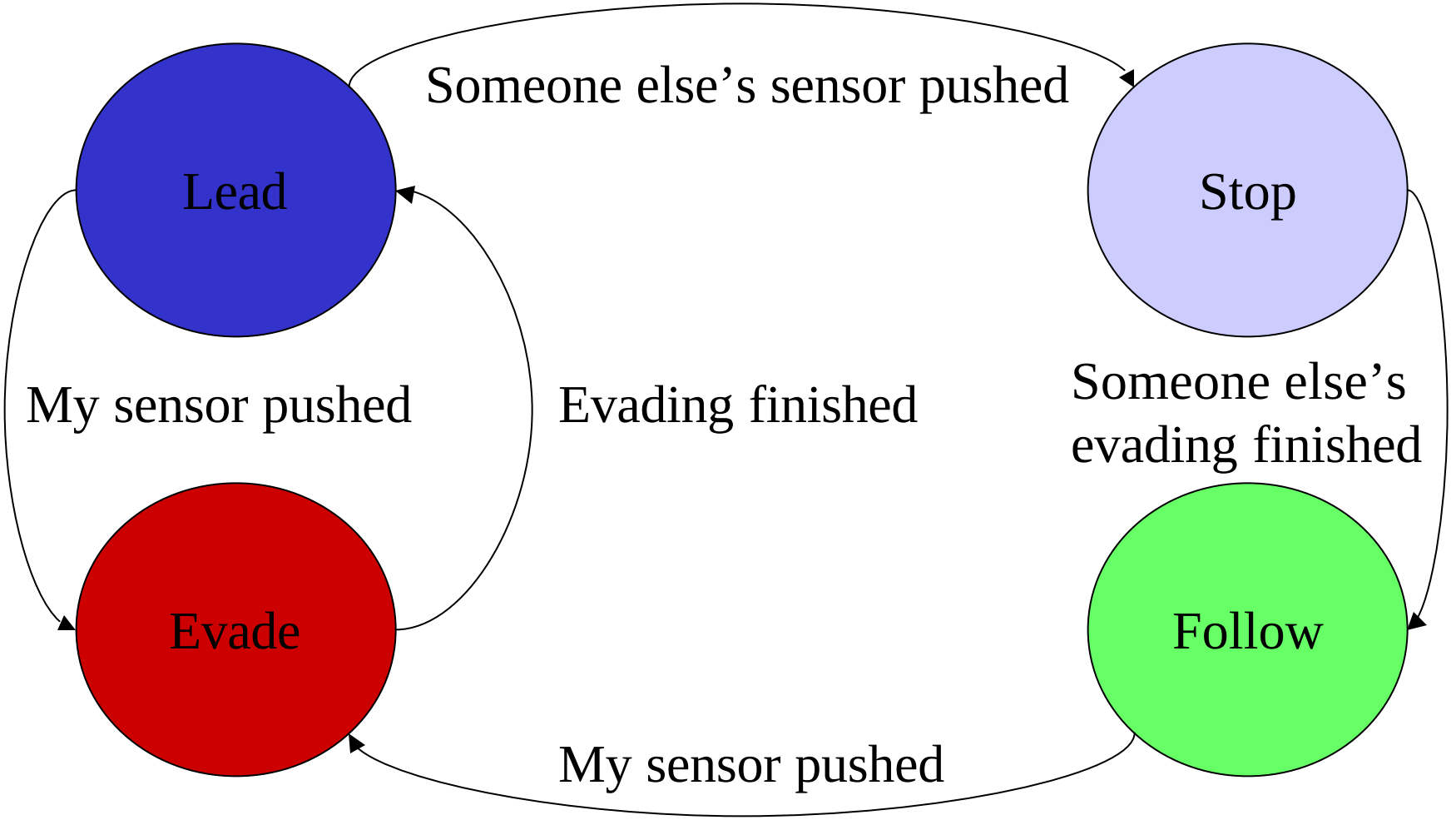
- Giotto on Lego Mindstorms:

  Concurrent distributed execution
- Giotto on Lego Mindstorms and x86 bots running VxWorks:

  Heterogeneous platforms
- Giotto in Ptolemy:

  Design and simulation of Giotto programs

Behavior of a Bot



Demo

- Giotto on Lego Mindstorms:
  Concurrent distributed execution

Heterogeneous Platforms

1. Lego Mindstorms: Lego Firmware, Hitachi Microcontroller, Infrared Link
2. x86 bots: VxWorks, x86 single board computer, Wireless Ethernet

3. Infrared – Wireless Ethernet Bridge: Laptop

Demo

- Giotto on Lego Mindstorms and x86 bots running VxWorks:

  Heterogeneous platforms

Dmitry Derevyanko

Benjamin Horowitz

Christoph Meyer Kirsch

Win Williams

Ptolemy Simulation

Ptolemy is a software package supporting design and simulation of concurrent, real-time, embedded systems:

Giotto defines a model of computation

1. Ptolemy simulates bot example
2. Lego Mindstorms display simulation

Demo

- Giotto in Ptolemy:
  Design and simulation of Giotto programs

Christoph Meyer Kirsch
Edward A. Lee
Xiaojun Liu

End