# Development of hard real-time systems with Giotto

O.Univ.-Prof. Dipl.-Ing. Dr. Wolfgang Pree
University of Salzburg
UC Berkeley (guest)

www.SoftwareResearch.net

# Contents

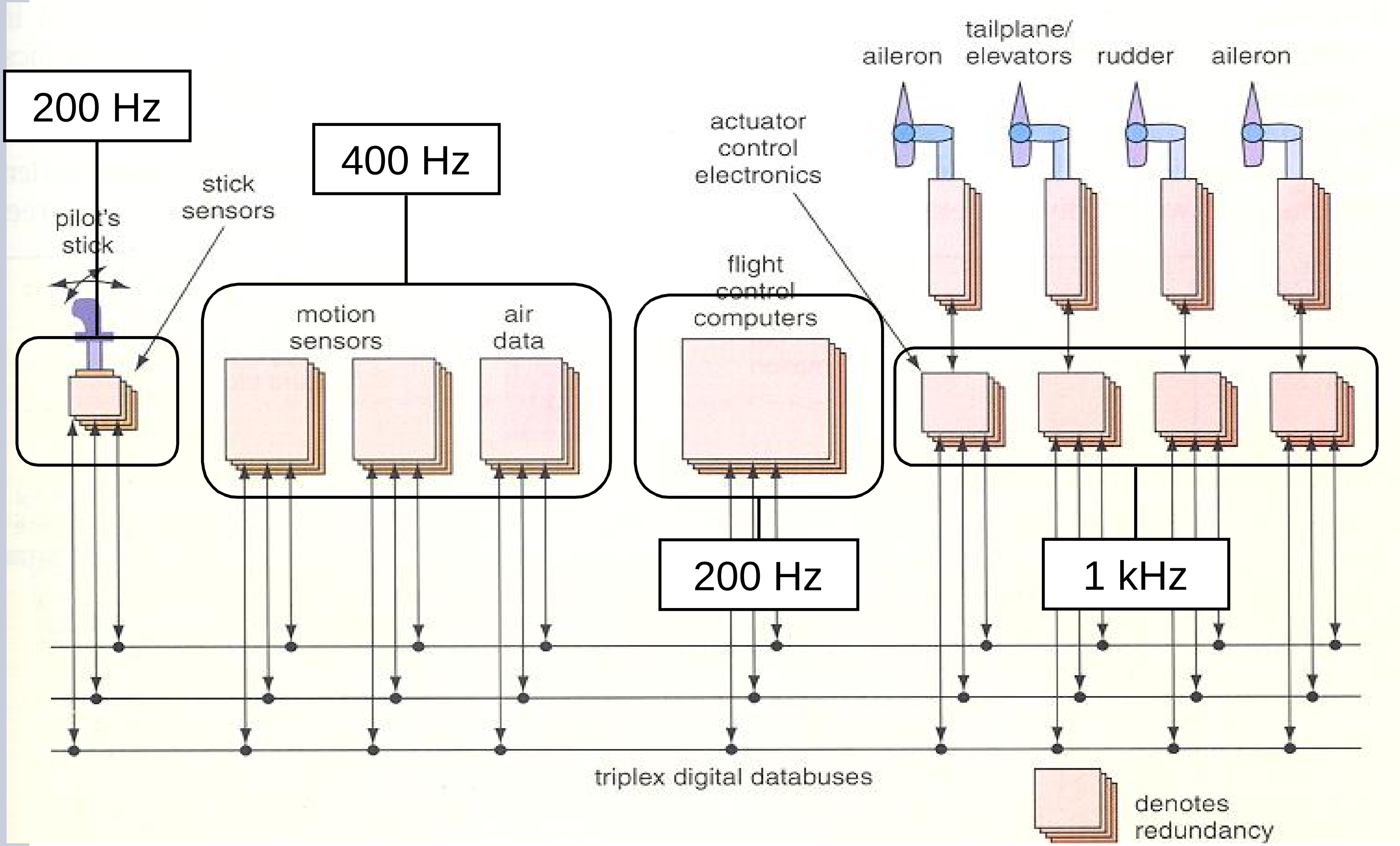
- Giotto: predictable, reusable real-time code
  - concepts
  - case study: helicopter control system

# Giotto concepts

# Motivation: Flight Control Software

Kirsch, Pree, in cooperation with ETH Zurich (Sanvido, Schaufelberger, Wirth). Single CPU.

# Motivation: Flight Control Software



# Platform-independent Software Model

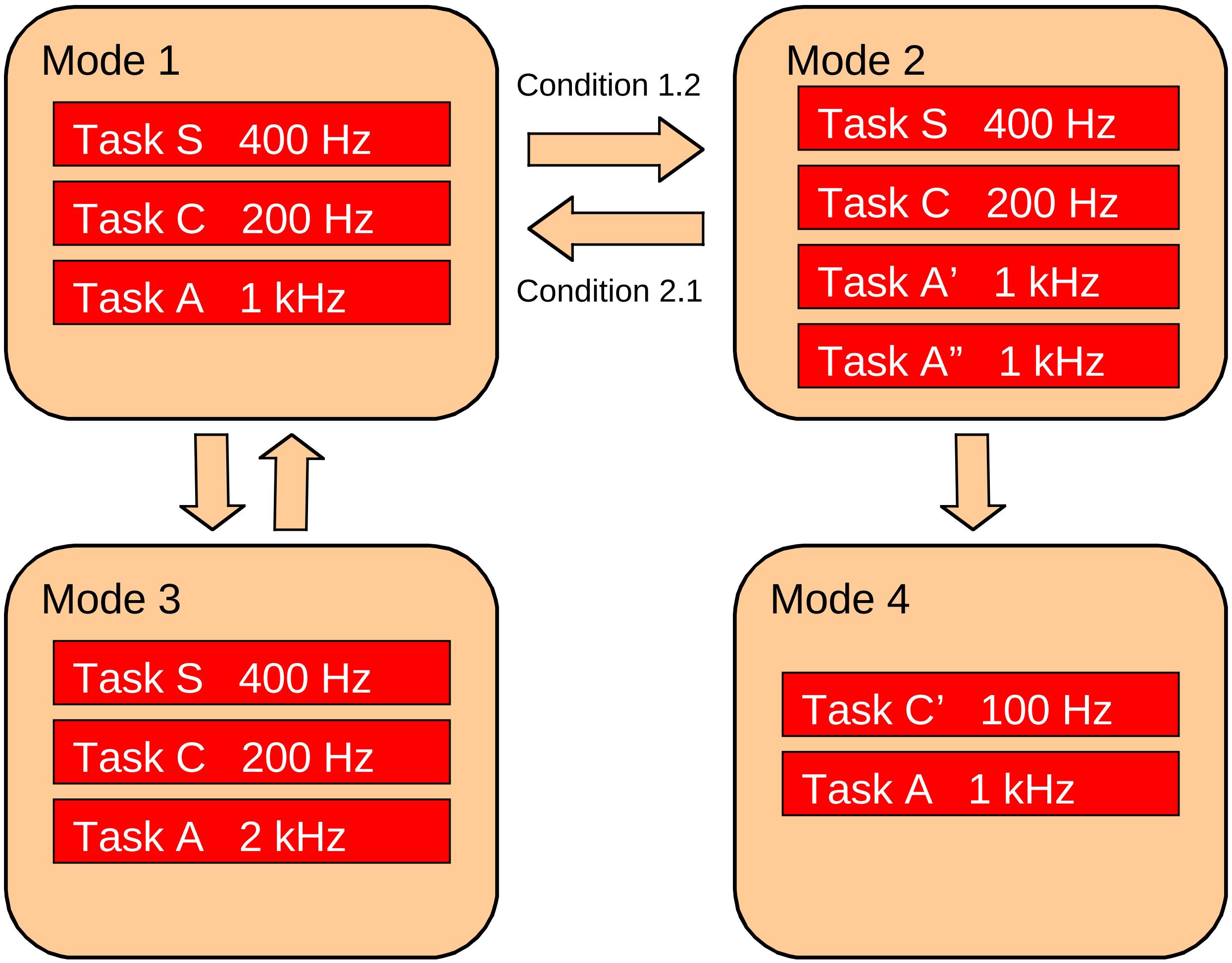
## 1. Concurrent periodic tasks:

-sensing
-control law computation
-actuating

## 2. Multiple modes of operation:

-navigational modes (autopilot, manual, etc.)
-maneuver modes (taxi, takeoff, cruise, etc.)
-degraded modes (sensor, actuator, CPU failures)

# Platform-independent Software Model



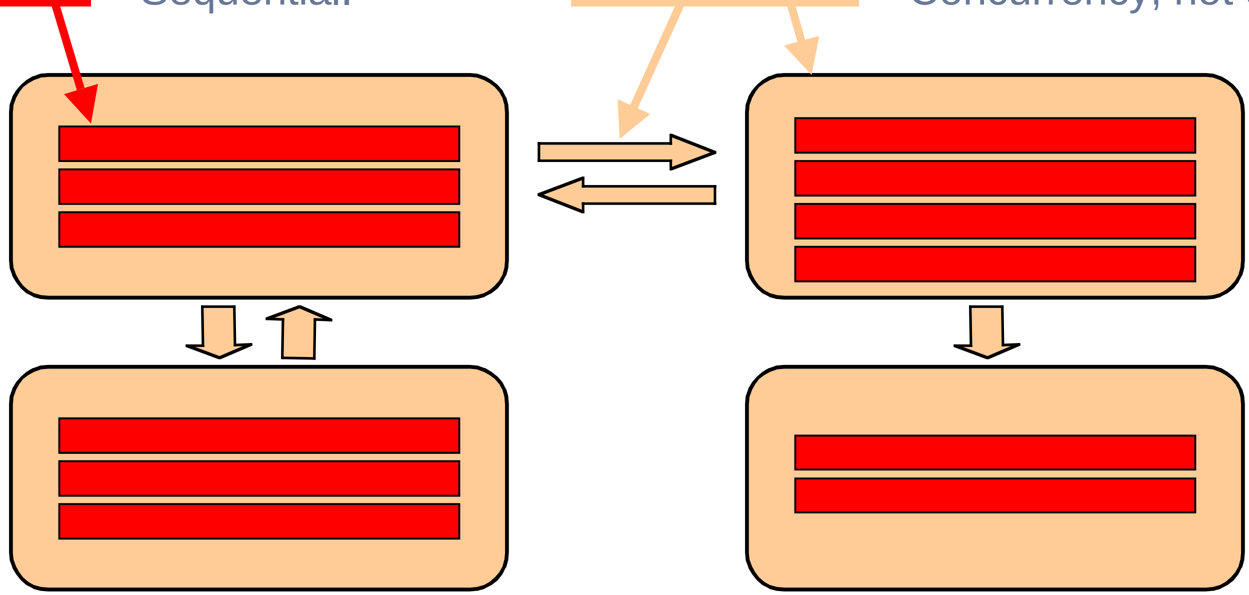
# Platform-independent Software Model

Host code
e.g. C

Functionality.
-No time.
-Sequential.

Glue code
Giotto

Timing and interaction.
-Environment time, not platform time.
-Concurrency, not distribution.



This kind of software is understood:
Host code may (sometimes) be generated automatically.

The software complexity lies in the glue code (minimize jitter!) :
Giotto enables requirements-driven rather than platform-driven glue-code programming.

# The Giotto model

## The Giotto Programmer's Model

### Programming in terms of environment time:

**Programmer's fiction:**

-time-triggered task invocation
-tasks are functions with a fixed duration
-platform offers sufficient performance

### Implementation in terms of platform time:

**Compiler must maintain programmer's fiction:**

-needs access to global time, no other platform requirements
-tasks may finish early, but outputs cannot be observed early
-tasks may be preempted and distributed

# The Giotto Programmer's Model

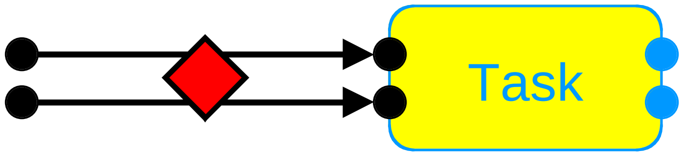
Given:

1. Units of scheduled host code (application-level tasks).

   e.g. control law computation


2. Units of synchronous host code (system-level drivers).

   e.g. device drivers

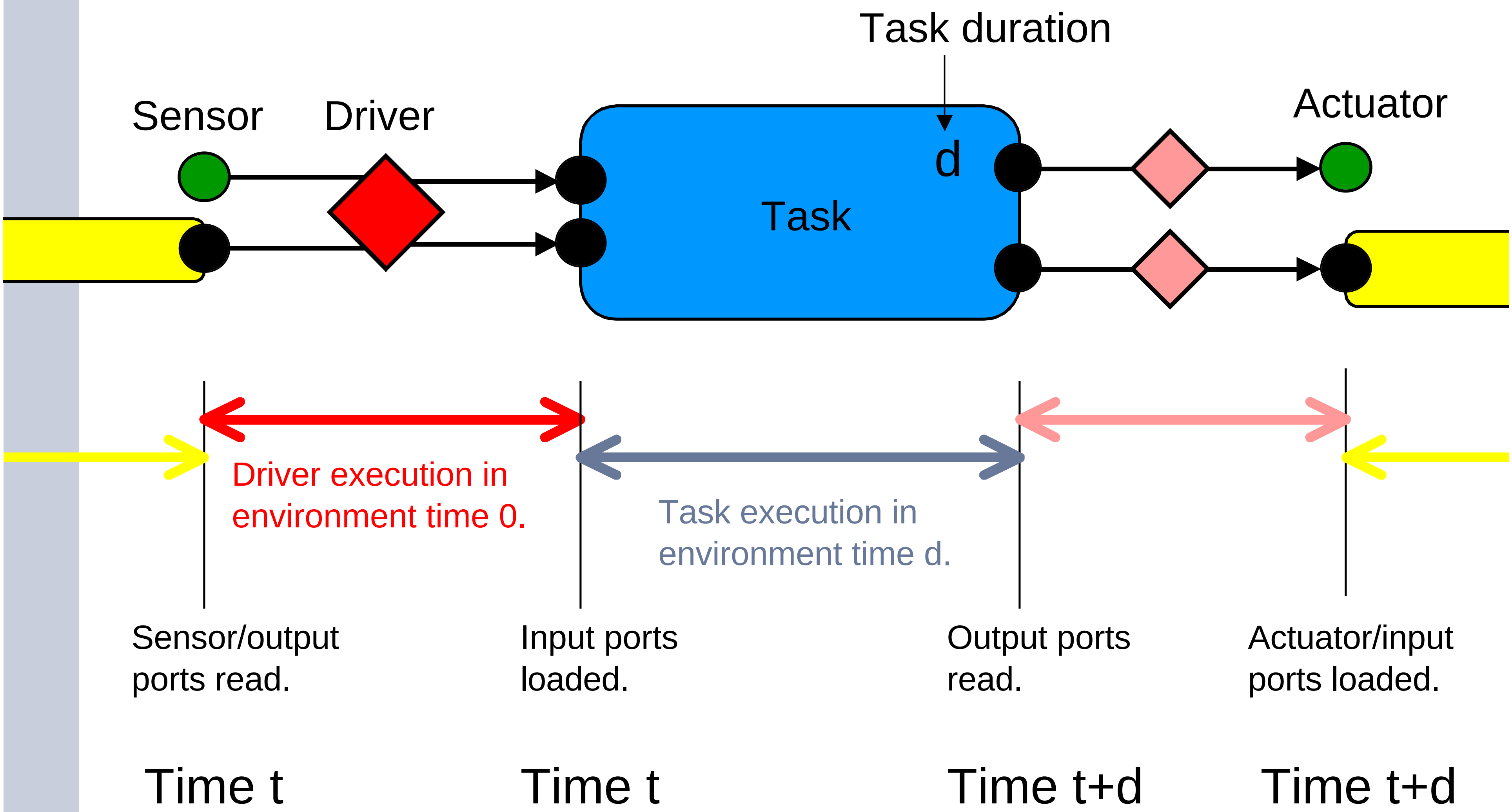



Task driver loads task input ports.

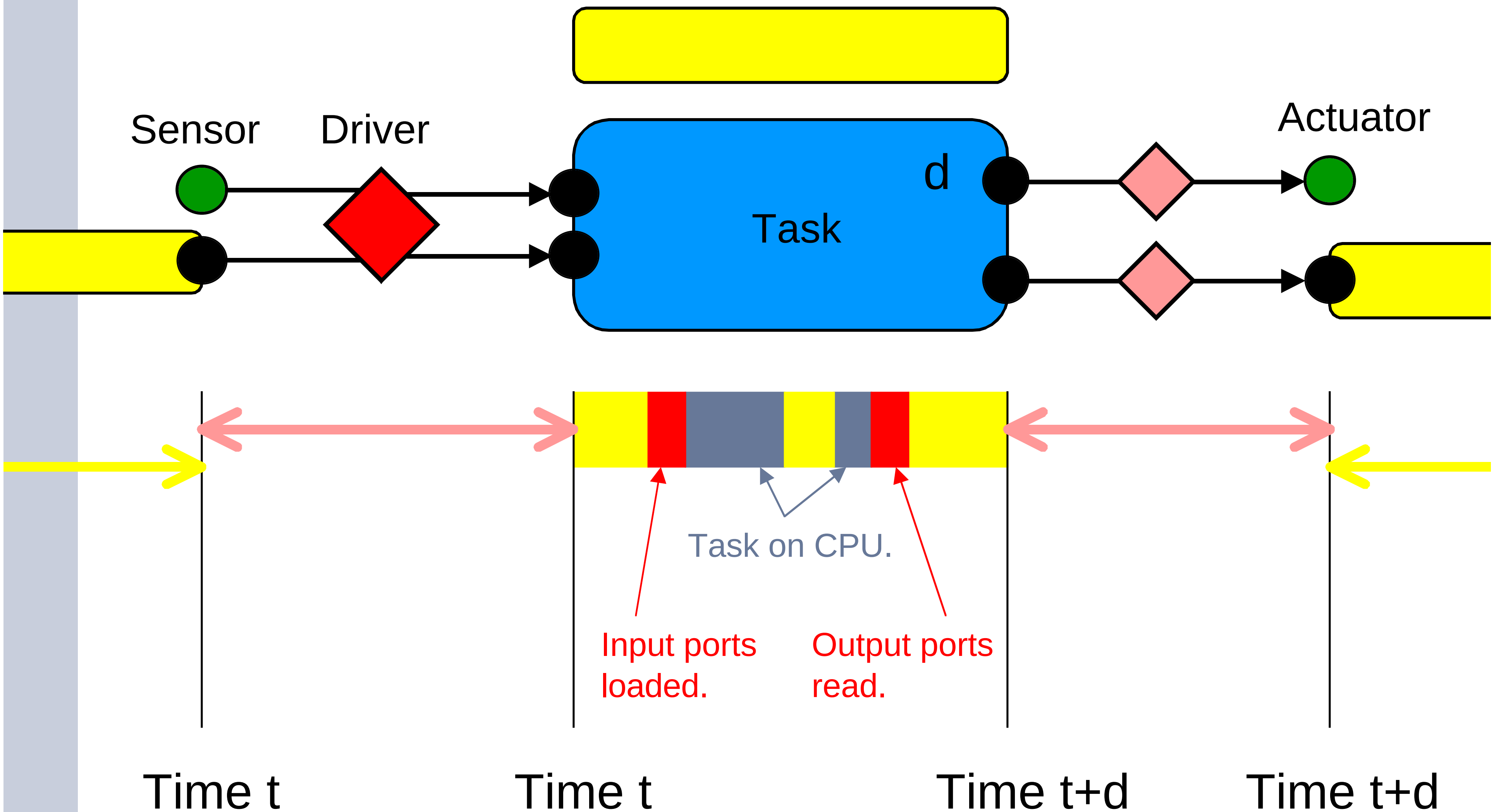
3. Real-time requirements and data flow between tasks.

| |
|---|
| Giotto: Glue code that calls 1. and 2. in order to realize 3. |

# Environment Timeline (defined by Giotto semantics)



# Platform Timeline (chosen by Giotto compiler)



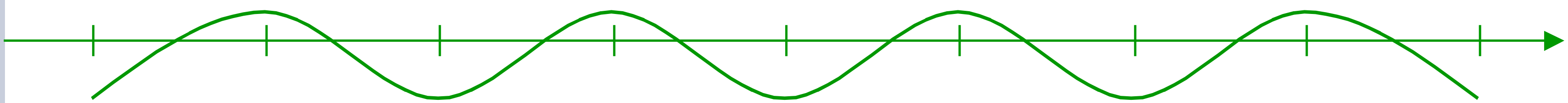
# Platform Independence ensures Predictability

The Giotto compiler chooses for a given platform a platform timeline that is value equivalent to the environment timeline defined by the Giotto semantics.

## Internal Determinism:

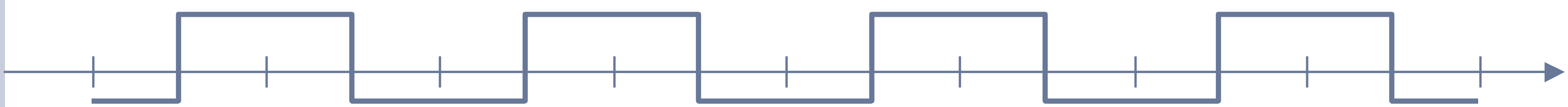
For a given sequence of sensor readings, the corresponding sequence of actuator settings is uniquely determined (i.e., there are no race conditions).

Environment

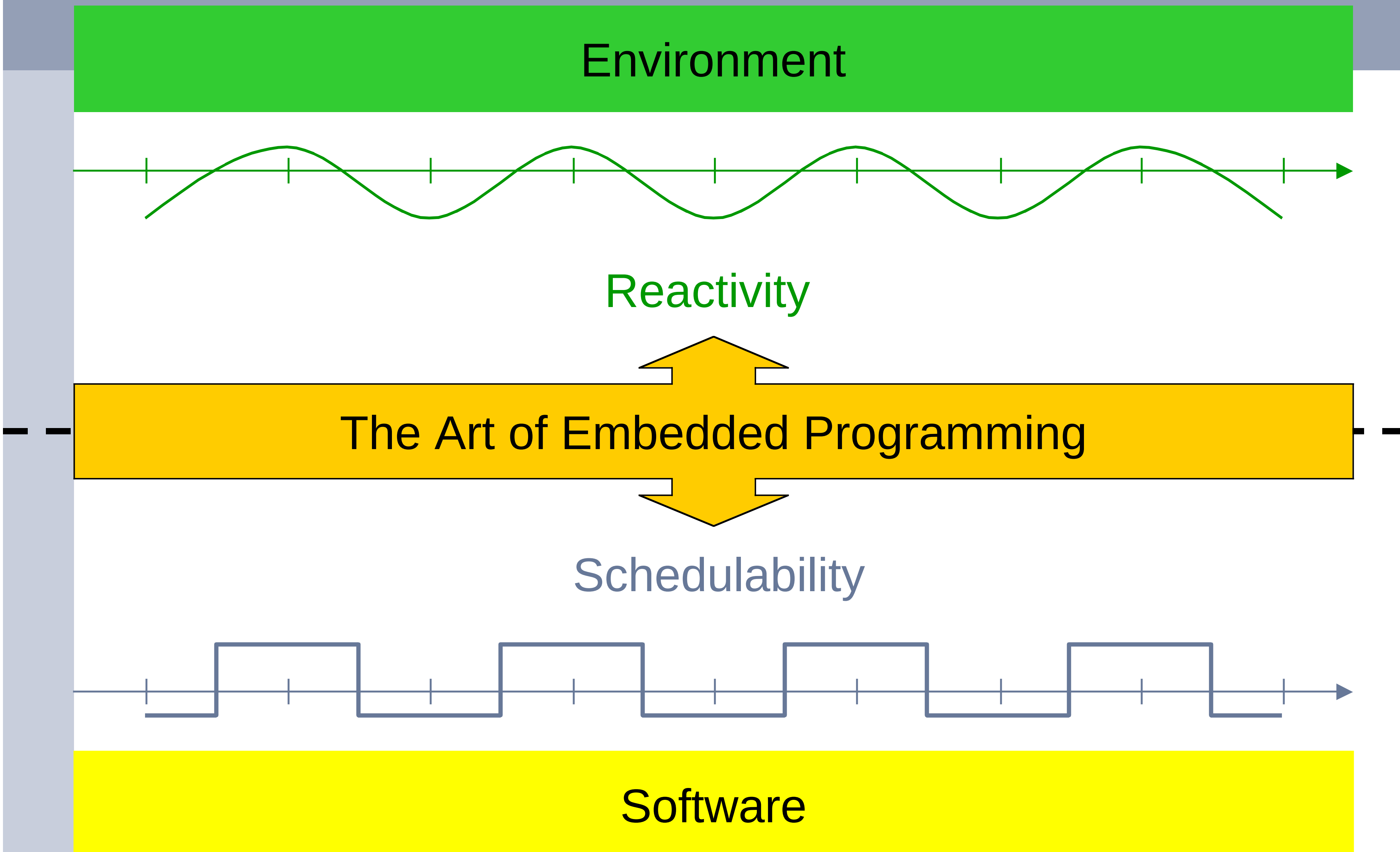


Environment Processes: environment time

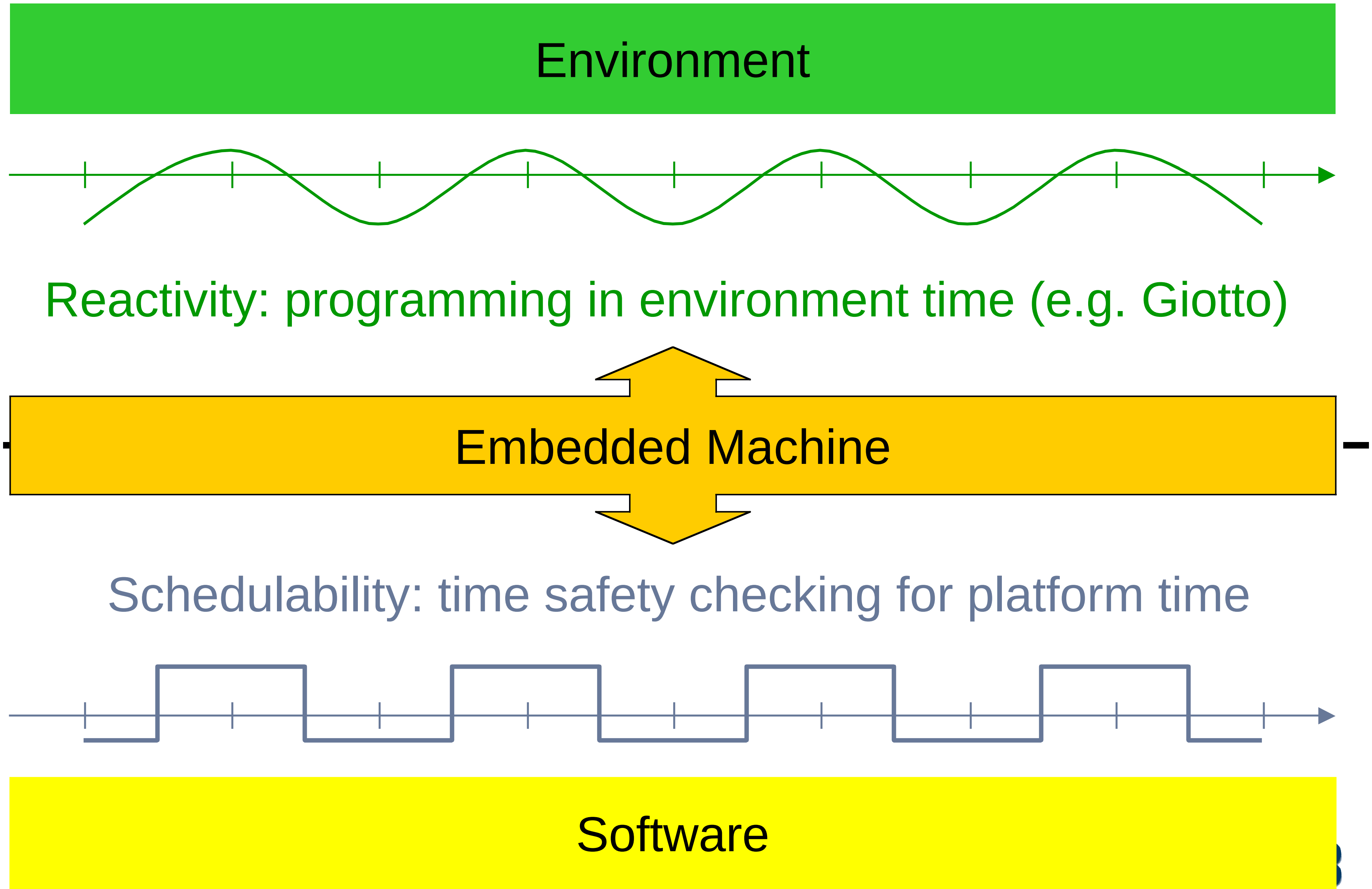
Software Processes: platform time



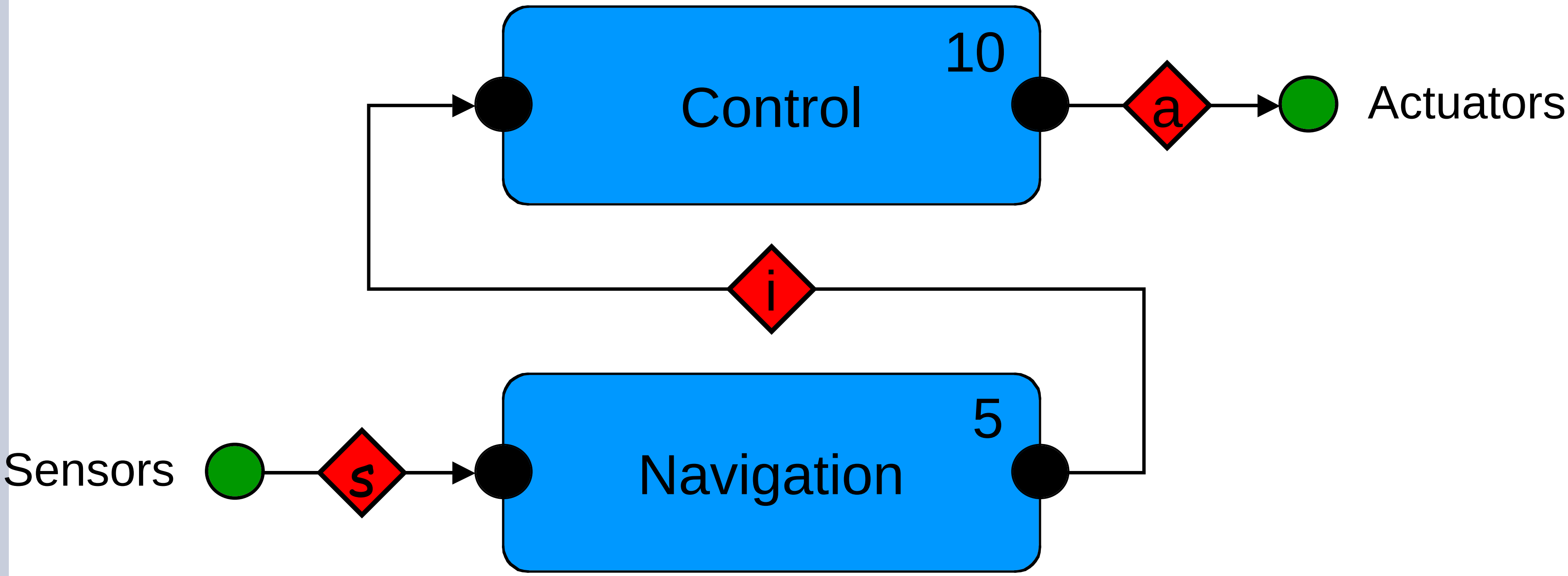
Software


Environment
Reactivity
The Art of Embedded Programming
Schedulability
Software

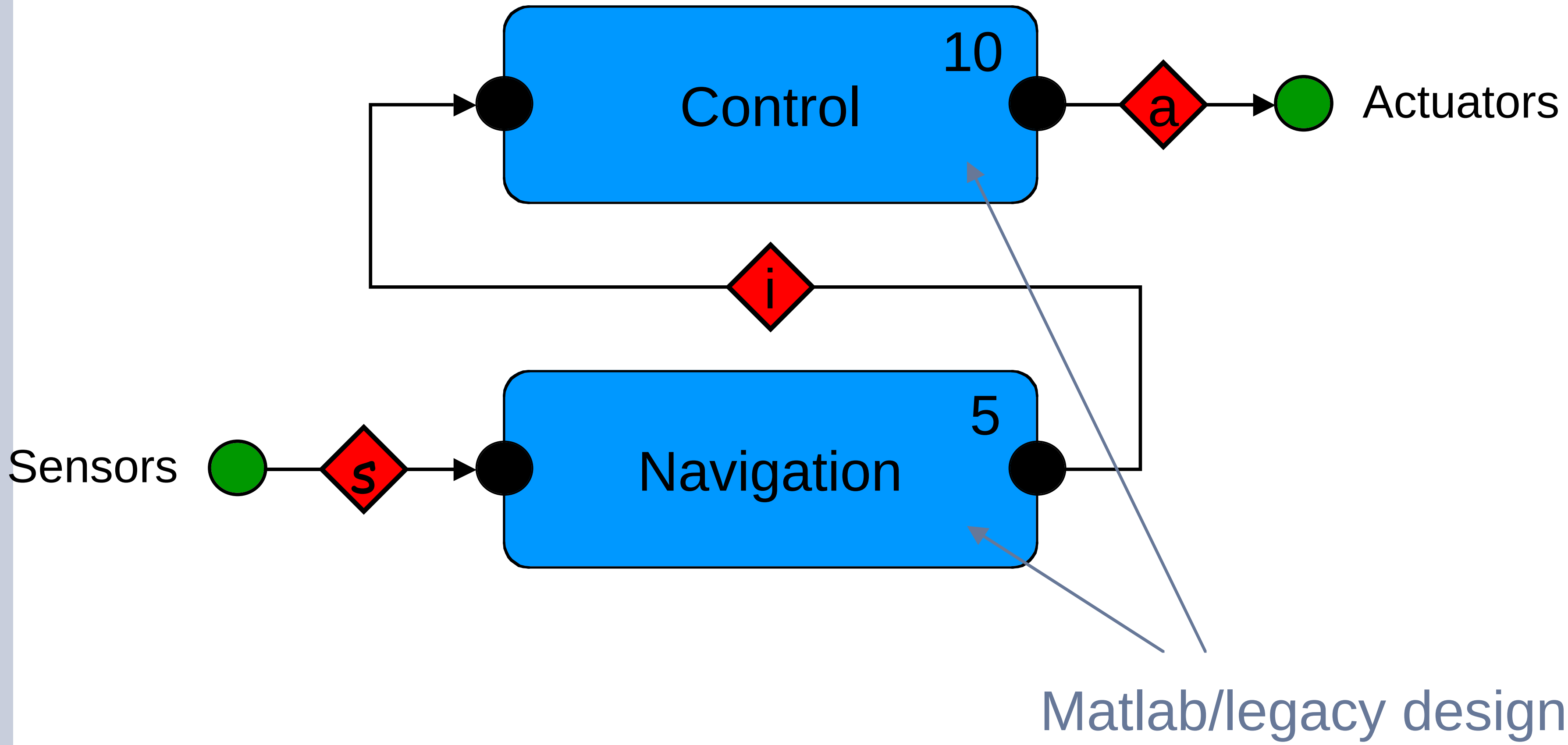
# The Embedded Machine: Time is like Memory



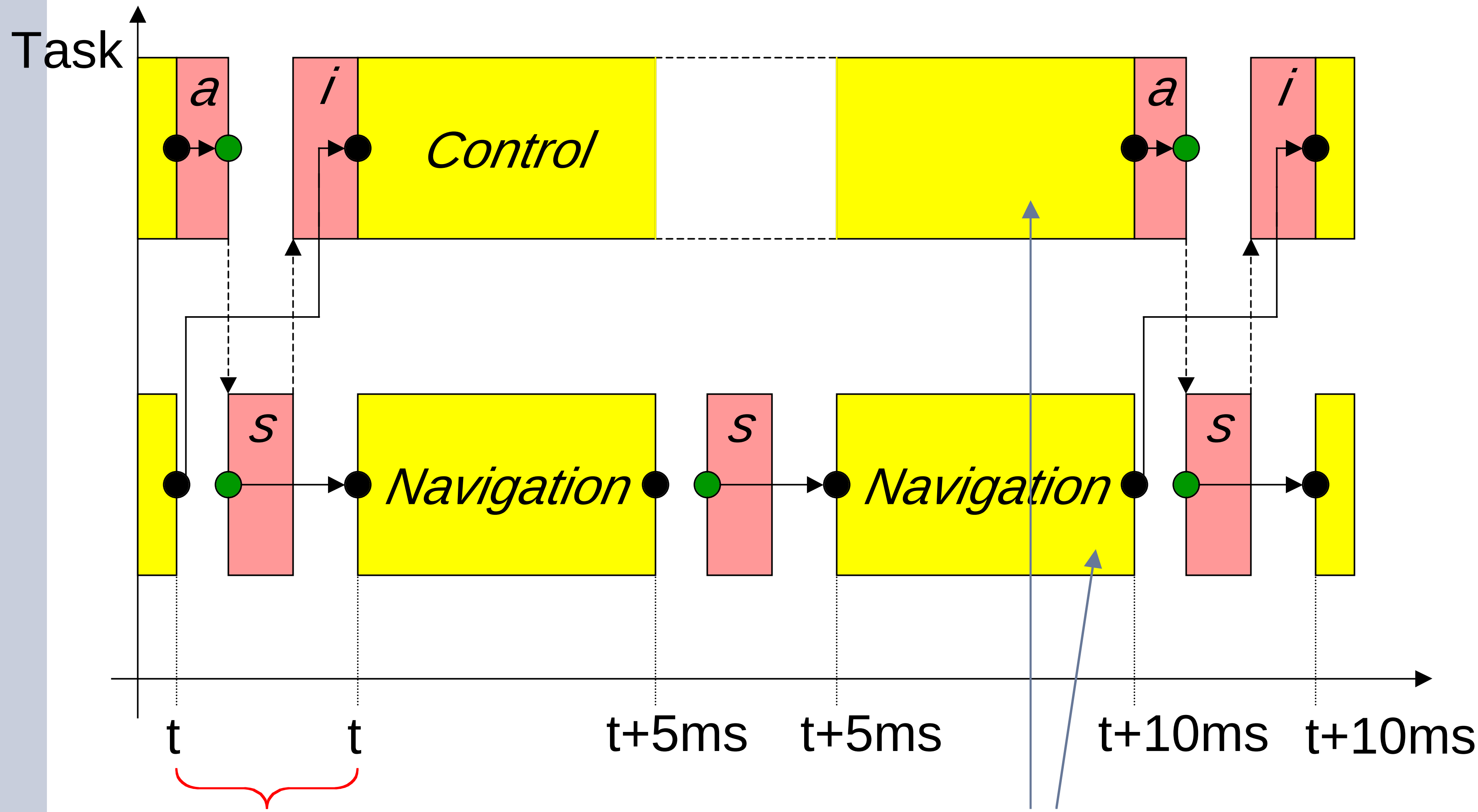
# Simplified Helicopter Software



# Simplified Helicopter Software



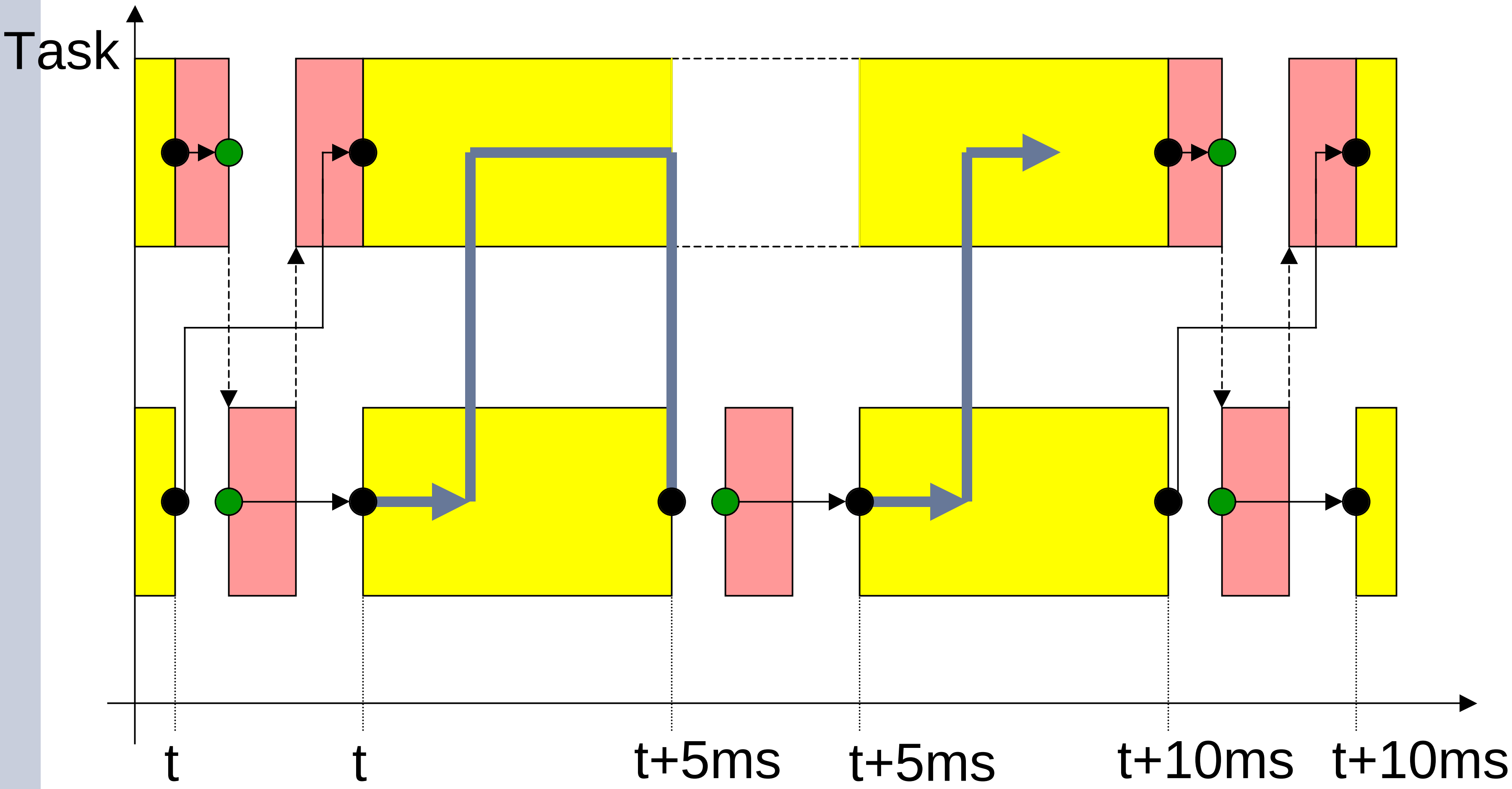
# Helicopter Software: Environment Timeline



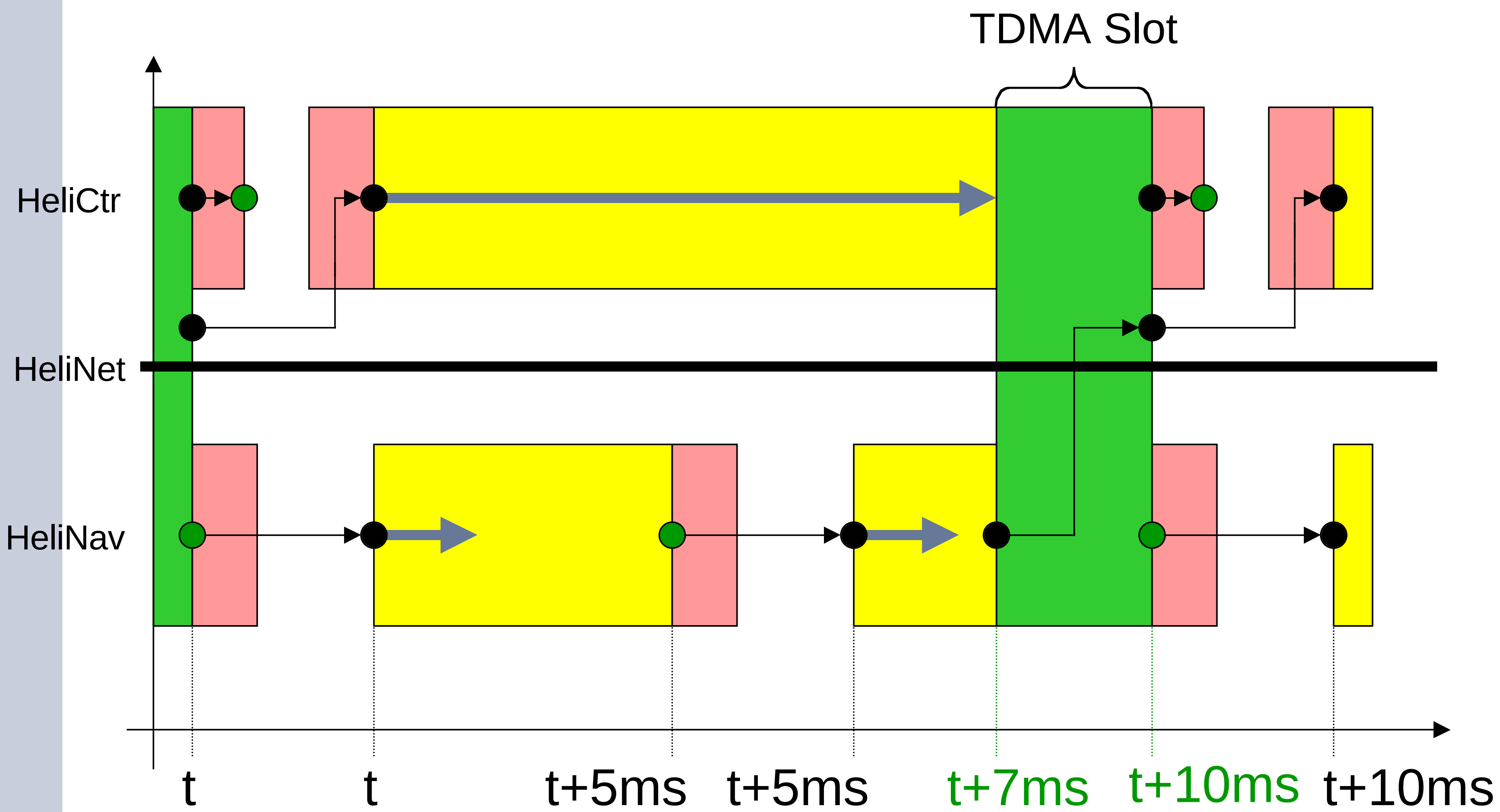

Block of synchronous code (nonpreemptable)

Scheduled tasks (preemptable)

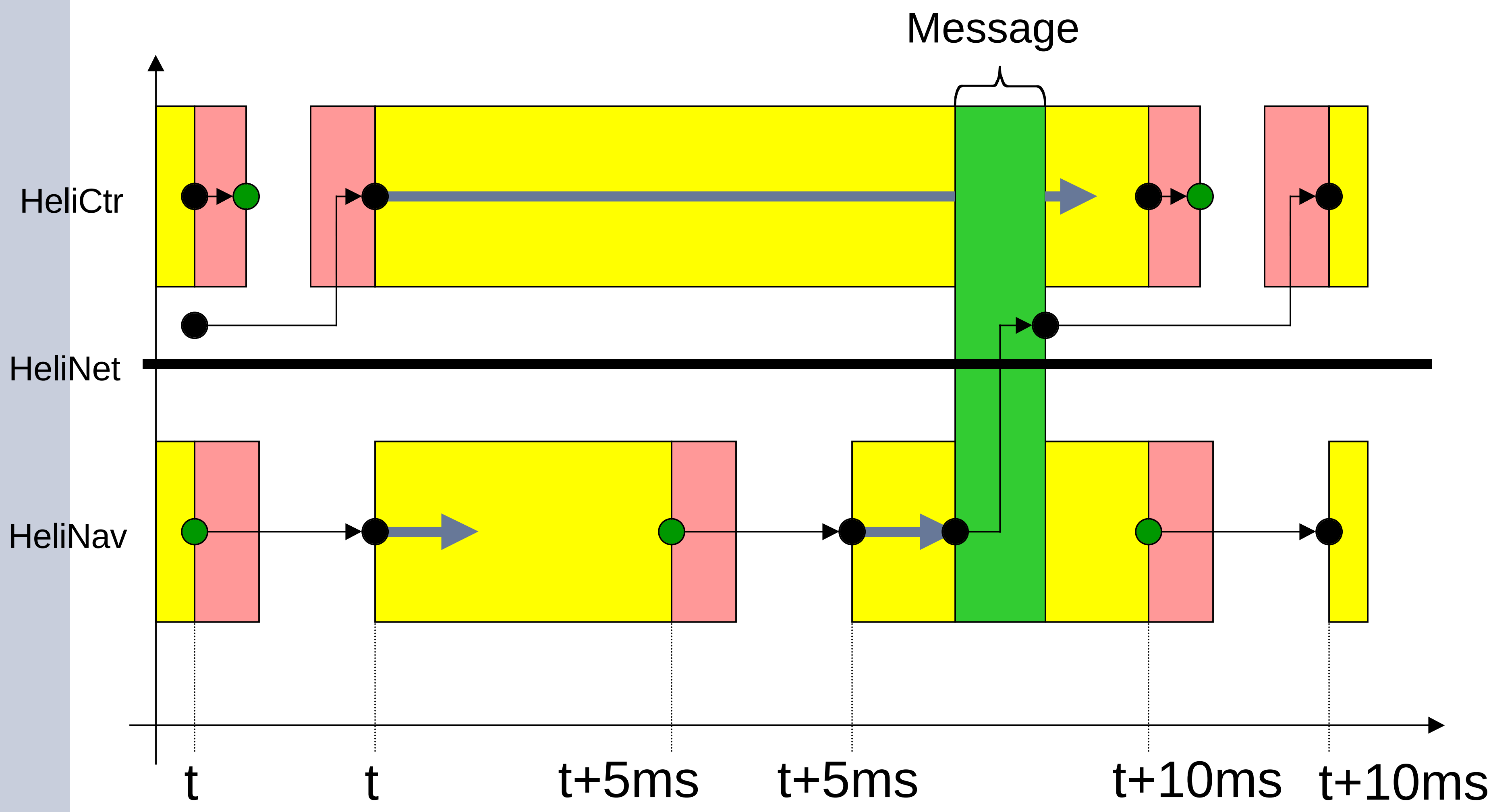
# Single-CPU Helicopter: Platform Timeline (EDF)



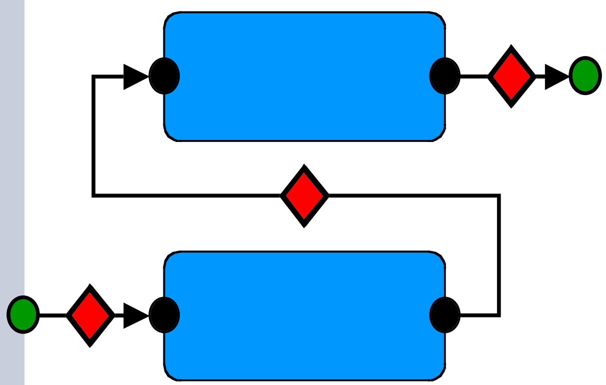
# Two-CPU Helicopter: Platform Timeline (Time-triggered Communication)



# Two-CPU Helicopter: Platform Timeline (Event-triggered Communication)

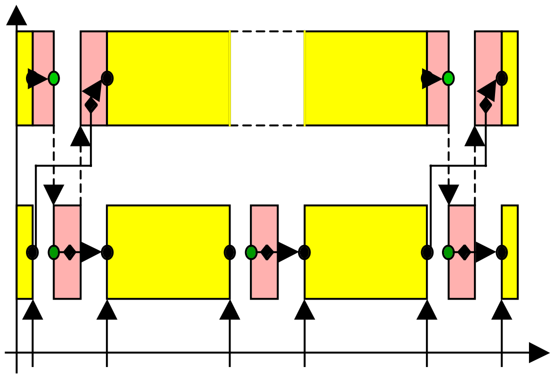


# Helicopter Software: Giotto Syntax (Functionality)



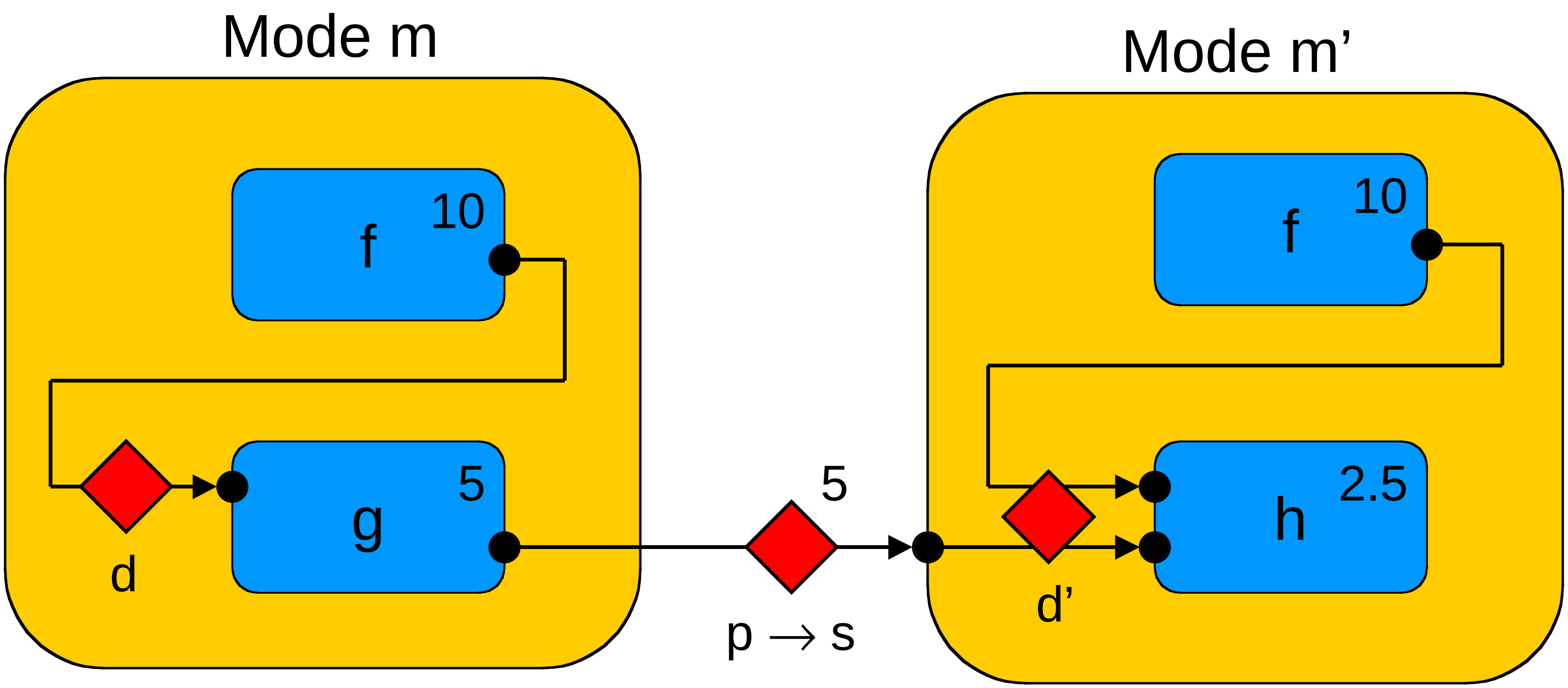
```
sensor gps_type GPS uses c_gps_device ;

actuator servo_type Servo := c_servo_init
        uses c_servo_device ;

output
  ctr_type CtrOutput := c_ctr_init ;
  nav_type NavOutput := c_nav_init ;

driver sensing (GPS) output (gps_type gps)
{ c_gps_pre_processing ( GPS, gps ) }

task Navigation (gps_type gps) output (NavOutput)
{ c_matlab_navigation_code ( gps, NavOutput ) }

…
```

# Helicopter Software: Giotto Syntax (Timing)

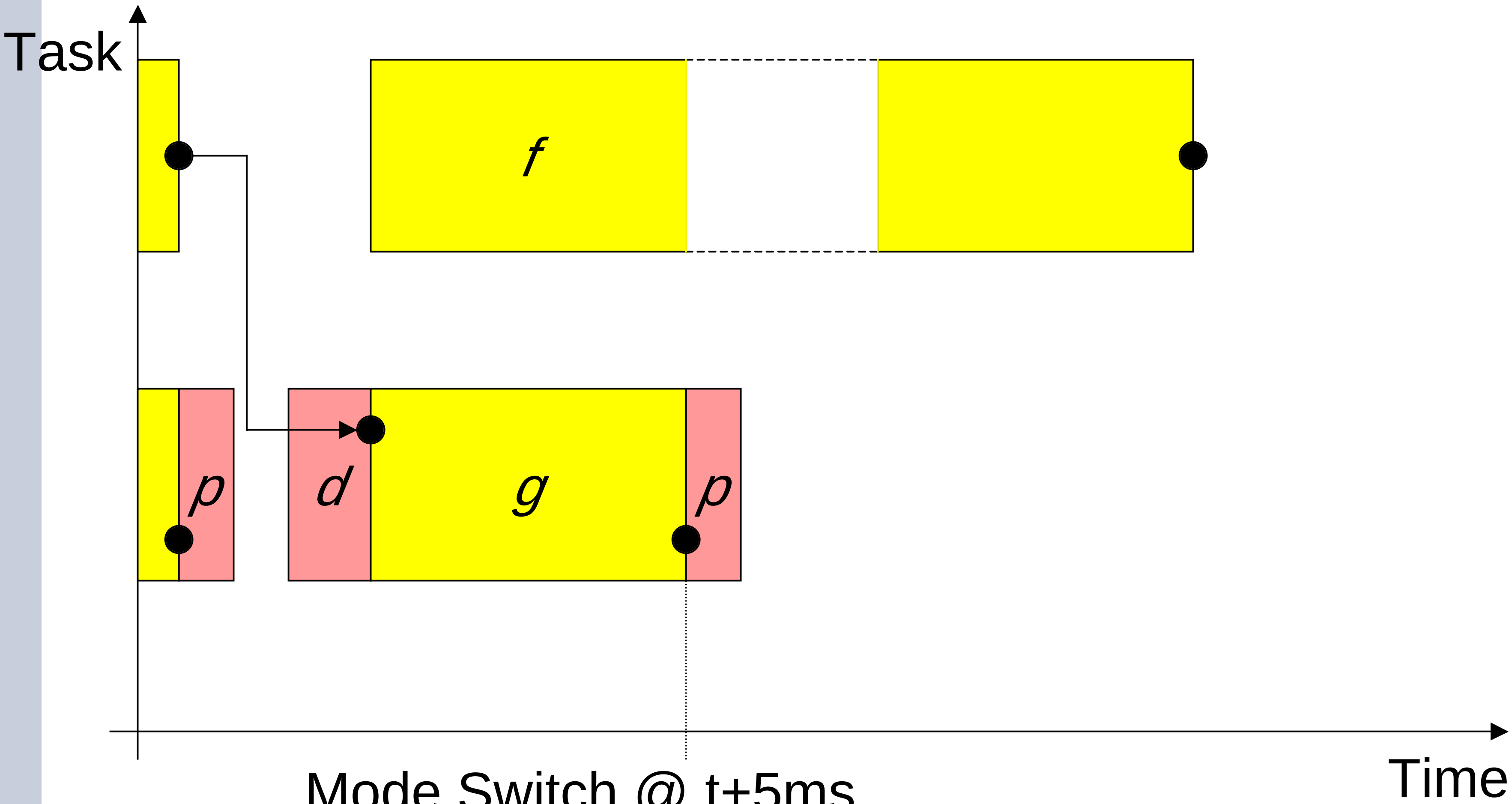


```
...
mode Flight ( ) period 10ms
  {
      actfreq 1 do Actuator ( actuating ) ;

      taskfreq 1 do Control ( input ) ;
      taskfreq 2 do Navigation ( sensing ) ;
  }
...
```

# Mode Switch

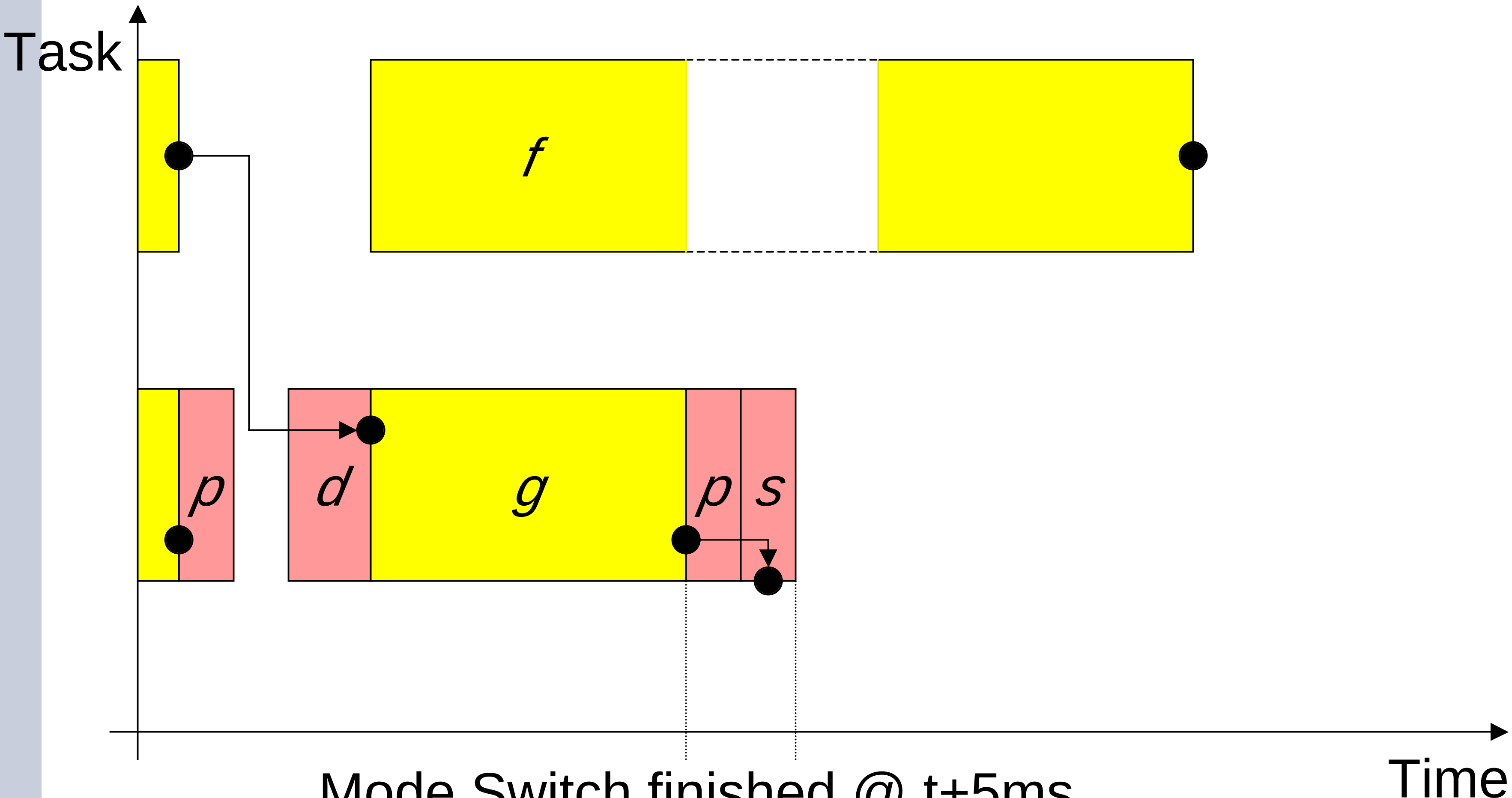


# Mode Switch: Environment Timeline



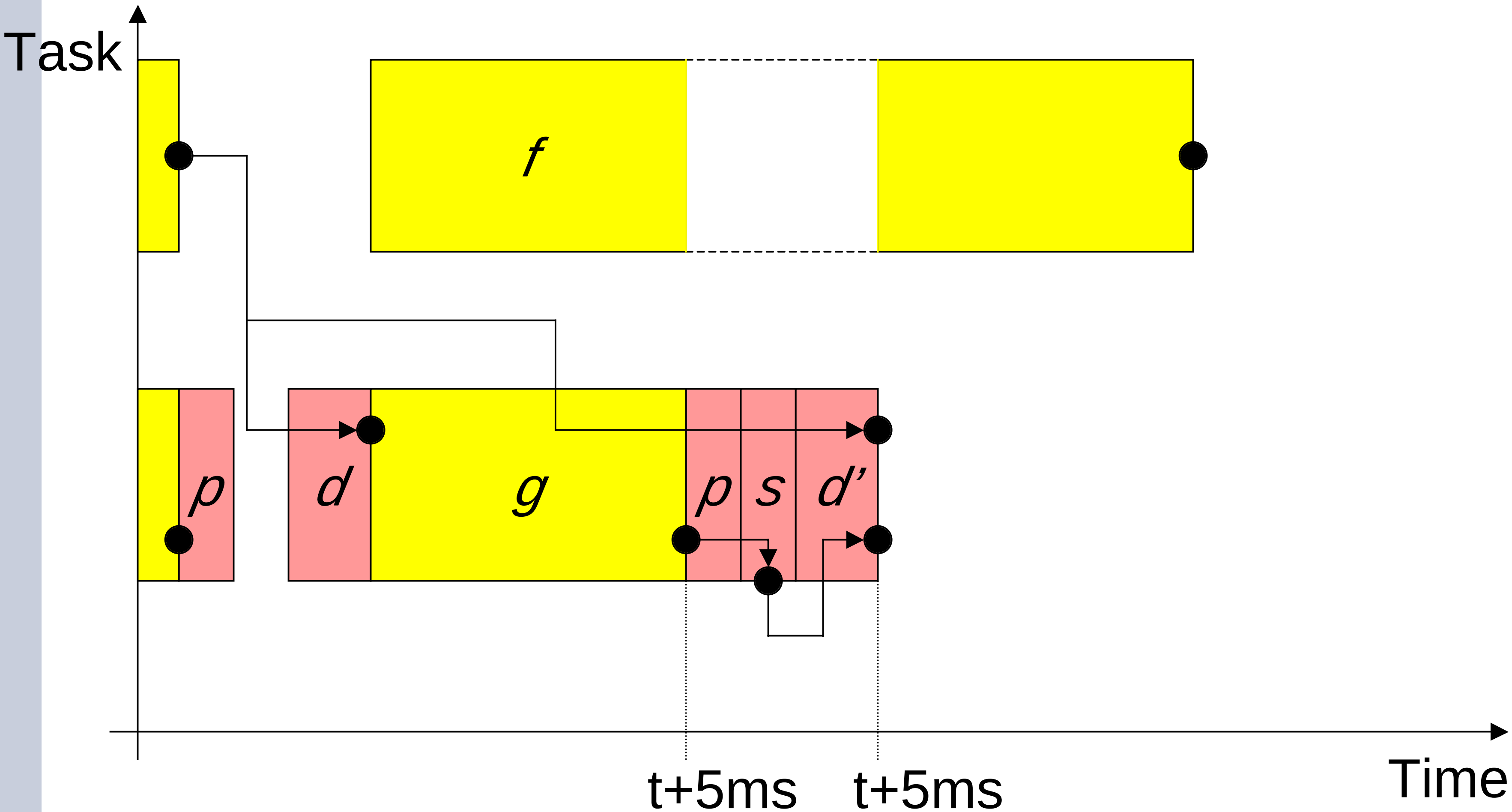

Mode Switch @ t+5ms

# Mode Switch: Environment Timeline

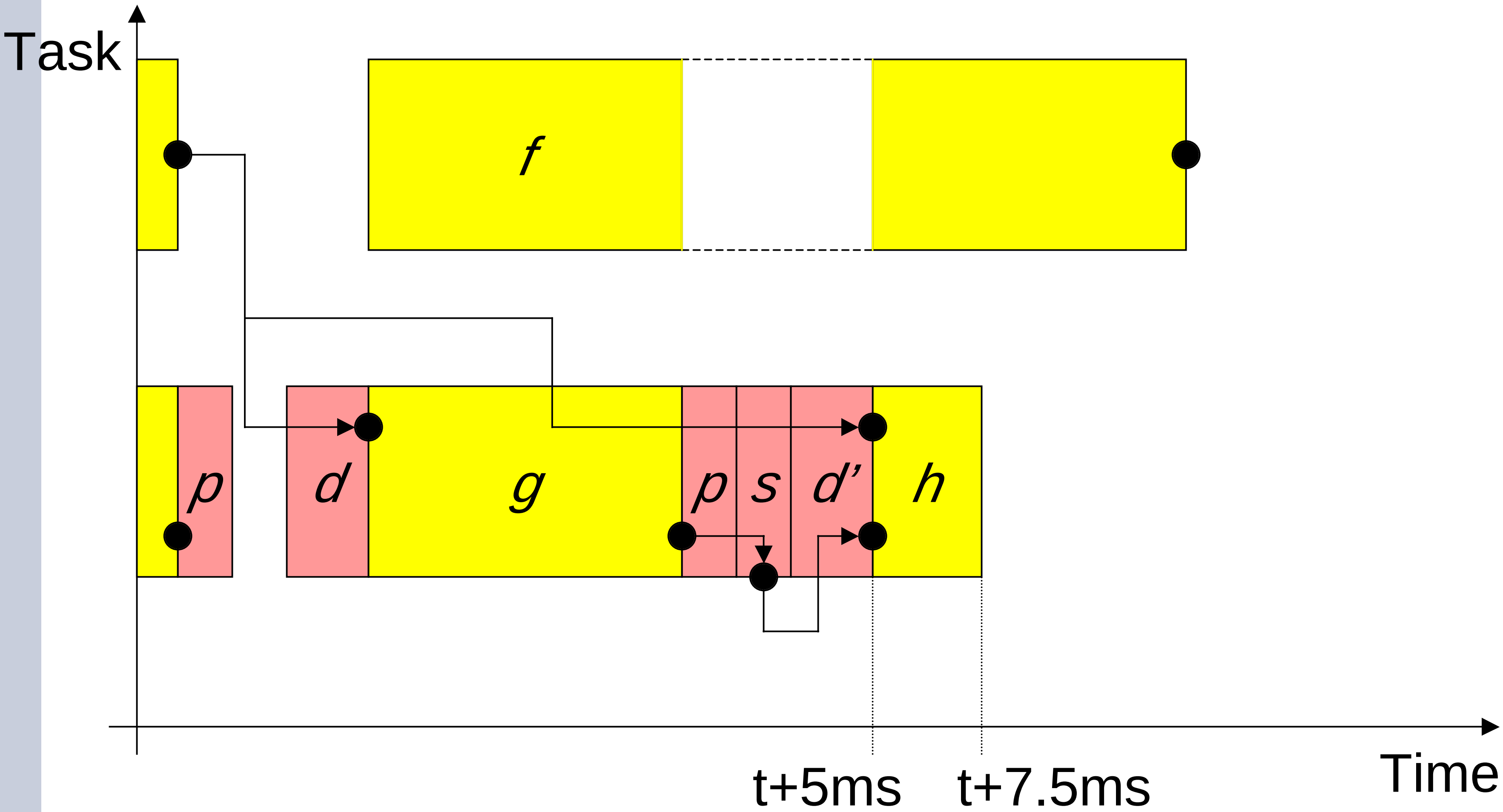



Mode Switch finished @ t+5ms

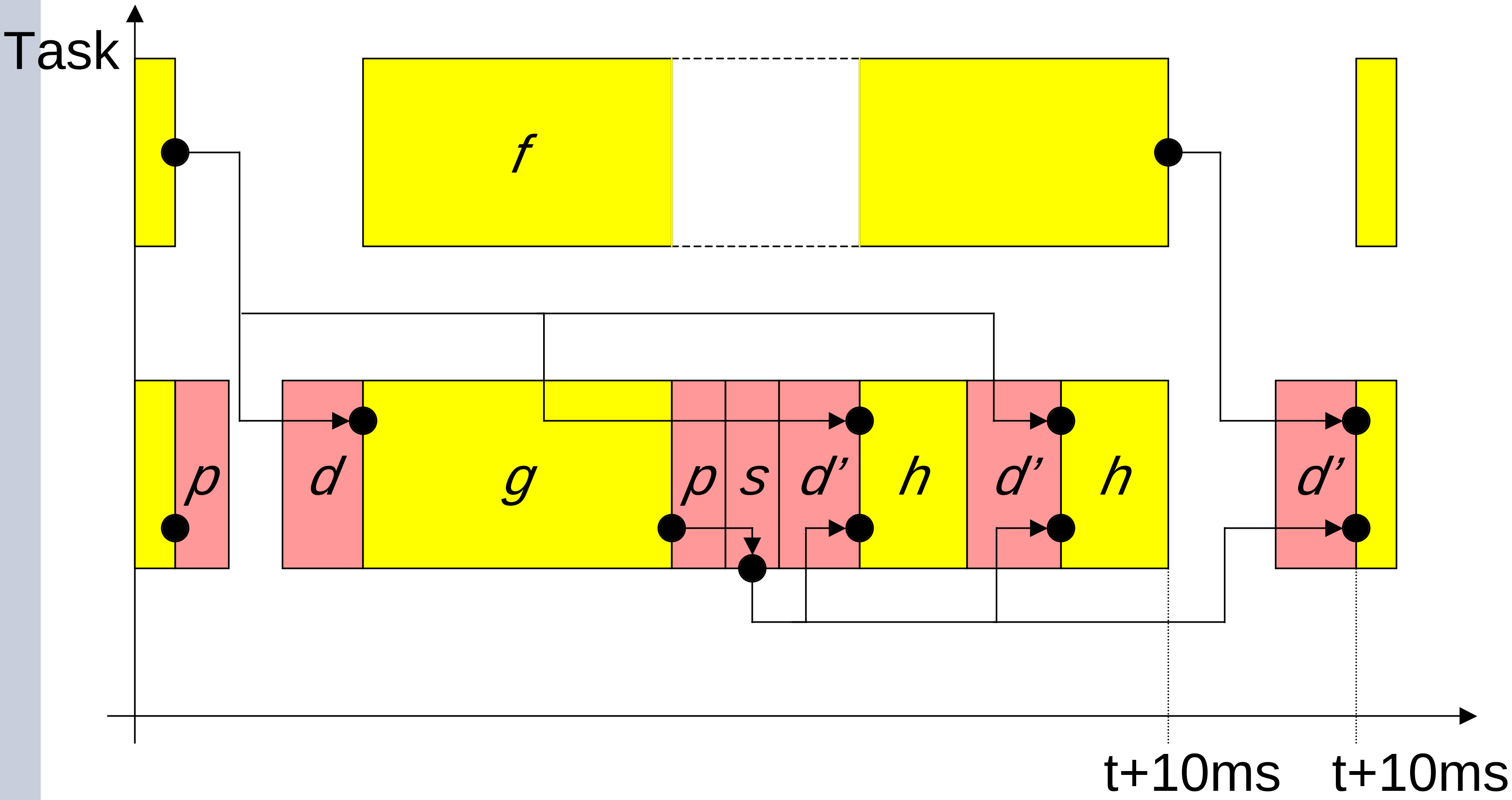
# Mode Switch: Environment Timeline



# Mode Switch: Environment Timeline



# Mode Switch: Environment Timeline



# The Giotto Compiler

| | | |
|---|---|---|
| Functionality | Native Code | Tasks and Drivers |
| Timing<br>Interaction | Giotto Program | |
| Platform | Giotto-P | Platform Specification |

-topology (CPUs, nets)
-performance (WCETs, latencies)
-APIs (RTOSs, protocols)

Giotto Compiler

Executables

or

"Failure"

either Giotto-P overconstrained,
or compiler not smart enough
(distributed scheduling problem)

# Closing the Gap: Annotated Giotto

| | | |
|---|---|---|
| Functionality | Native Code | Tasks and Drivers |
| Timing<br>Interaction | Giotto Program | |
| Platform | Giotto-P | -topology (CPUs, nets)<br>-performance (WCETs, latencies)<br>-APIs (RTOSs, protocols) |
| Map | Giotto-PM | -assign tasks to CPUs<br>-assign connections to nets |

Giotto Compiler

"Failure"

Executables or either Giotto-PM overconstrained, or compiler not smart enough (global scheduling problem)

# Closing the Gap: Annotated Giotto

| | | |
|---|---|---|
| Functionality | Native Code | Tasks and Drivers |
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| Platform | Giotto-P | -topology (CPUs, nets)<br>-performance (WCETs, latencies)<br>-APIs (RTOSs, protocols) |
| Map | Giotto-PM | -assign tasks to CPUs<br>-assign connections to nets |
| Communication | Giotto-PMC | -assign connections to TDMA slots (say) |

Giotto Compiler ↓

Executables

or

"Failure"

Giotto-PMC overconstrained
(local scheduling problems solvable)

# Single-CPU Giotto Scheduling

Why is it simple?

-Static utilization test for each mode
-Mode switches are memory-free

Theorem: Given a Giotto program and WCETs for all tasks, it can be checked in quadratic time if an EDF scheduler meets all deadlines.

# Two-CPU Helicopter: Annotated Giotto (Time-triggered Communication)

```
[ host HeliCtr address 192.168.0.1;
  host HeliNav address 192.168.0.2;
  network HeliNet address 192.168.0.0 connects HeliCtr, HeliNav ]
…
mode Flight ( ) period 10ms
   {
        actfreq 1 do Actuator ( actuating ) ;

        taskfreq 1 do Control ( input ) [ host HeliCtr ] ;
        taskfreq 2 do Navigation ( sensing ) [host HeliNav;
        push ( NavOutput ) to ( HeliCtr ) in HeliNet slots (7,10) ] ;
   }
…
```

# Code Generation

| | | |
|---|---|---|
| Functionality | Native Code | Tasks and Drivers |
| Timing Interaction | Giotto Program | |
| Platform | Giotto-P | -topology (CPUs, nets)<br>-performance (WCETs, latencies)<br>-APIs (RTOSs, protocols) |
| Map | Giotto-PM | -assign tasks to CPUs<br>-assign connections to nets |
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Giotto Compiler

VxWorks | OSEK | … or "Failure"

# Code Generation: The Embedded Machine

| | | |
|---|---|---|
| Functionality | Native Code | Tasks and Drivers |
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Giotto Compiler

Embedded Machine code or "Failure"

Embedded Machine interpreter

# The Embedded Machine

-a virtual machine that mediates the interaction of physical processes (sensors and actuators) and software processes (tasks and drivers) in real time

-the Giotto compiler can be retargeted to a new platform by porting the Embedded Machine

# The Giotto Project

Completed: **www.eecs.berkeley.edu/~tah/giotto**

-Software tools:

Simulink to Giotto translator, Part I (Kirsch, Pree, Stieglbauer)

Giotto compiler for single-CPU targets (Kirsch)

Embedded Machine for Linux and VxWorks (Kirsch, Pree)

-Applications:

Lego Mindstorms (Horowitz, Kirsch, Majumdar)

Zurich helicopter (Kirsch, Sanvido, Pree)

In progress:

-Software tools:

Giotto scheduler for distributed platforms (Horowitz)

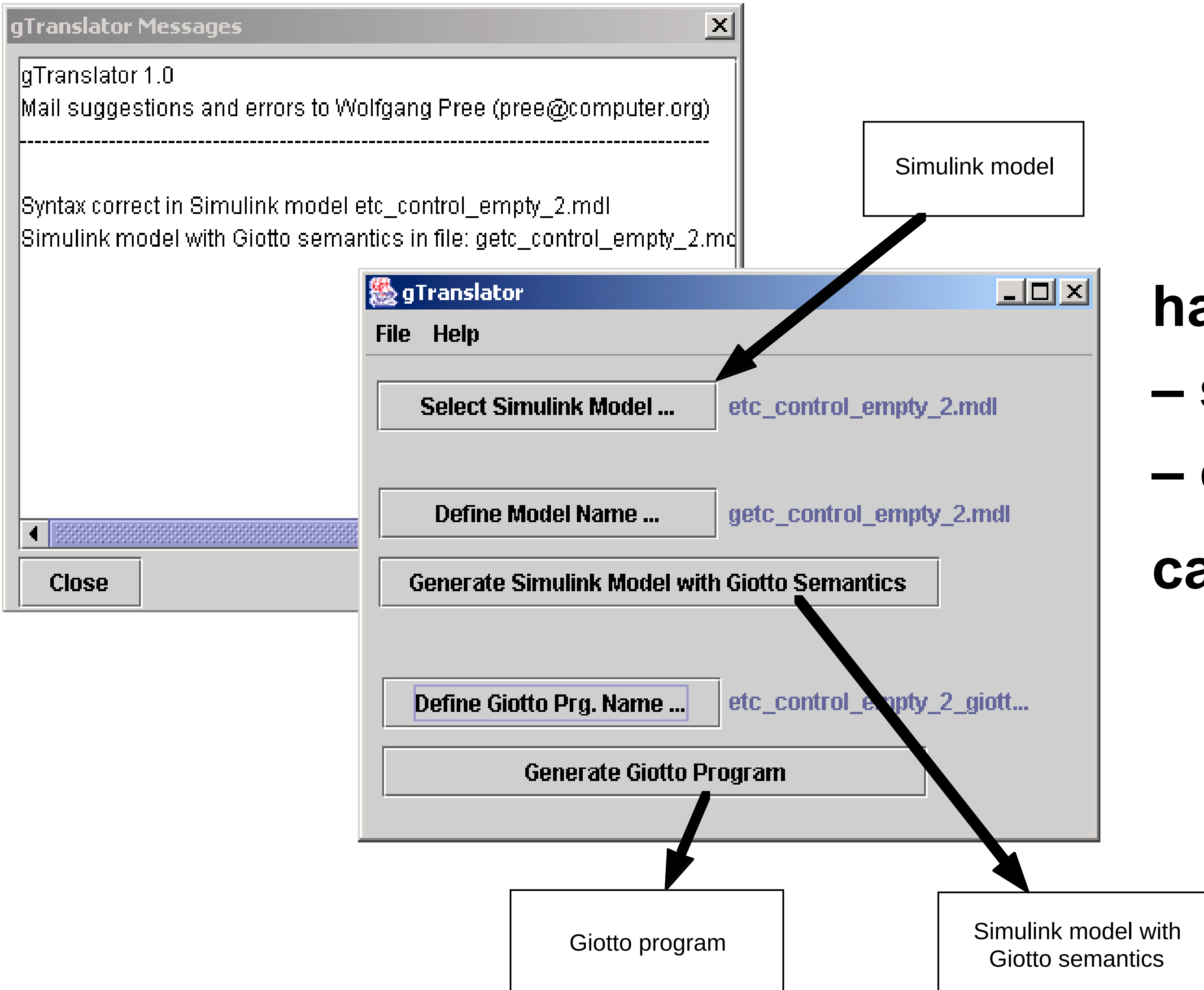
Simulink to Giotto translator, Part II (Pree, Stieglbauer, Kirsch)

Time safety checker for Embedded Machine code (Kirsch, Matic)

-Applications:

Electronic throttle control (Pree, Stieglbauer, Kirsch)

# gTranslator tool: seamless integration of Giotto and Simulink




harnesses SL's
– simulation and
– code gen.
capabilities