Giotto

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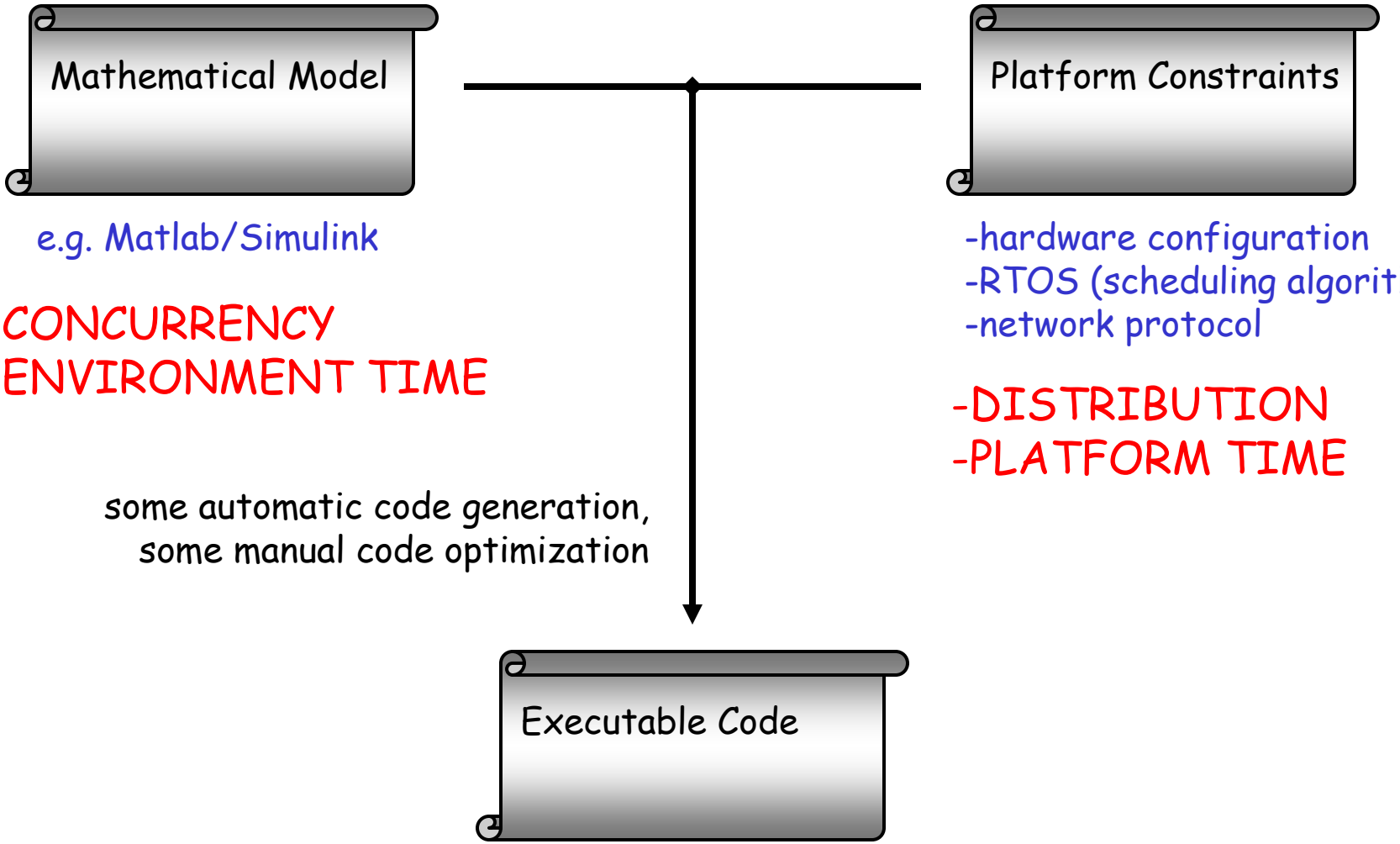
www.eecs.berkeley.edu/~fresco/giotto

Control Software Development



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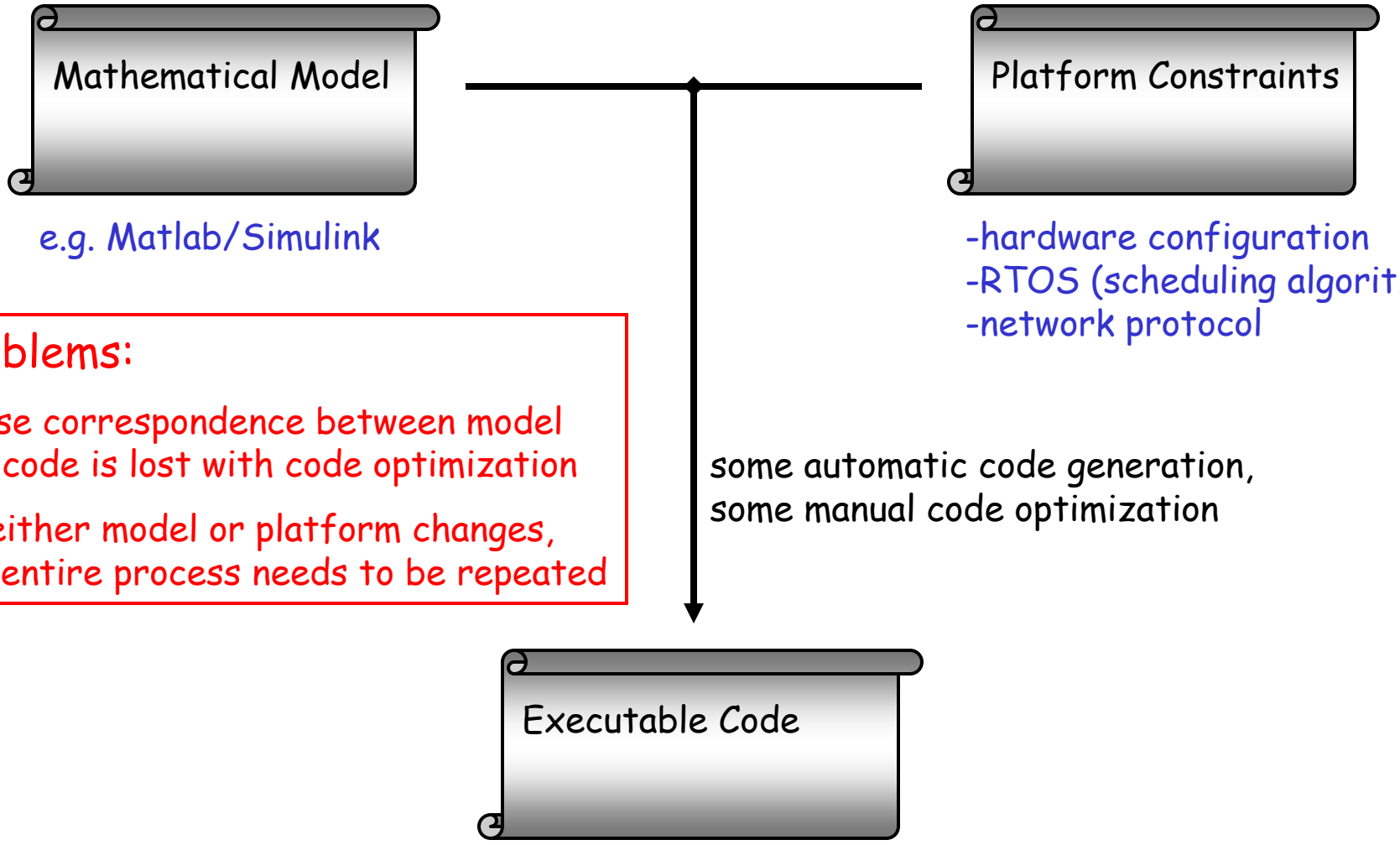

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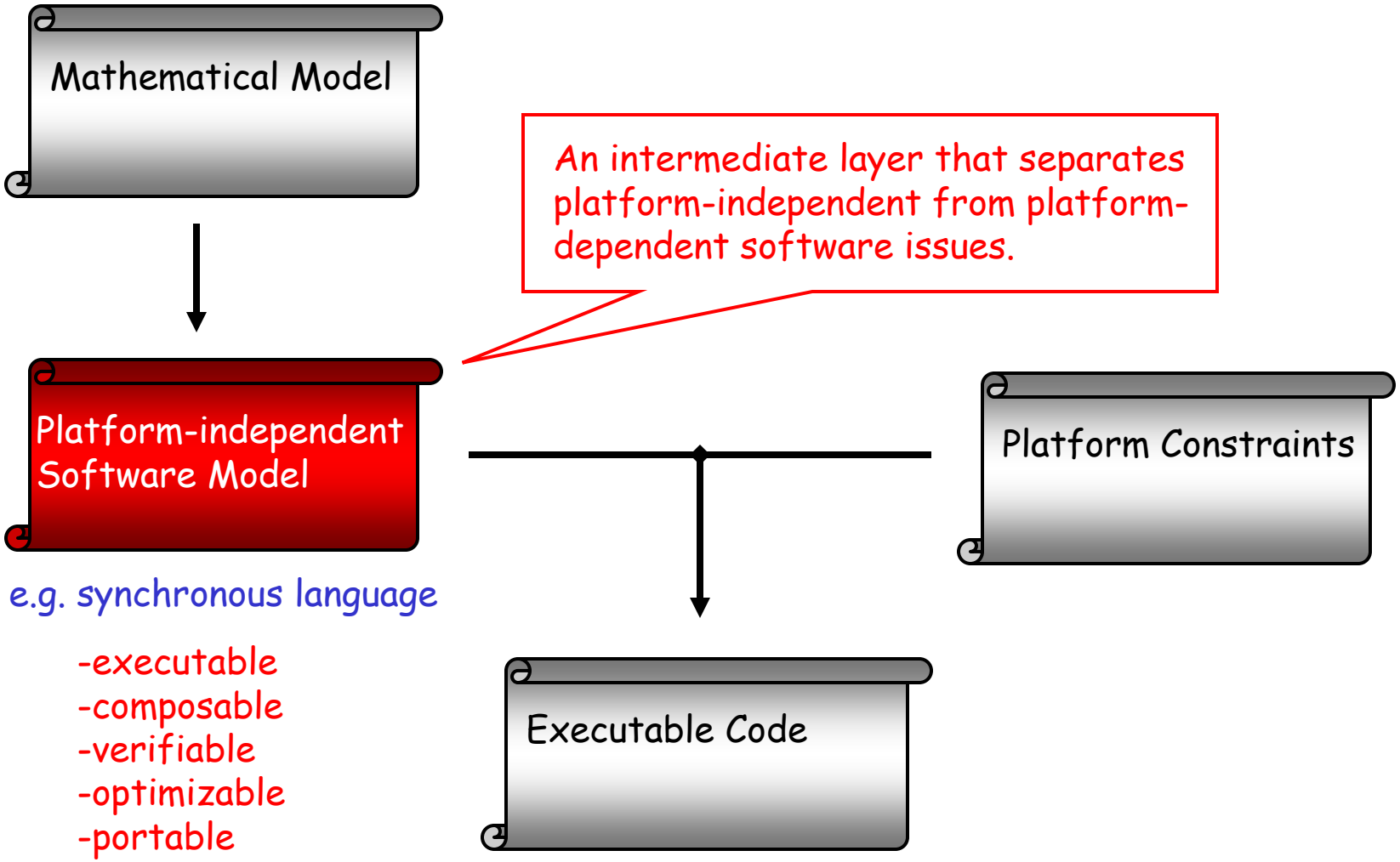

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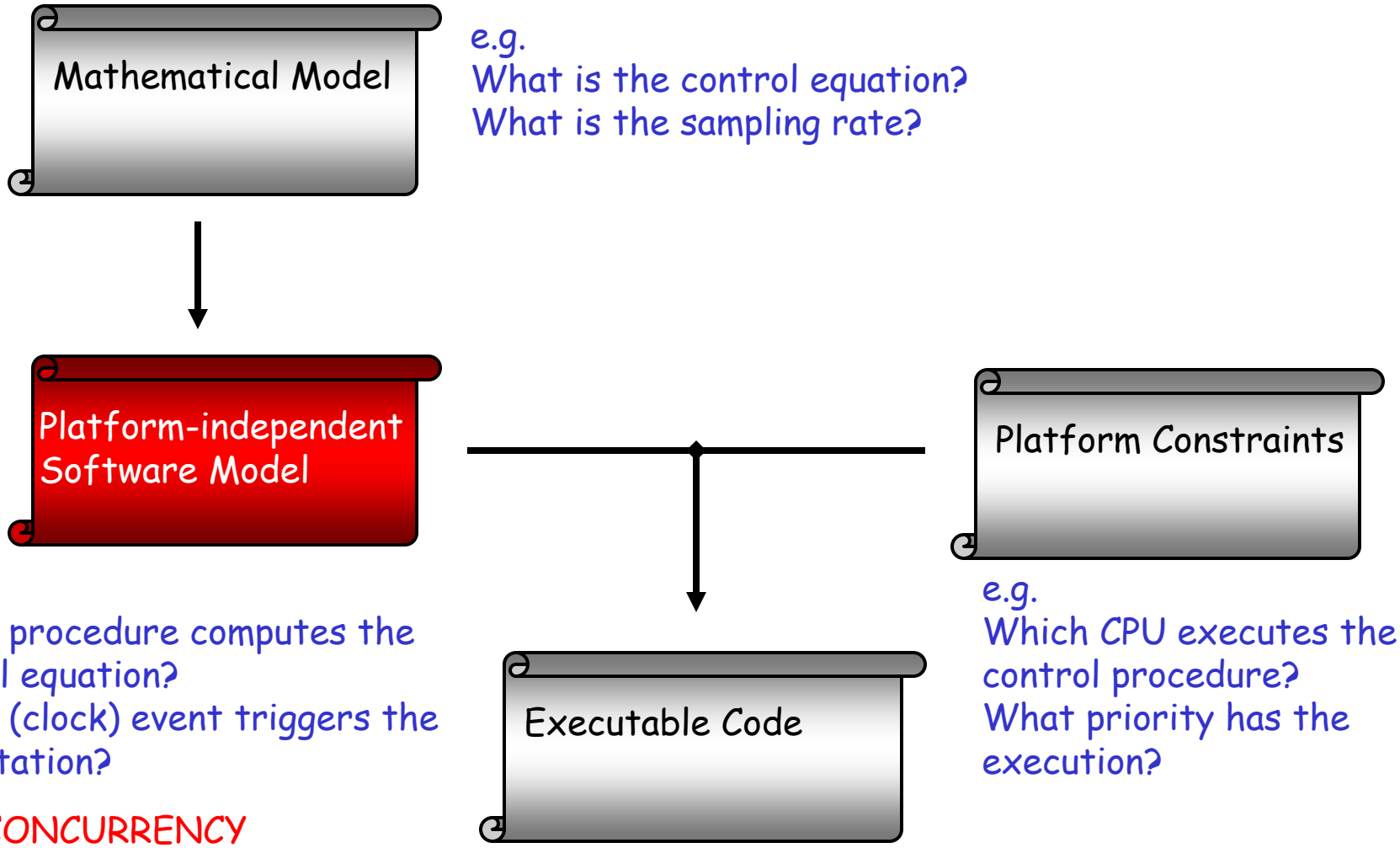
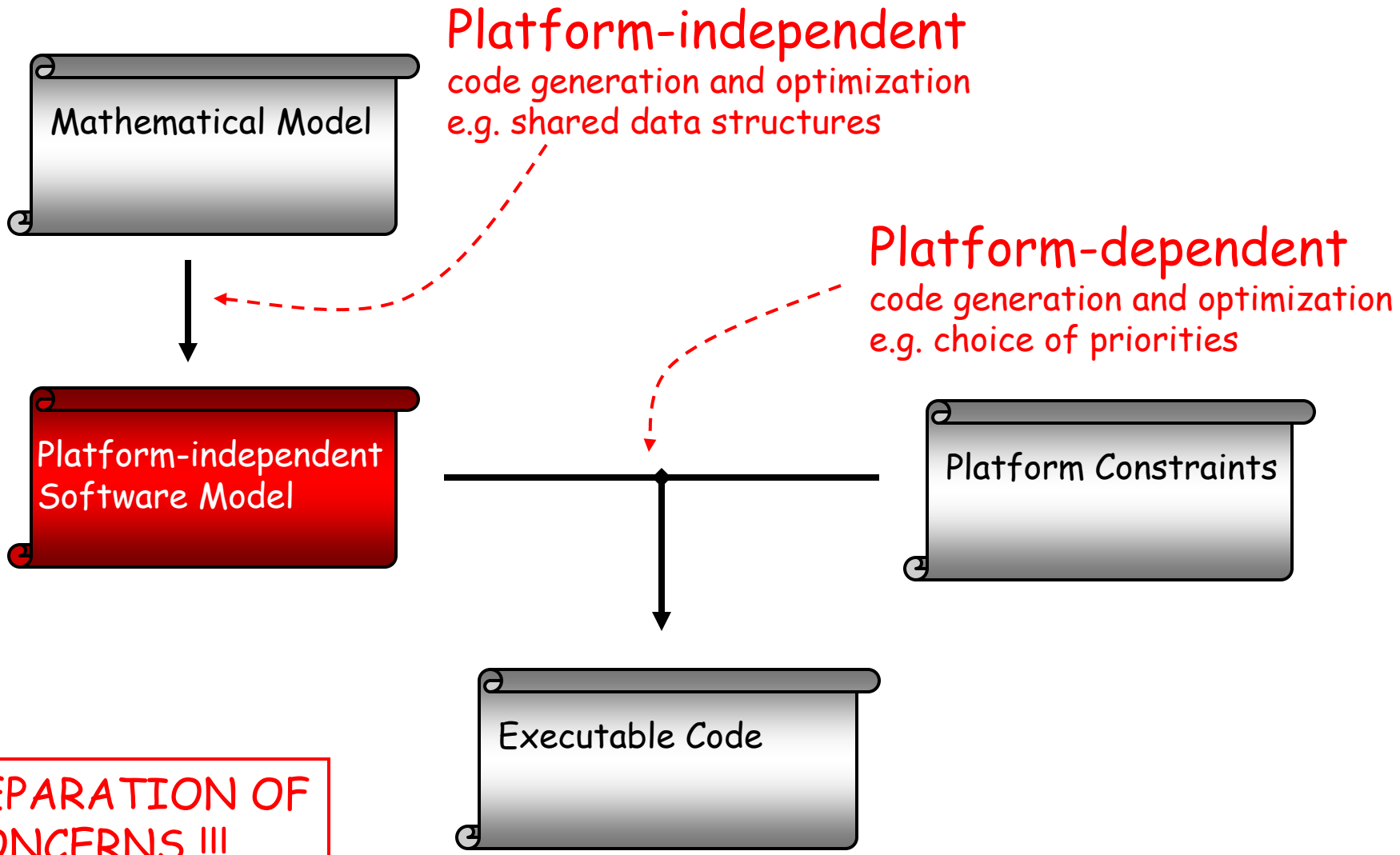


Control Software Development



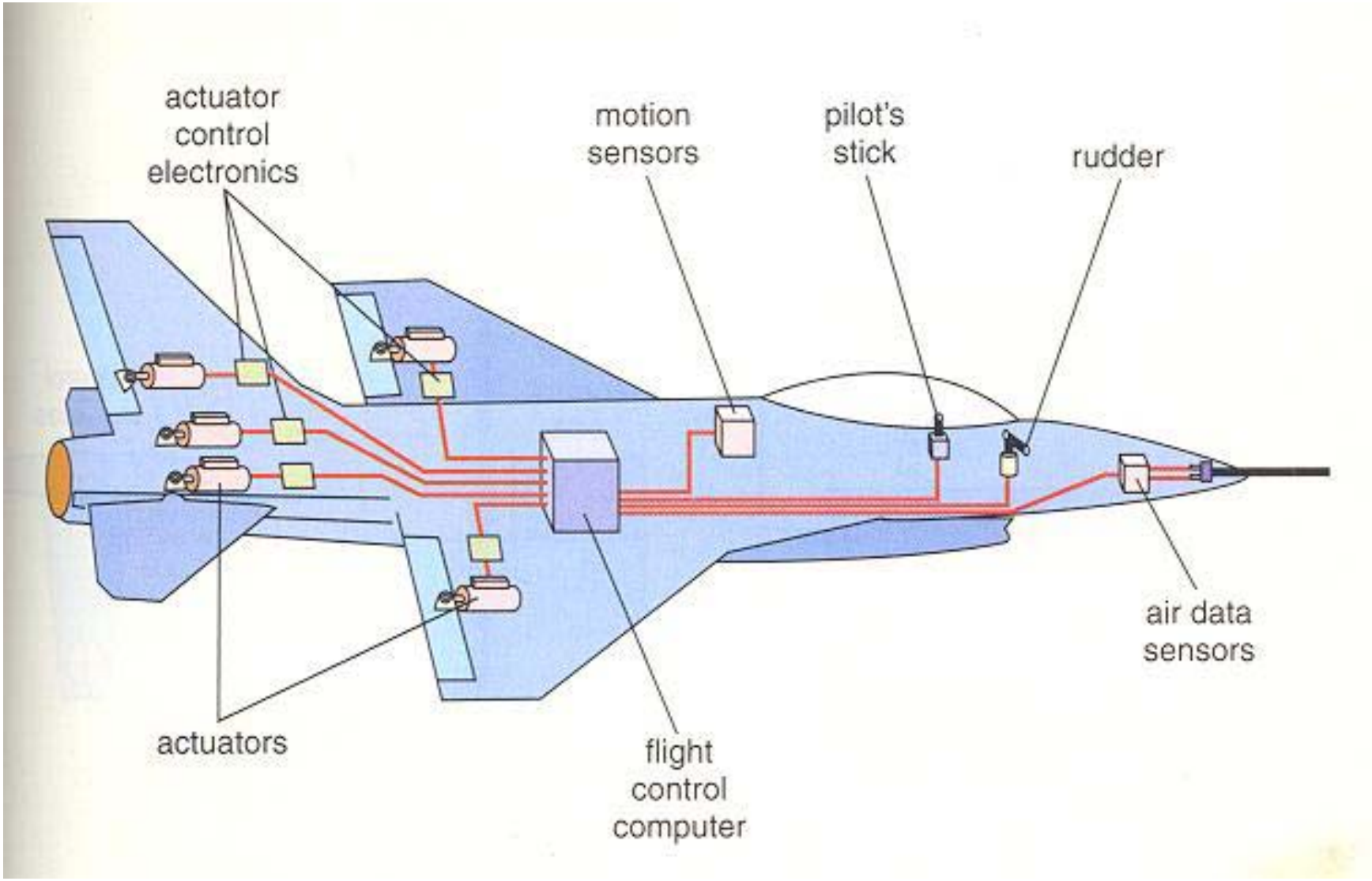
Motivation: Flight Control Software

Single CPU.

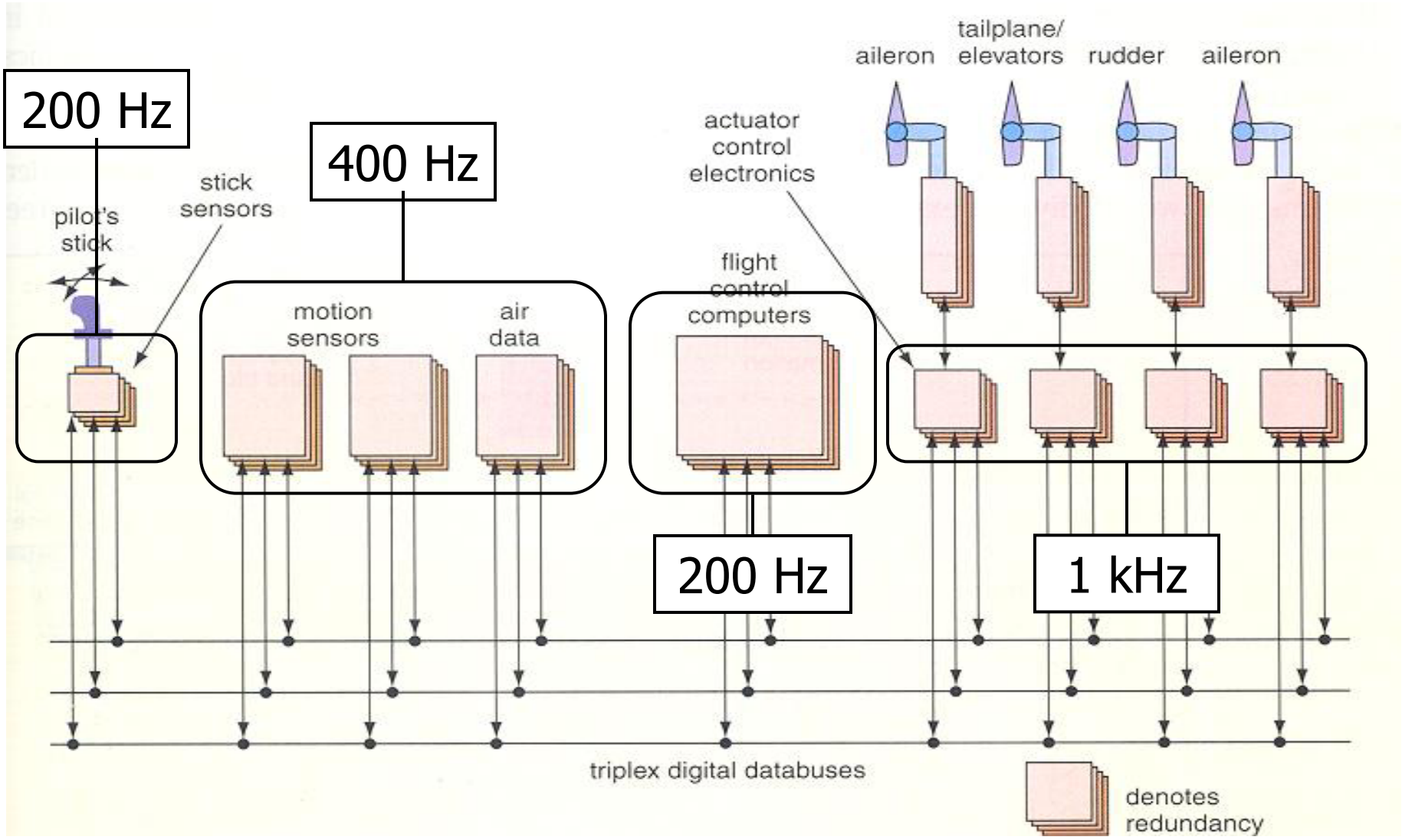
Motivation: Flight Control Software

Two or three connected CPUs.

Motivation: Flight Control Software



Motivation: Flight Control Software



Platform-independent Software Model

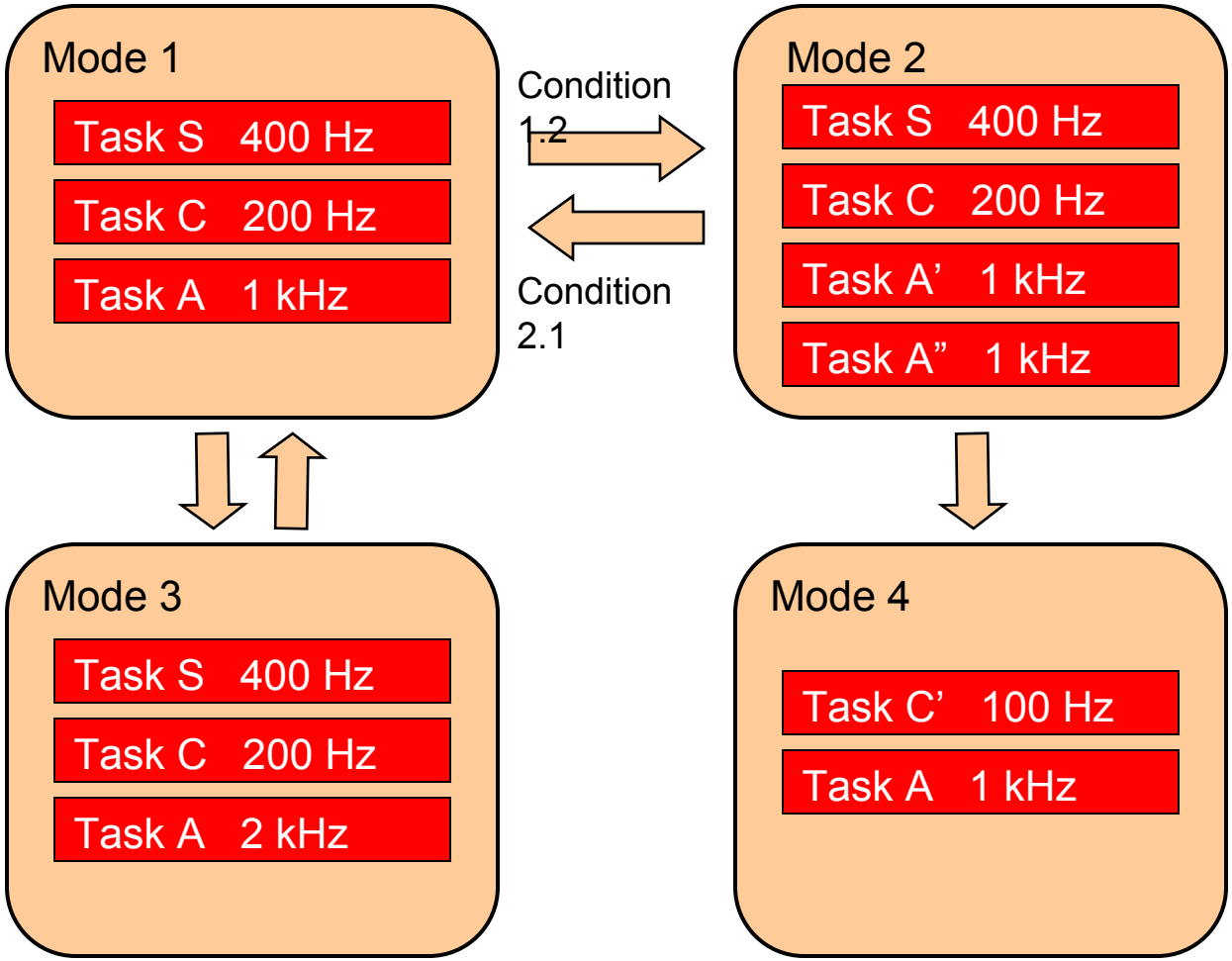
1. Concurrent periodic tasks:

-sensing
-control law computation
-actuating

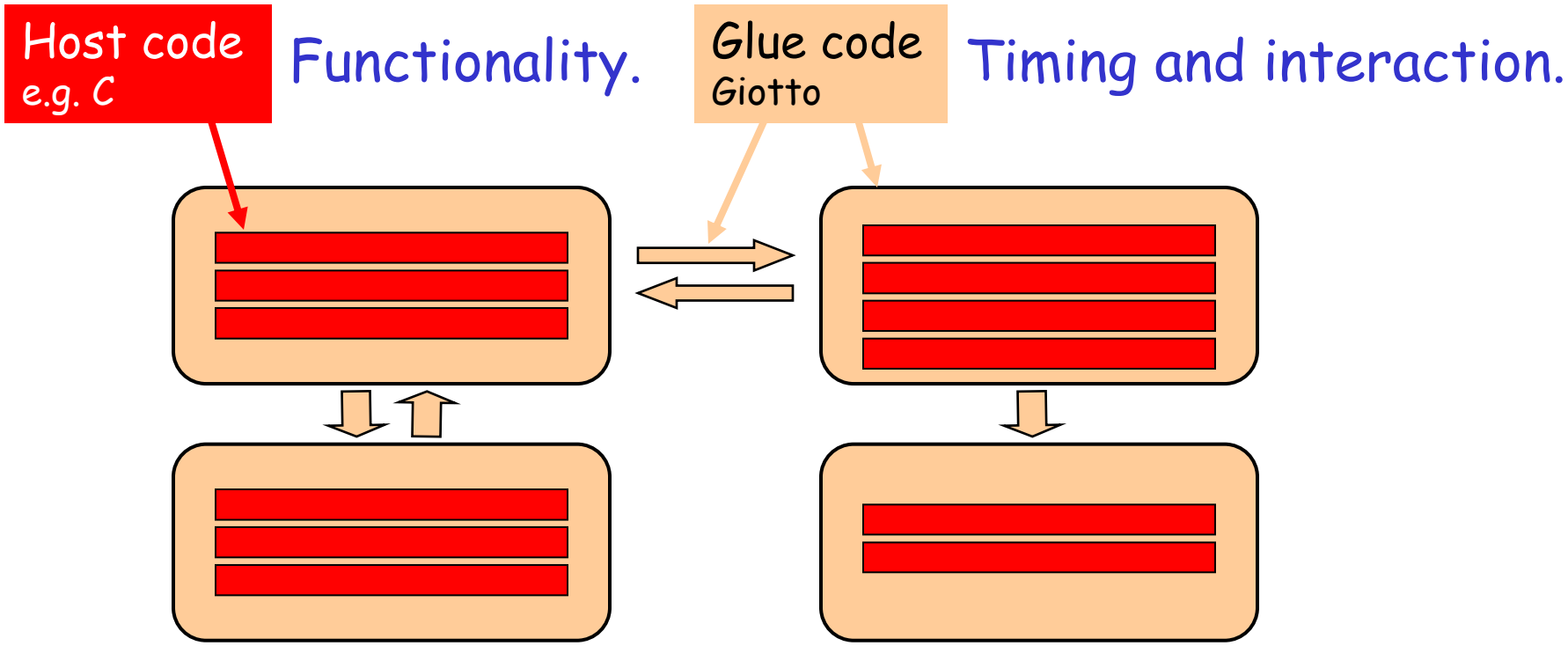
2. Multiple modes of operation:

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

Platform-independent Software Model

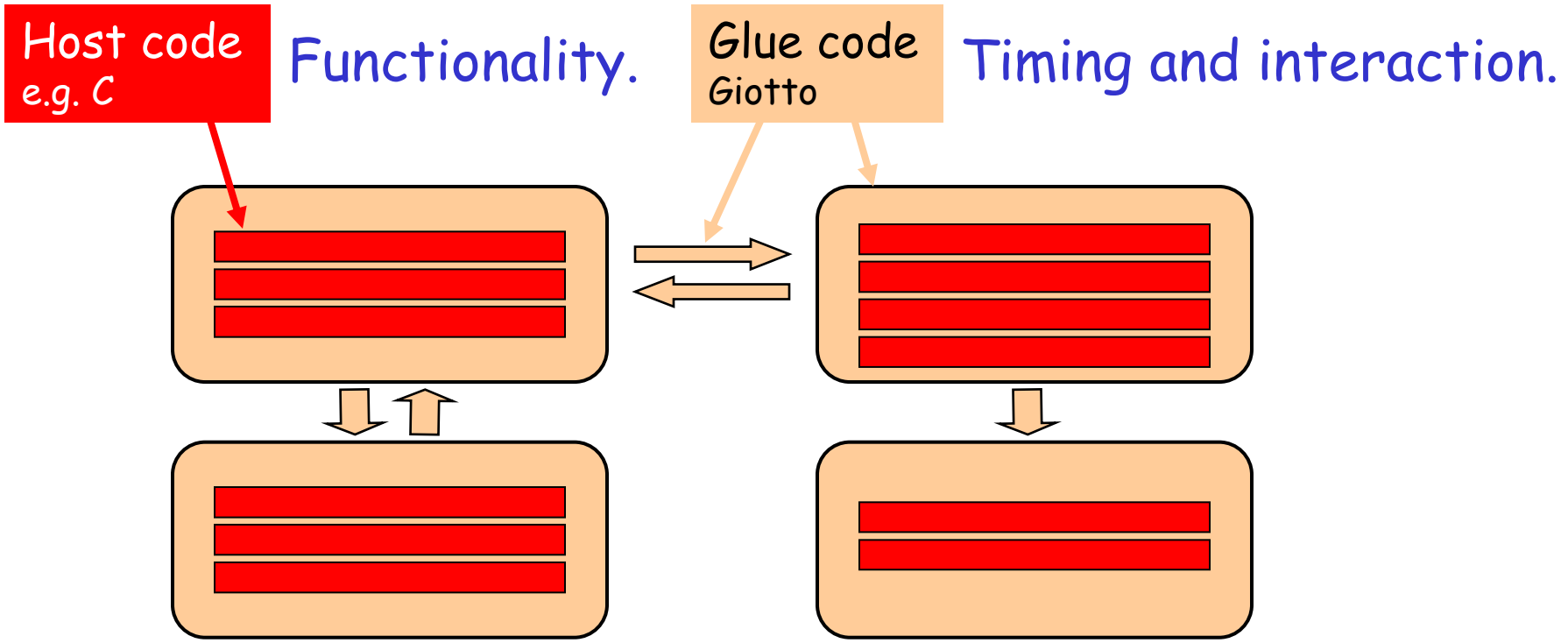


Platform-independent Software Model



-Concurrency,
not distribution.
-Environment time,
not platform time.

Platform-independent Software Model



This kind of software is understood:

Host code may be generated automatically.

The software complexity lies in the glue code:

Giotto enables requirements-driven rather than platform-driven glue-code programming.

The Giotto Programmer's Model

Programming in terms of environment time:

-time-triggered task invocation
-tasks have fixed duration ($\geq$ WCET)
-tasks are not preemptable

Implementation in terms of platform time:

-need access to (logical) global time,
no other platform requirements
-tasks may finish early,
but outputs cannot be observed early
-tasks may be preempted

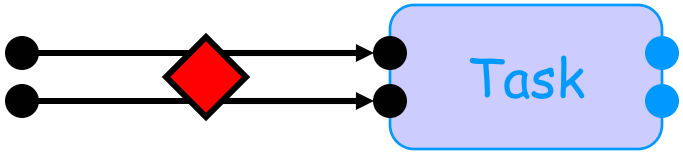
Similar to the synchronous programmer's model,
only simpler (no fixpoint issues).

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

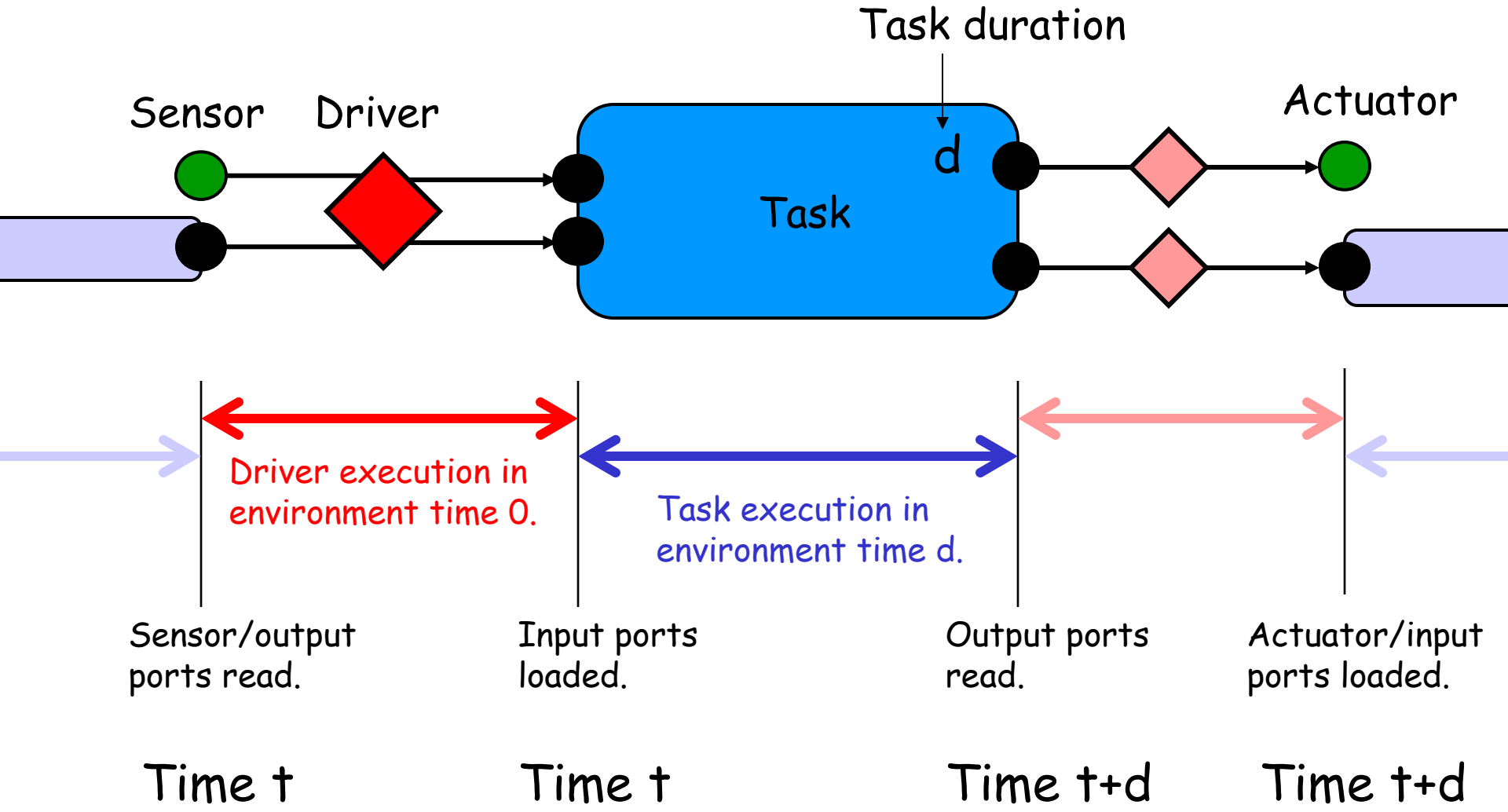


Task driver loads
task input ports.

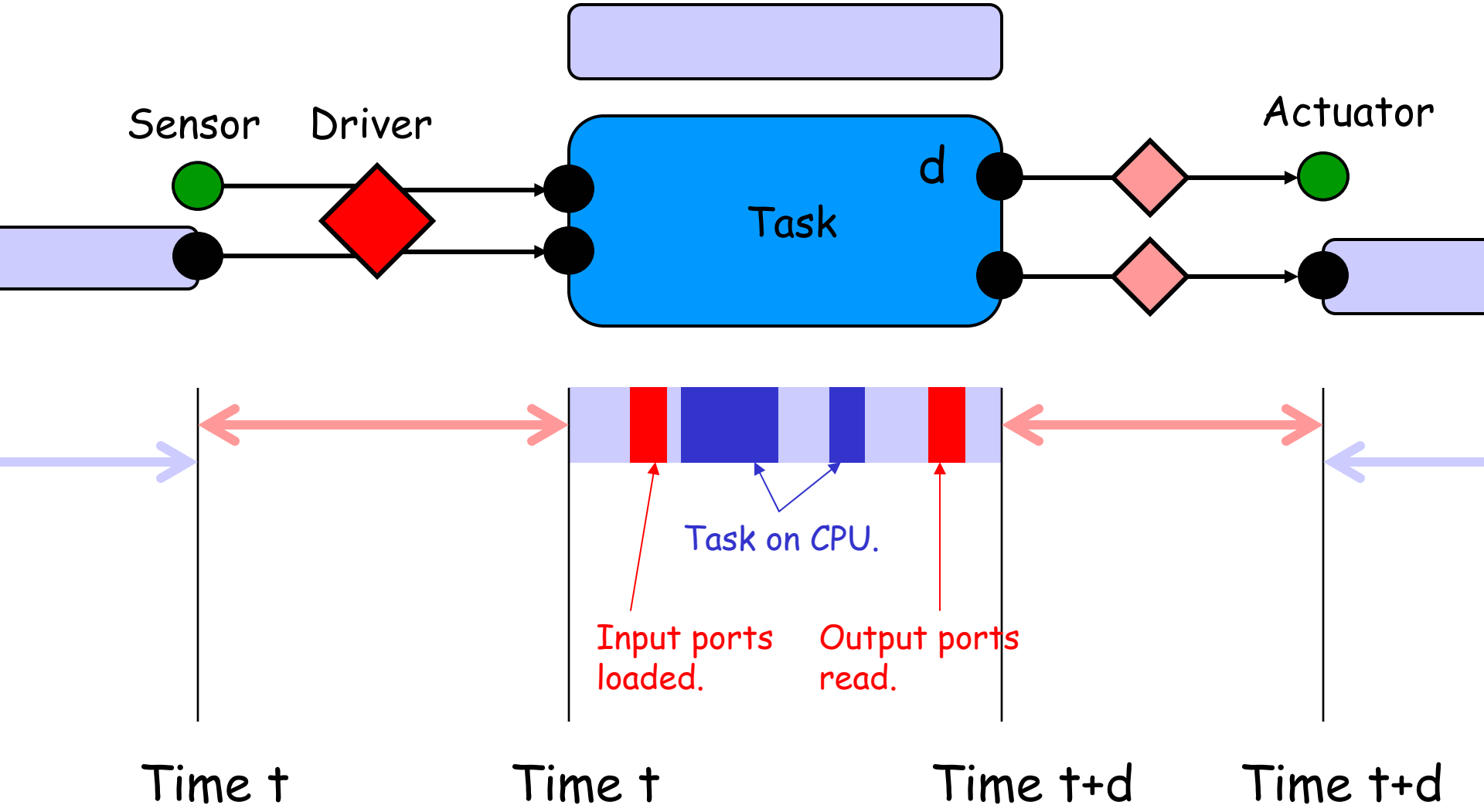
3. Real-time requirements and data flow between tasks.

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

Environment Timeline (defined by Giotto semantics)



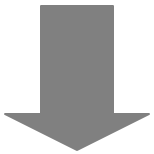
Platform Timeline (chosen by Giotto compiler)



Platform Independence ensures Predictability

Input Determinism:

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

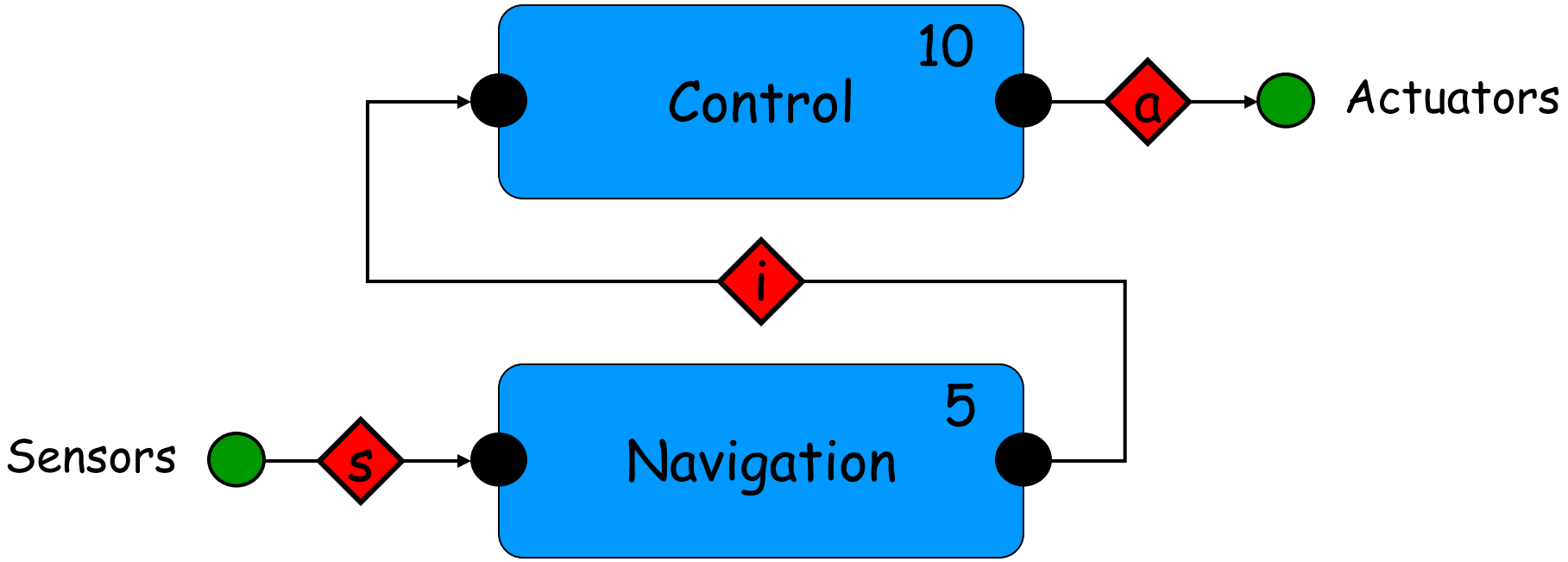


implies

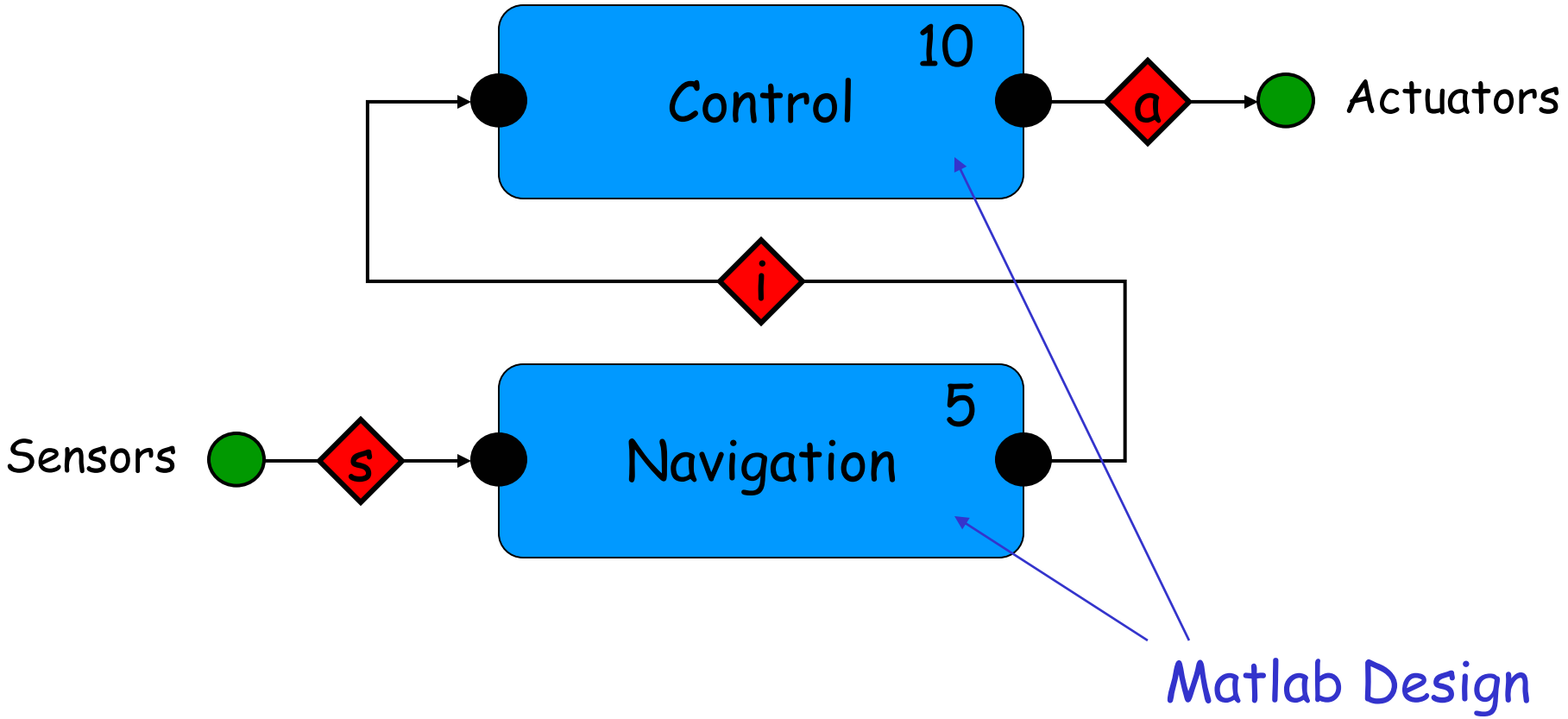
Time Determinism:

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

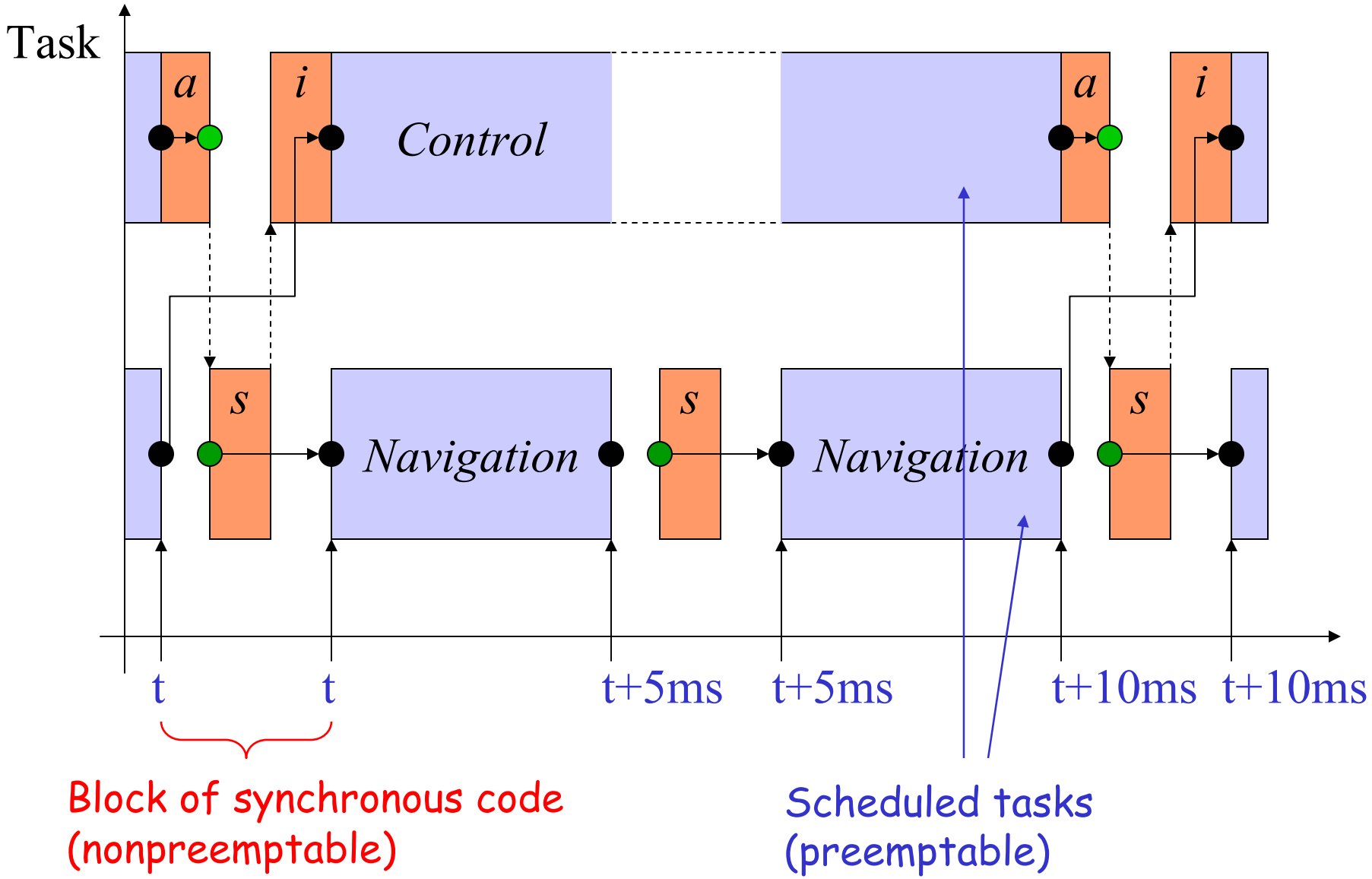
Helicopter Software



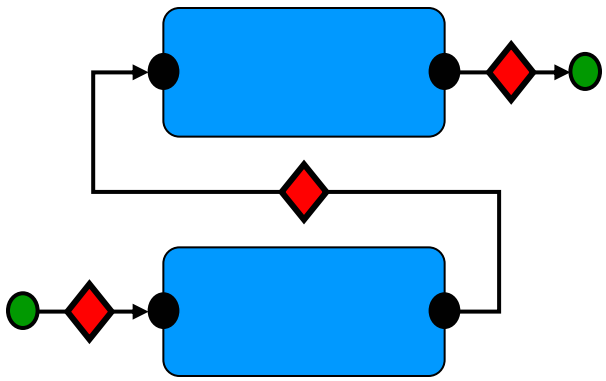
Helicopter Software



Helicopter Software: Environment Timeline

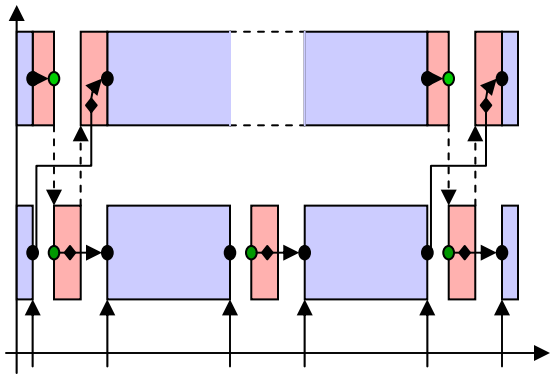


Helicopter Software: Giotto Syntax (Functionality)



```
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 ) ;
  }
...
```

The Giotto Compiler

Functionality — Native Code — for tasks and drivers

Timing Interaction — Giotto Program

Hardware — Giotto-H — hardware specification

-topology (CPUs, nets)
-performance (WCET, latency)

Giotto Compiler

Executables

or

"Failure"

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

Closing the Gap: Annotated Giotto

Functionality — Native Code — for tasks and drivers

Timing, Interaction — Giotto Program

Hardware — Giotto-H
- -topology (CPUs, nets)
- -performance (WCET, latency)

Map — Giotto-HM
- -assign tasks to CPUs
- -assign connections to nets

Giotto Compiler

Executables

or

"Failure"

either Giotto-HM overconstrained, or compiler not smart enough (local scheduling problems)

Closing the Gap: Annotated Giotto

Functionality	Native Code	for tasks and drivers
Timing Interaction	Giotto Program	
Hardware	Giotto-H	-topology (CPUs, nets) -performance (WCET, latency)
Map	Giotto-HM	-assign tasks to CPUs -assign connections to nets
Schedule	Giotto-HMS	-assign tasks to priorities (say) -assign connections to TDMA slots (say)

Giotto Compiler

Executables

or

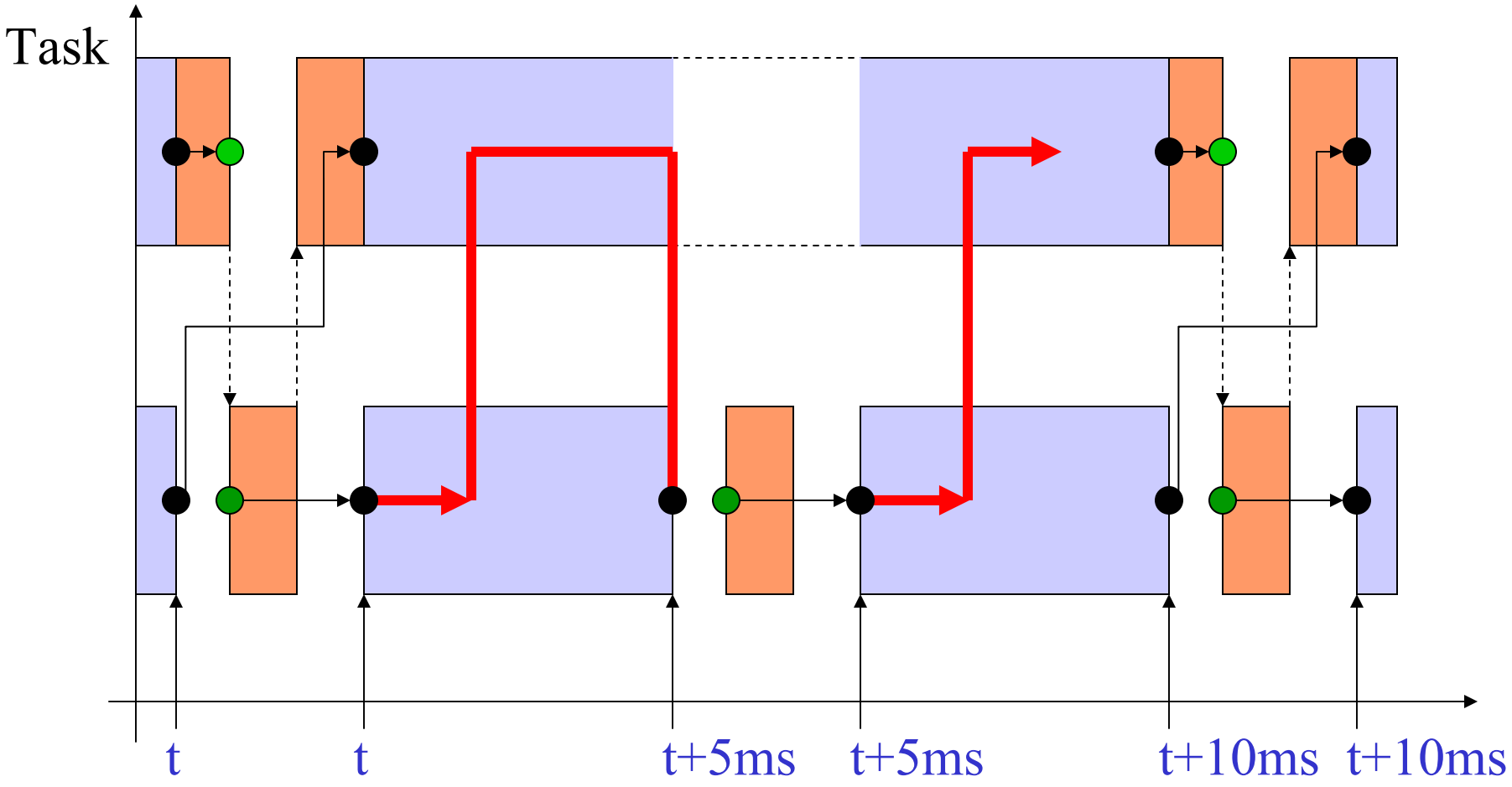
"Failure"

Giotto-HMS overconstrained

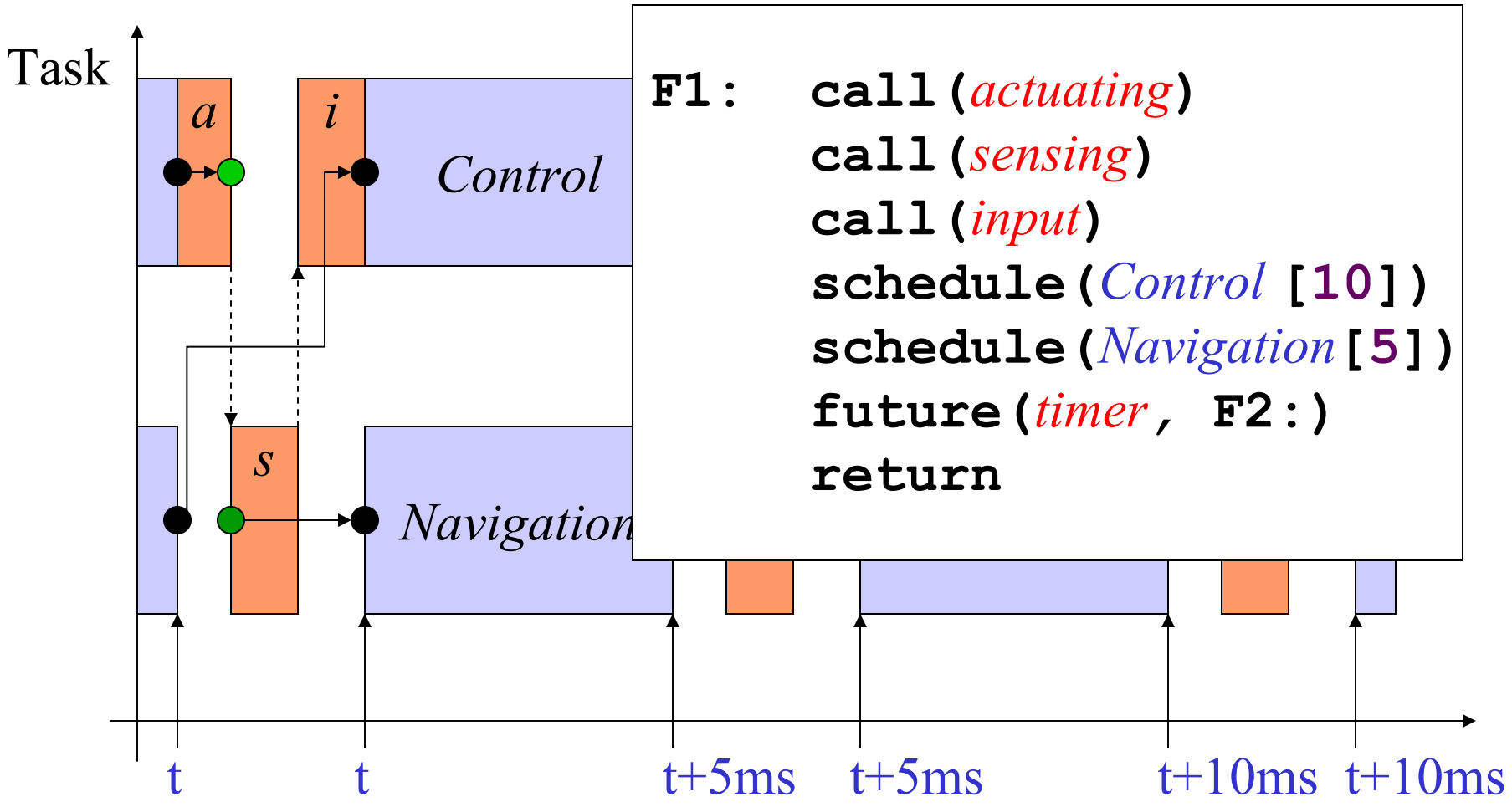
Single-CPU Helicopter: Annotated Giotto

```
[ host Heli address 192.168.0.1 ]  // Giotto-H Annotation
…
mode Flight ( ) period 10ms
  {
      actfreq 1 do Actuator ( actuating ) ;

      taskfreq 1 do Control ( input ) [ host Heli deadline 10 ] ;  // Giotto-MS
      taskfreq 2 do Navigation ( sensing ) [host Heli deadline 5 ] ;
  }
…
```

Single-CPU Helicopter: Platform Timeline (EDF)

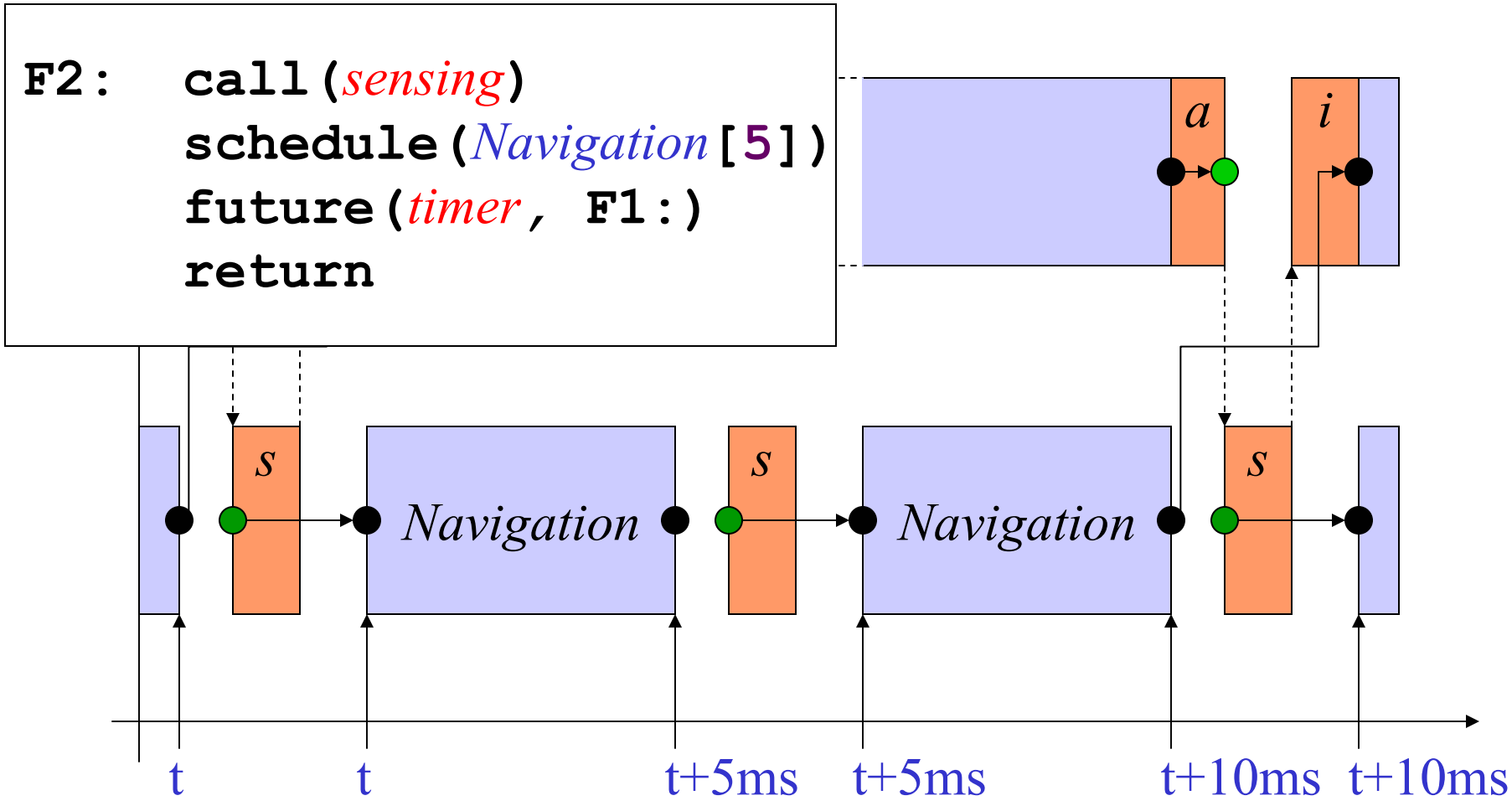


Code Generation



Code Generation

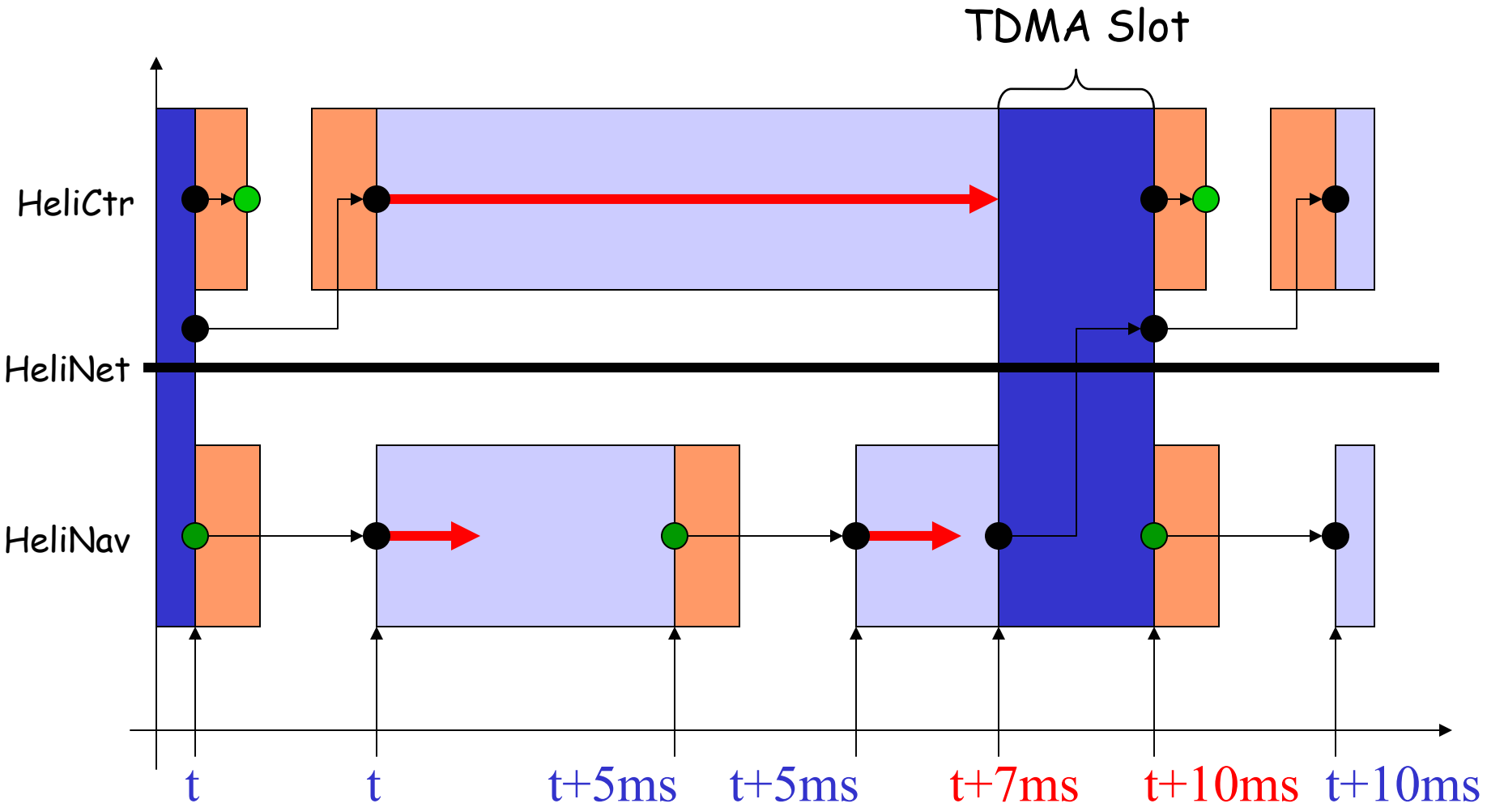
```
F2:   call(sensing)
      schedule(Navigation[5])
      future(timer, F1:)
      return
```



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

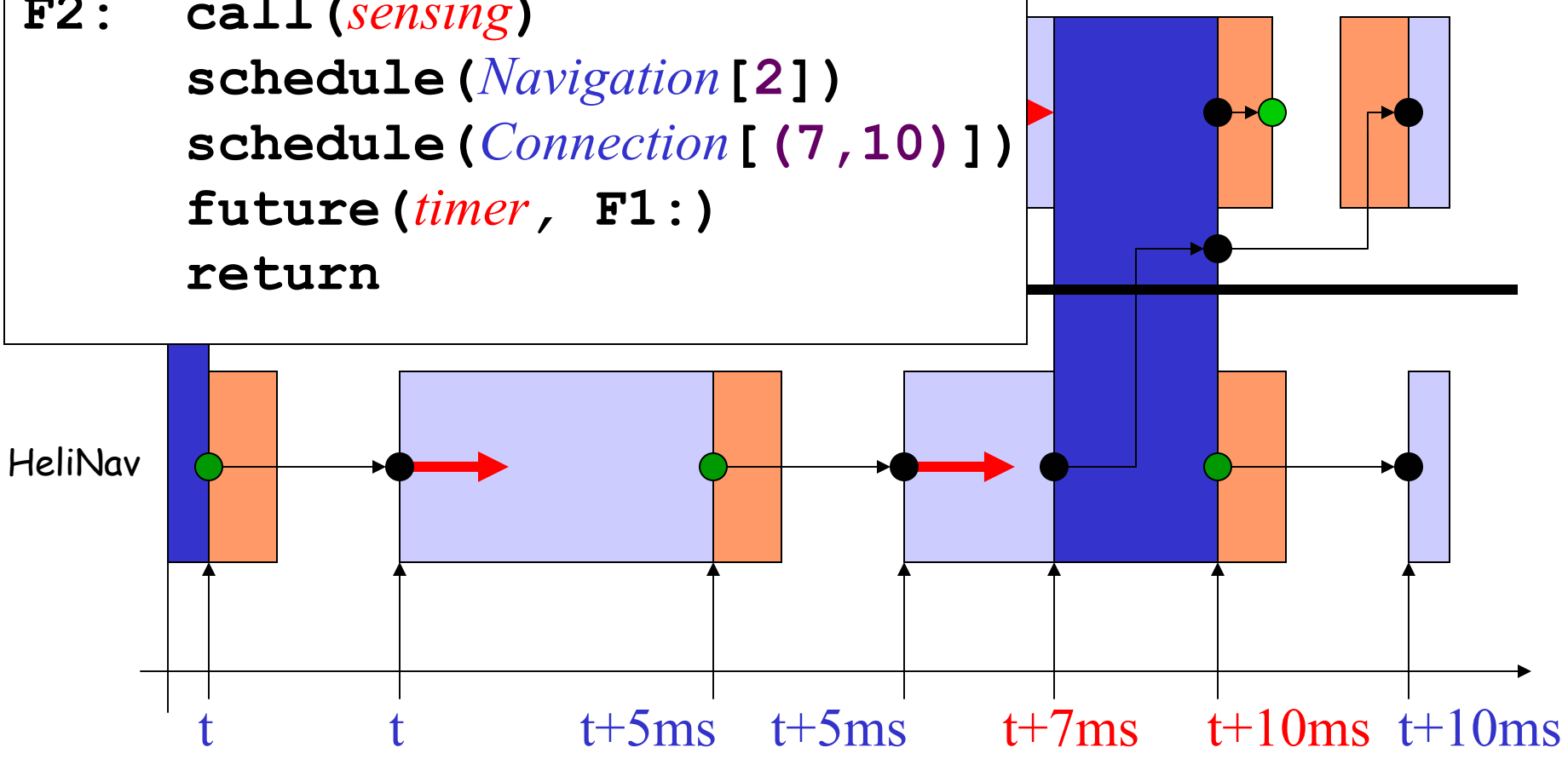
```
[ host HeliCtr address 192.168.0.1;
  host HeliNav address 192.168.0.2;
  network HeliNet address 192.168.0.0 connects HeliCtr, HeliNav ]
…
mode Flight ( ) period 10ms
   {
       actfreq 1 do Actuator ( actuating ) ;

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

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



Code Generation for HeliNav

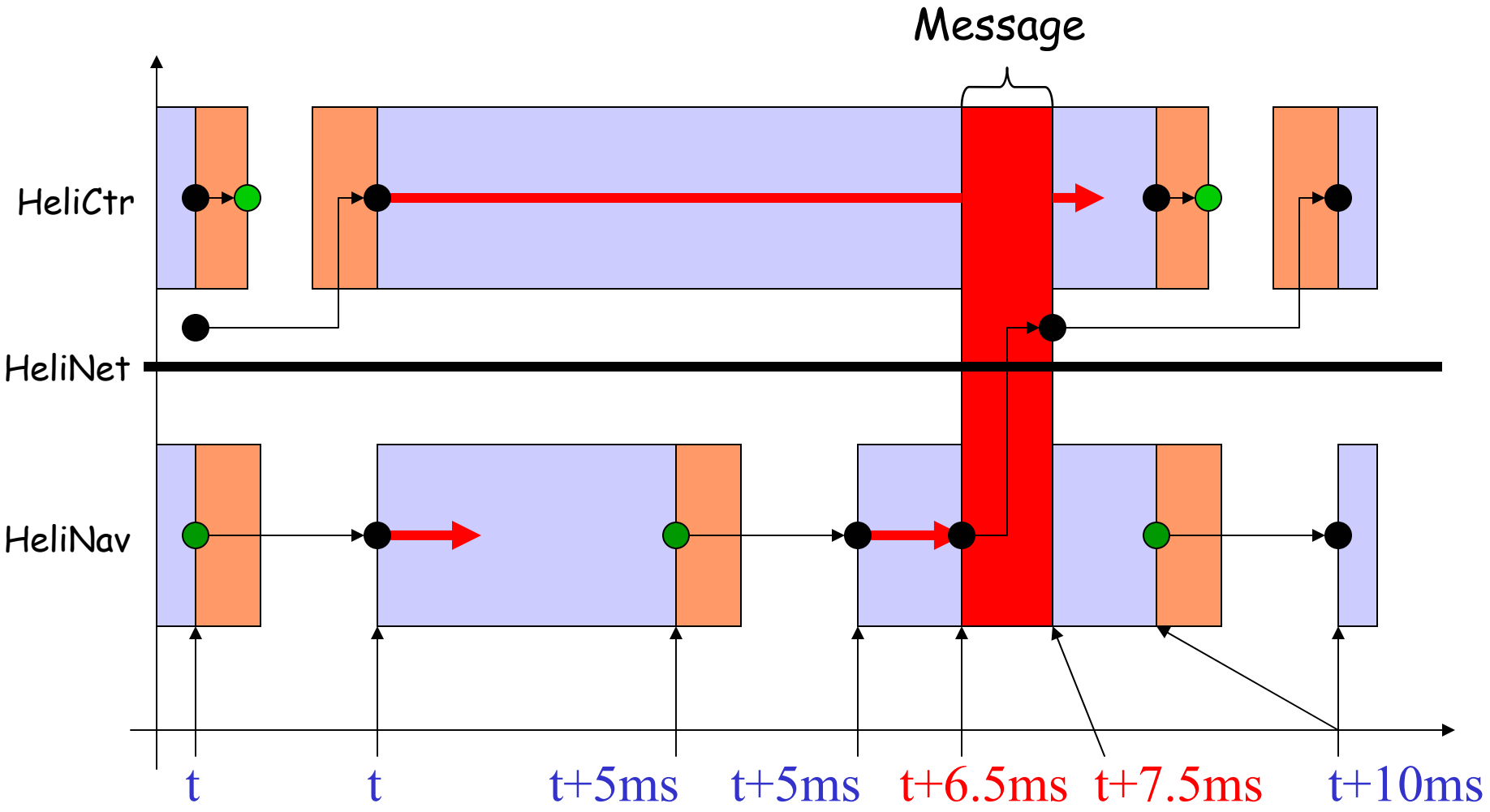
```
F2:   call(sensing)
      schedule(Navigation[2])
      schedule(Connection[(7,10)])
      future(timer, F1:)
      return
```



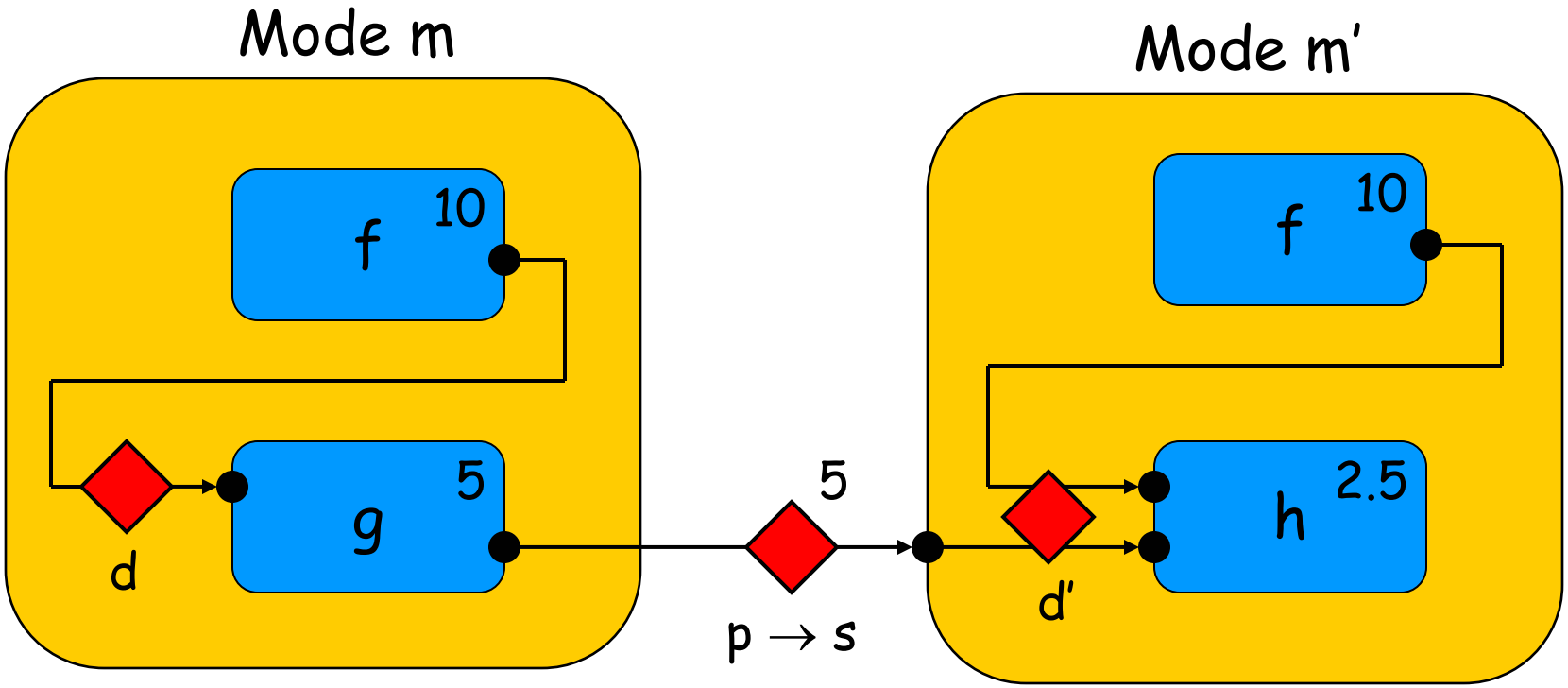
Two-CPU Helicopter: Annotated Giotto (Event-triggered Communication)

```
[ 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 deadline 10 ] ;
      taskfreq 2 do Navigation ( sensing ) [host HeliNav deadline 2;
      push ( NavOutput ) to ( HeliCtr ) in HeliNet deadline 3 ] ;
  }
…
```

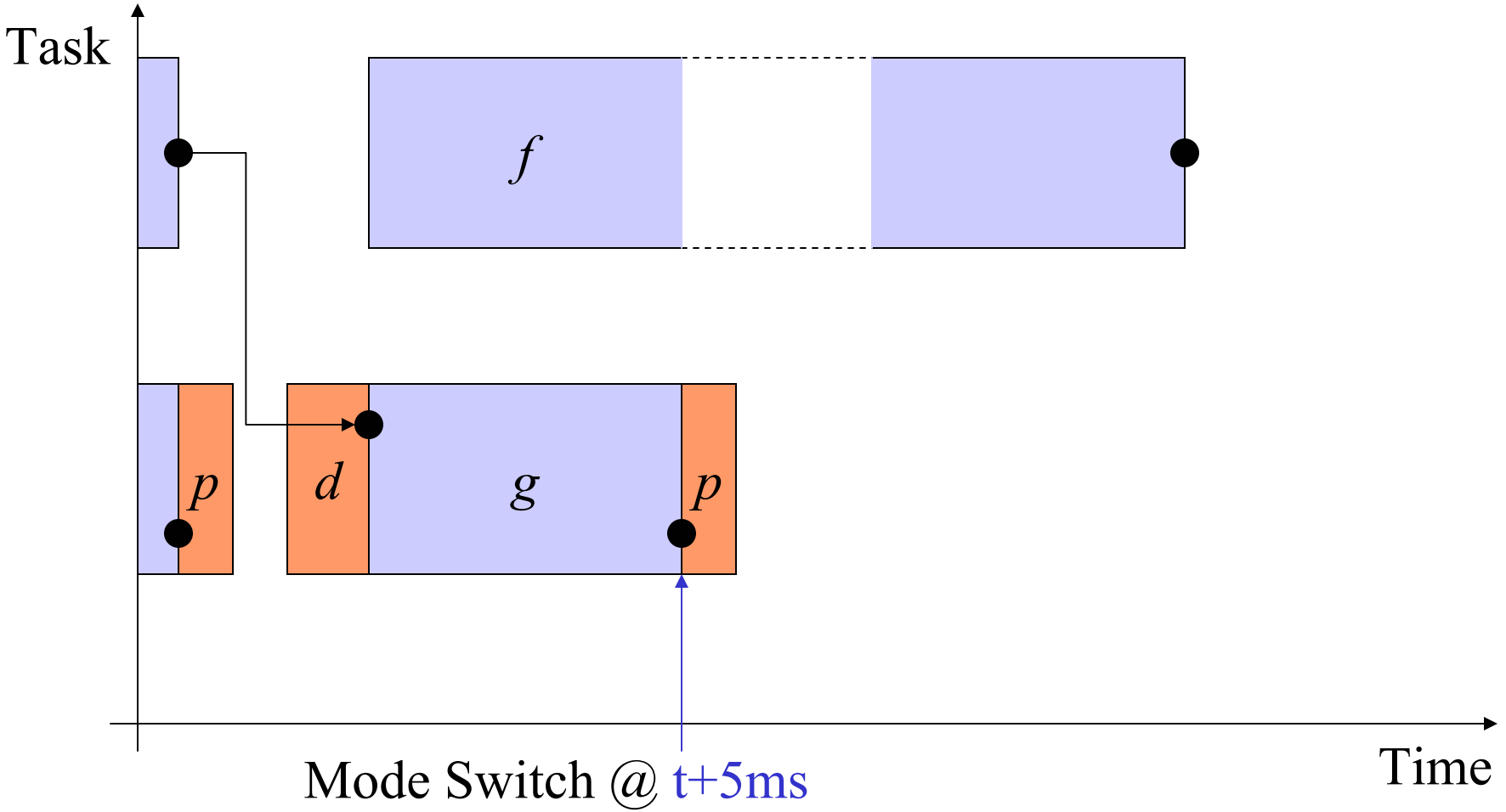
Two-CPU Helicopter: Platform Timeline (Event-triggered Communication)



Mode Switch



Mode Switch: Environment Timeline



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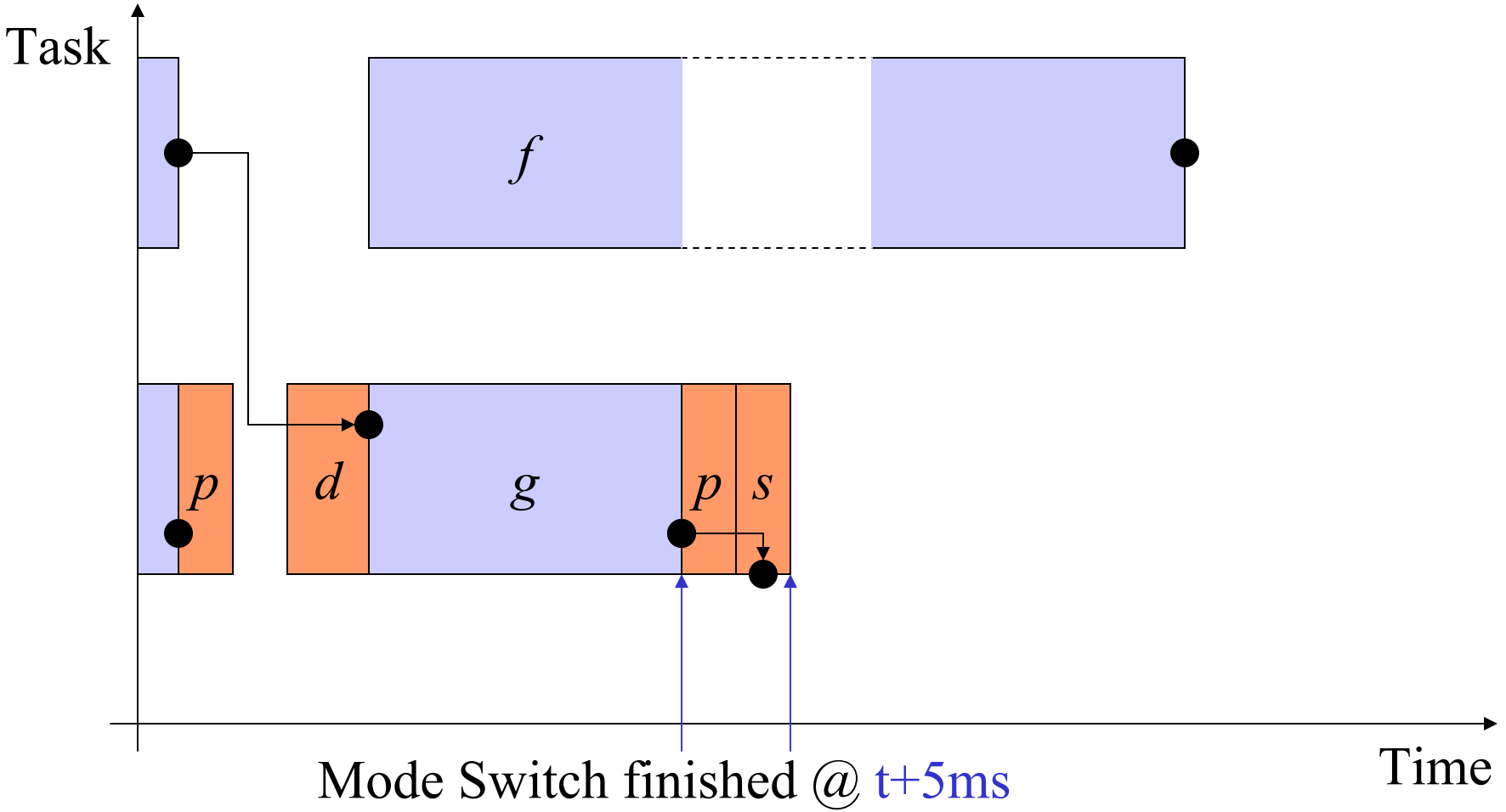

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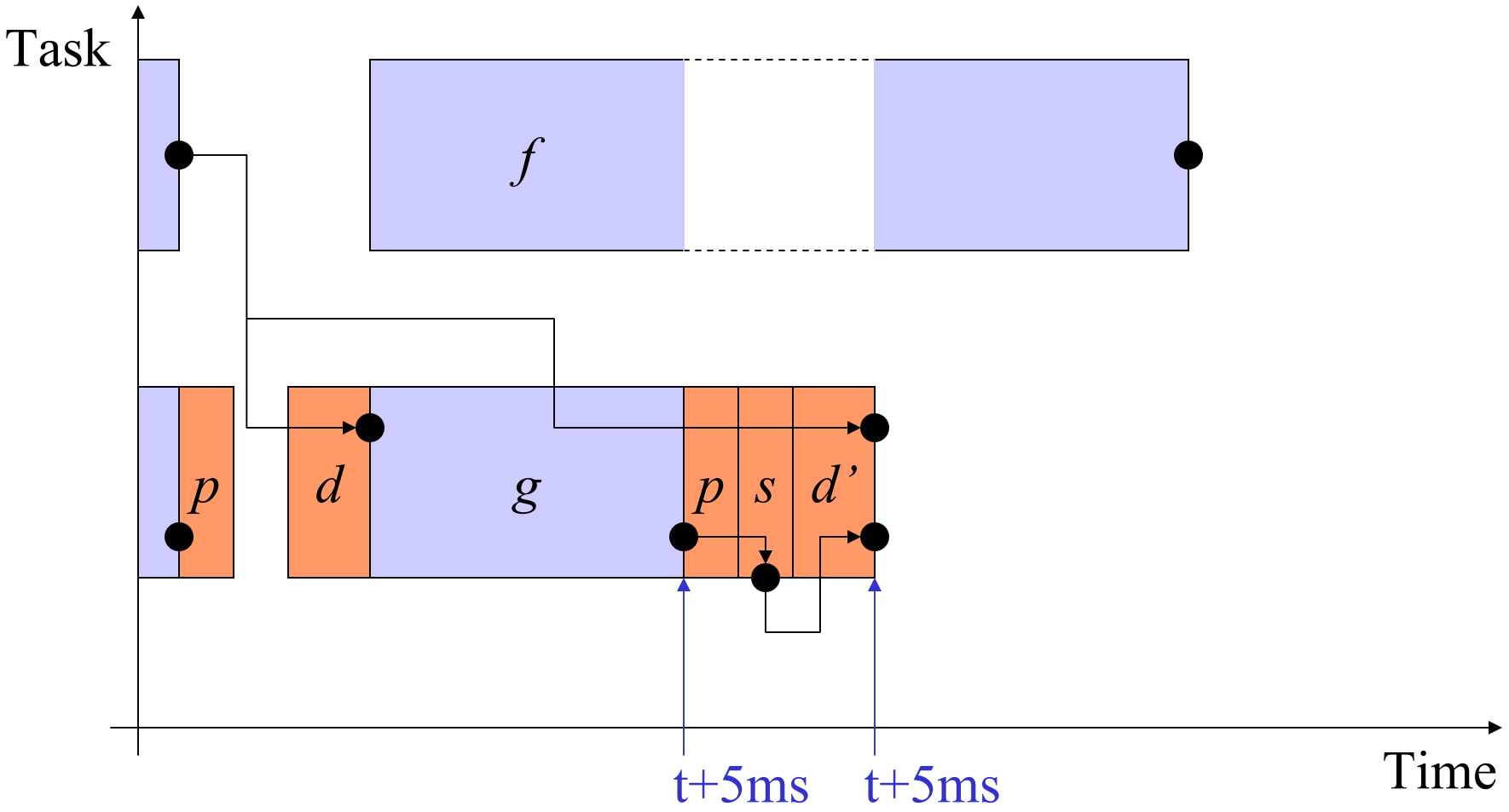

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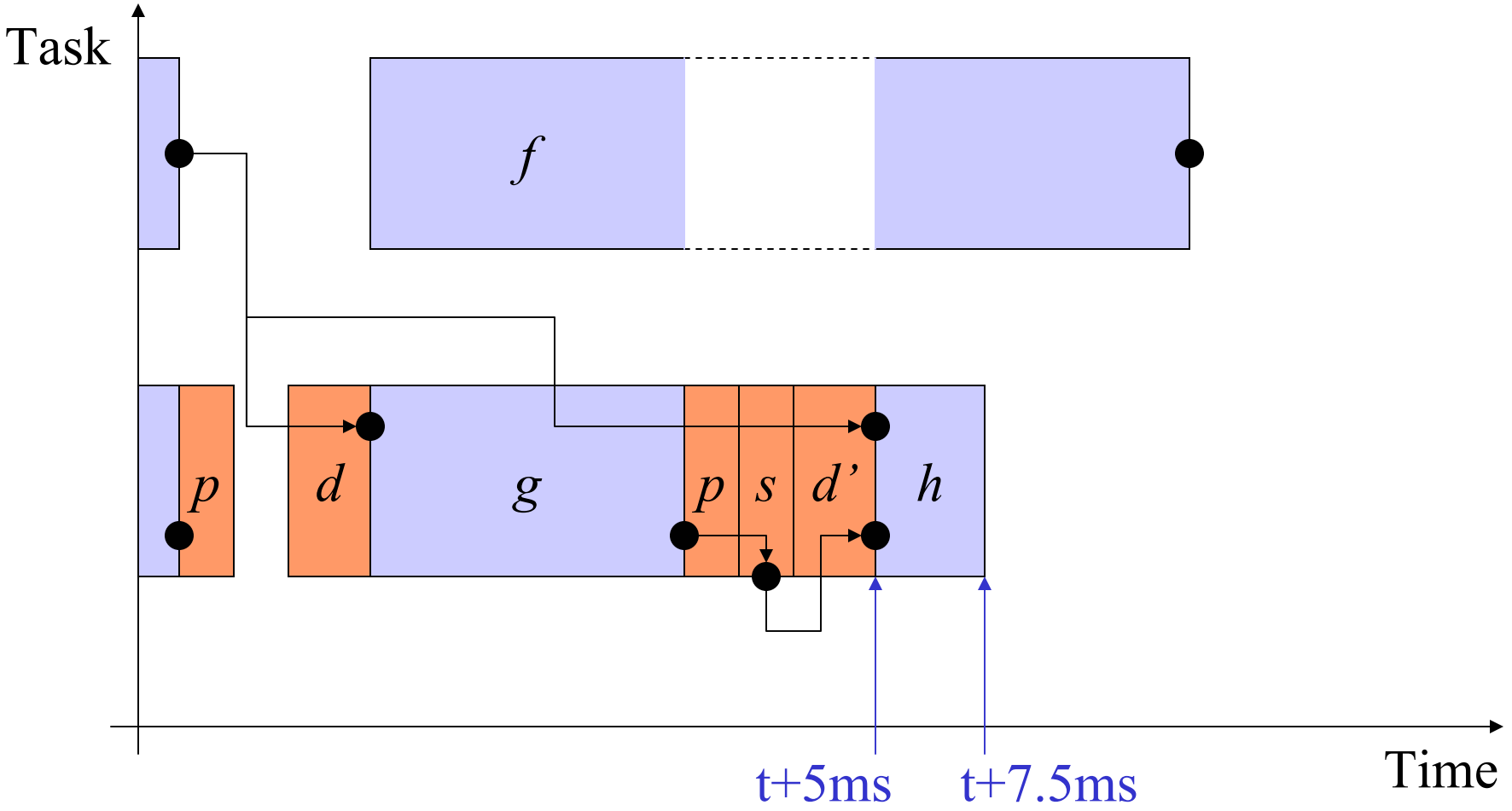

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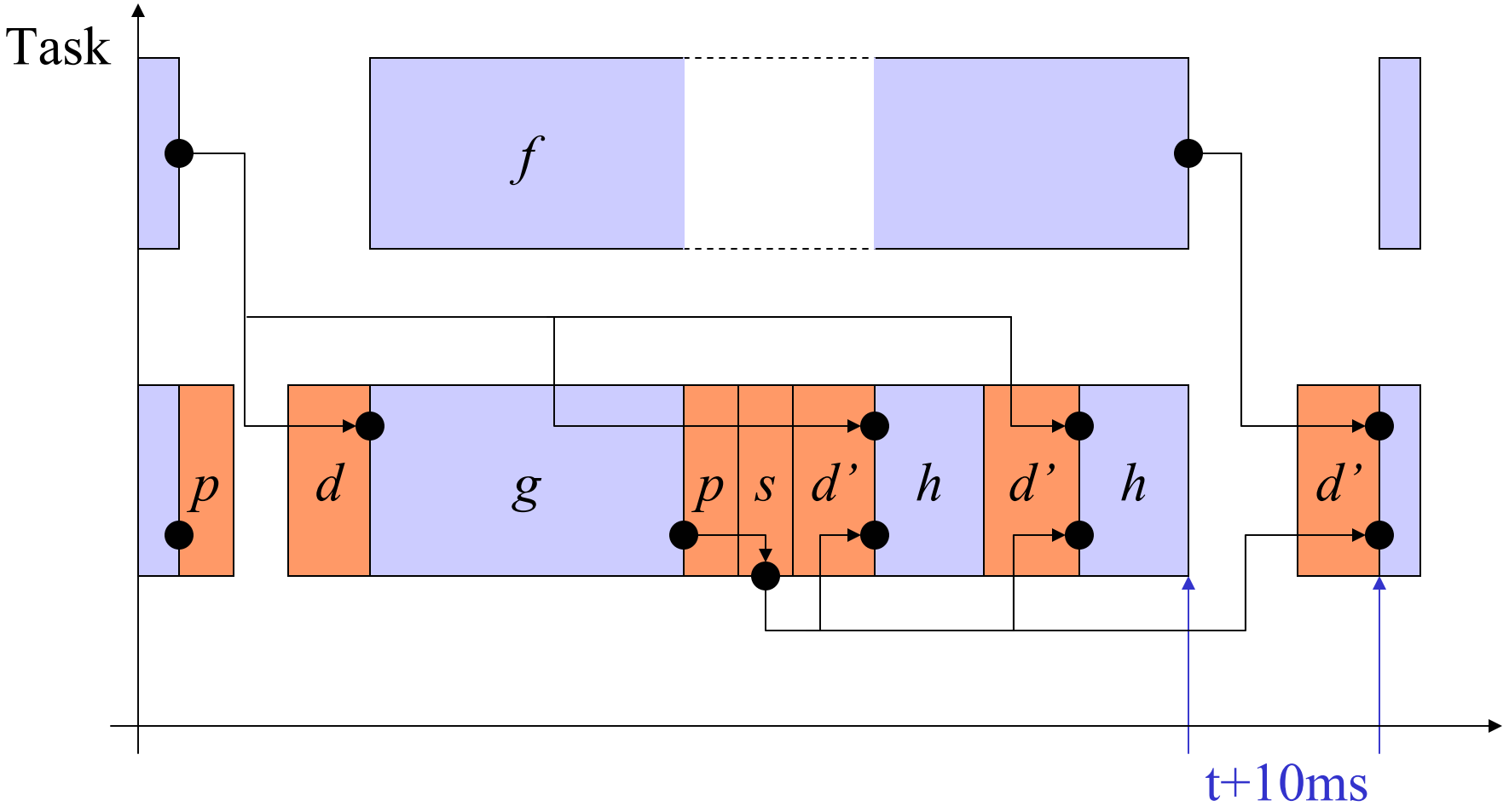

Try it out!

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