Development of hard real-time systems with Giotto and frameworks

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Contents

- Giotto: predictable, reusable real-time code
  - concepts
  - case study: helicopter control system
- Reusable framework components for high-level management tasks

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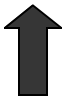
Giotto concepts

The History of Computer Science: Lifting the Level of Abstraction

High-level languages:
Programming to the application

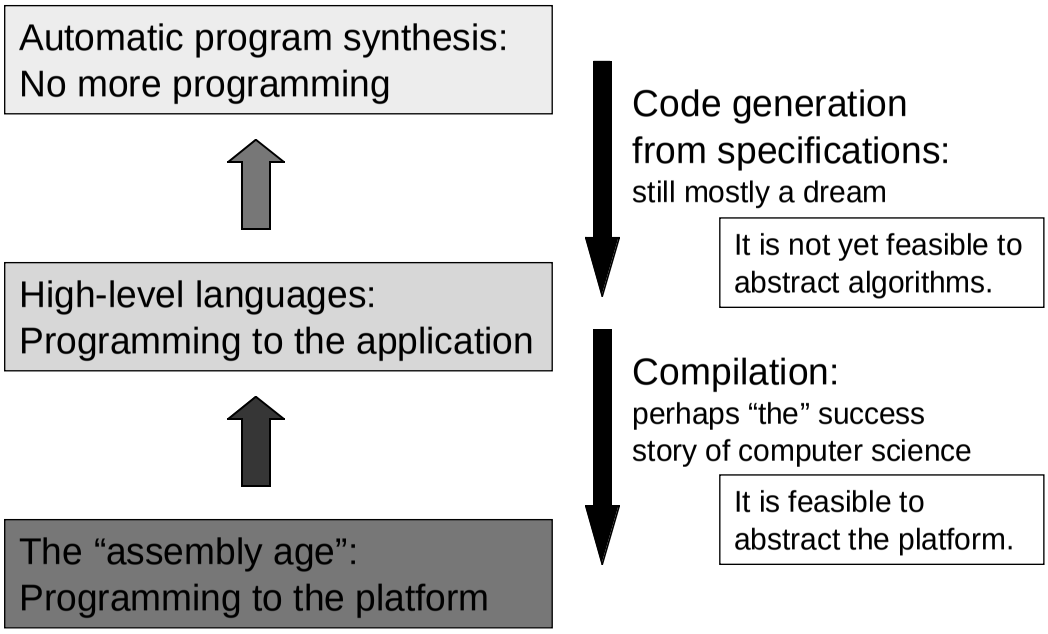


The “assembly age”:
Programming to the platform

Compilation:
perhaps “the” success story of computer science

It is feasible to abstract the platform.

The History of Computer Science: Lifting the Level of Abstraction



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Current Practice in Control Software

Some automatic
code generation from models

-often inefficient
-often unpredictable

Some manual
programming to the platform

-difficult to reuse
-difficult to verify
-requires systems experts

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Current Practice in Control Software

Some automatic
code generation from models

-often inefficient
-often unpredictable

The missing link:
platform-independent software

Some manual
programming to the platform

-difficult to reuse
-difficult to verify
-requires systems experts

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Advocated Practice in Control Software

Mathematical model
e.g. Simulink, HyTech

Control engineer

Platform-independent software
e.g. Giotto

Compiler

Executable code
for a specific platform

-verifiable
-reusable
-efficiently implementable

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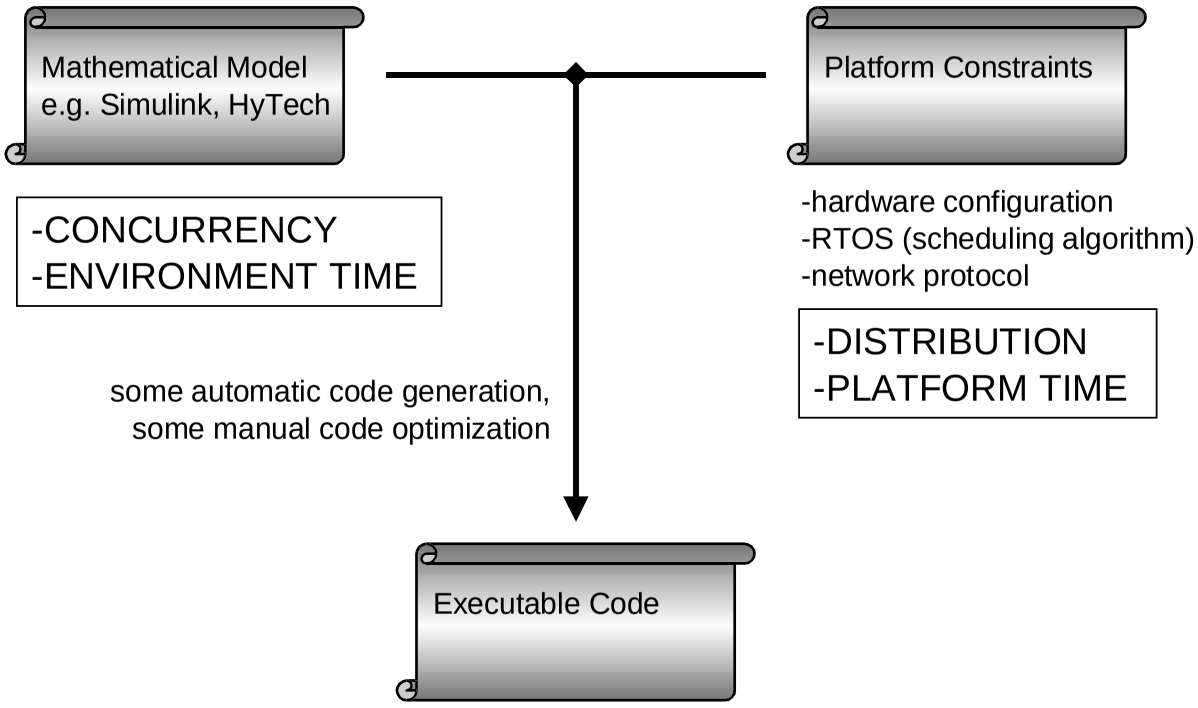
Current Control Software Development



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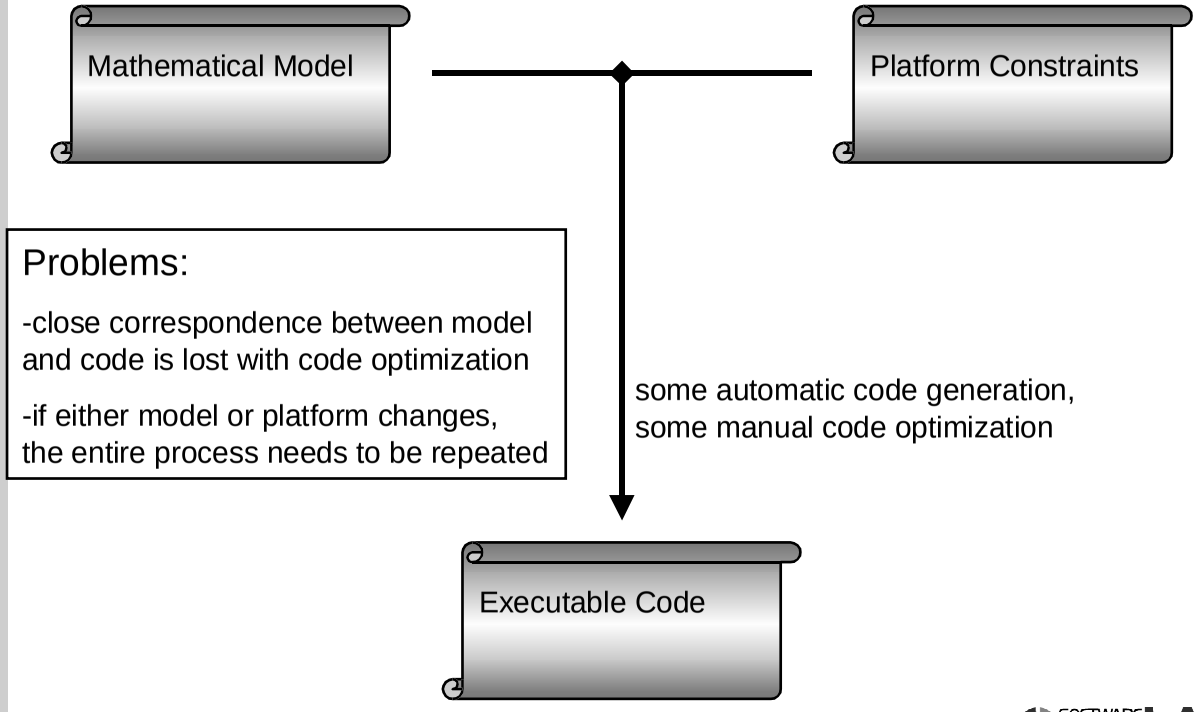
Current Control Software Development



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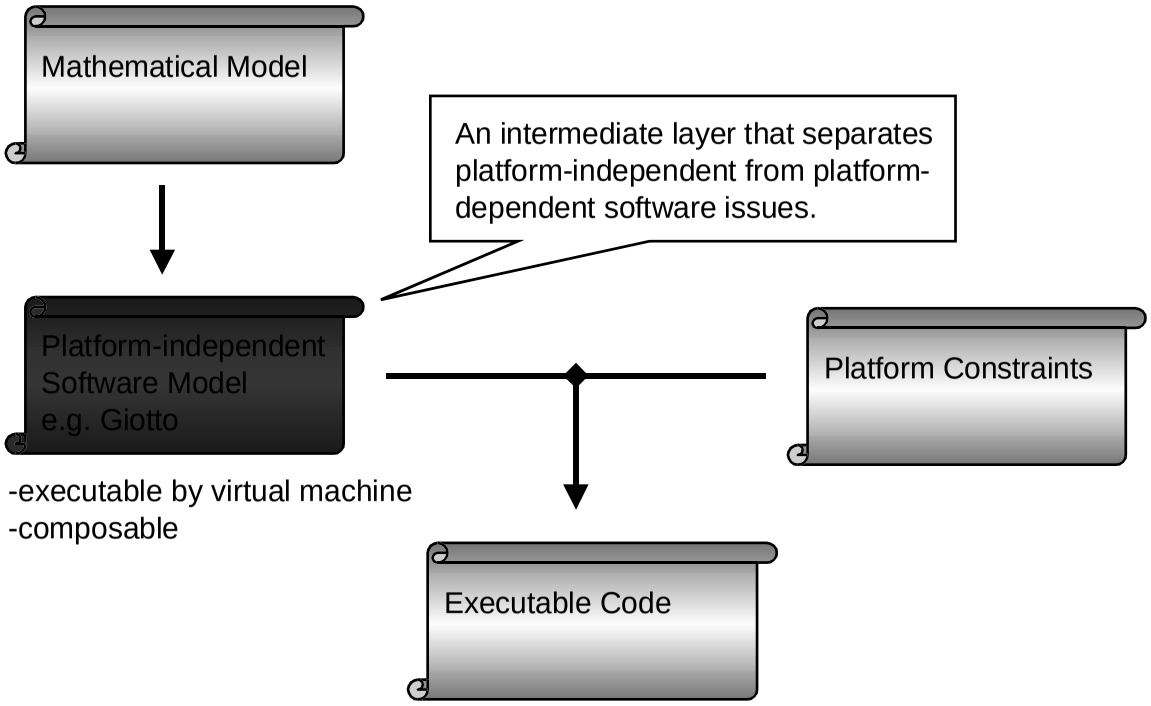
Advocated Control Software Development



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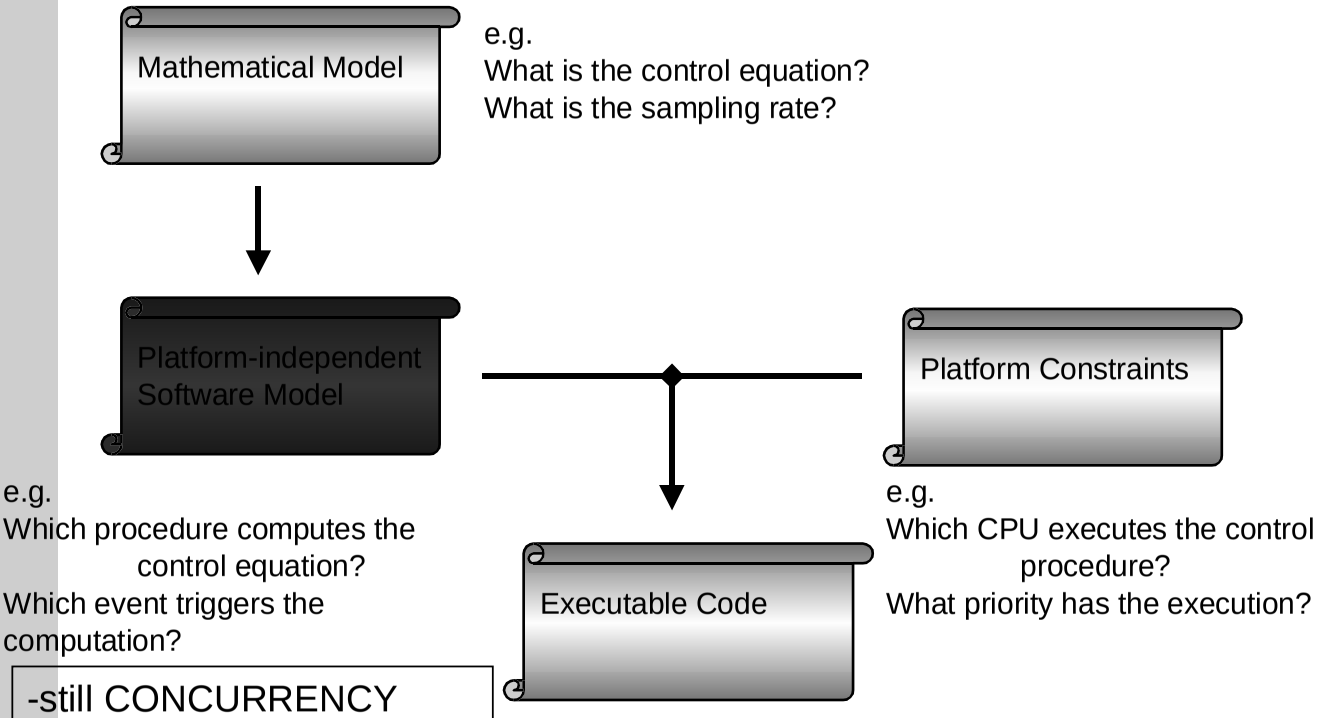
Advocated Control Software Development



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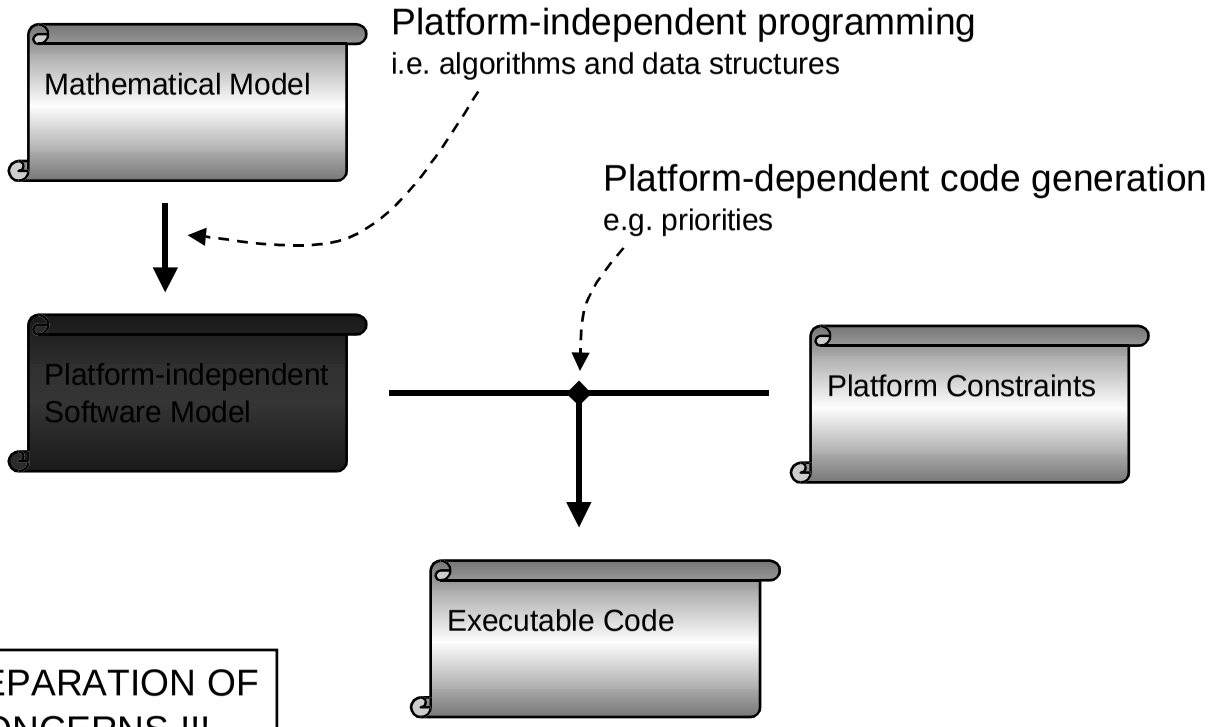
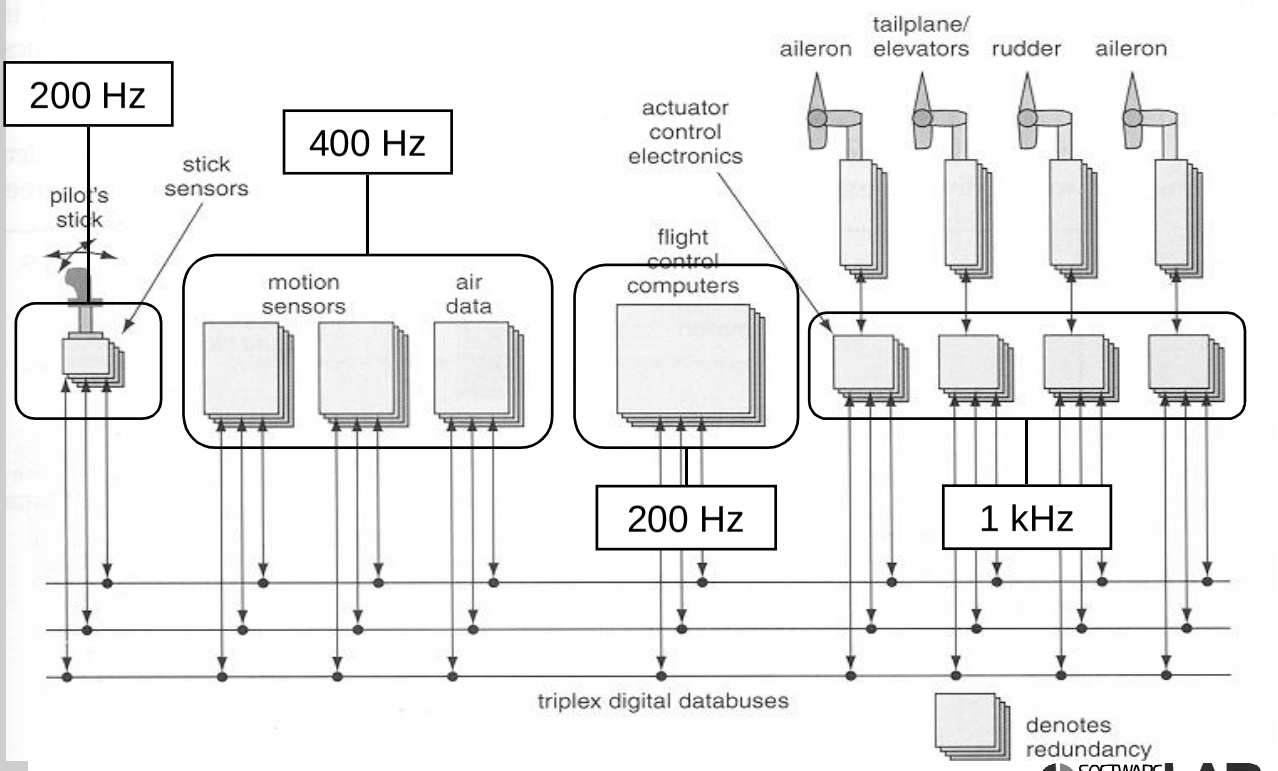
Advocated Control Software Development



Motivation: Flight Control Software

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

Motivation: Flight Control Software



Platform-independent Software Model

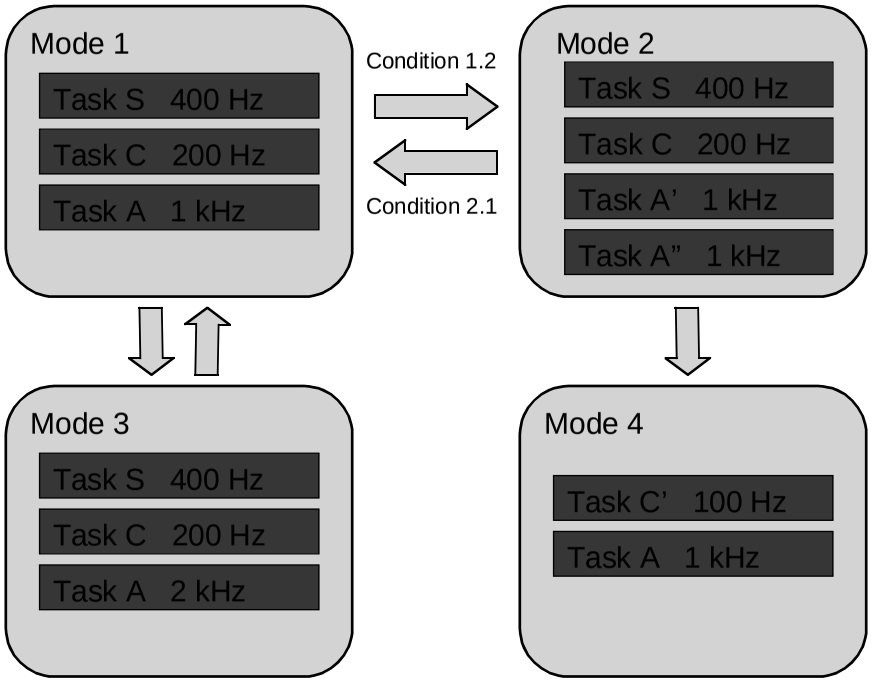
1. Concurrent periodic tasks:

   -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



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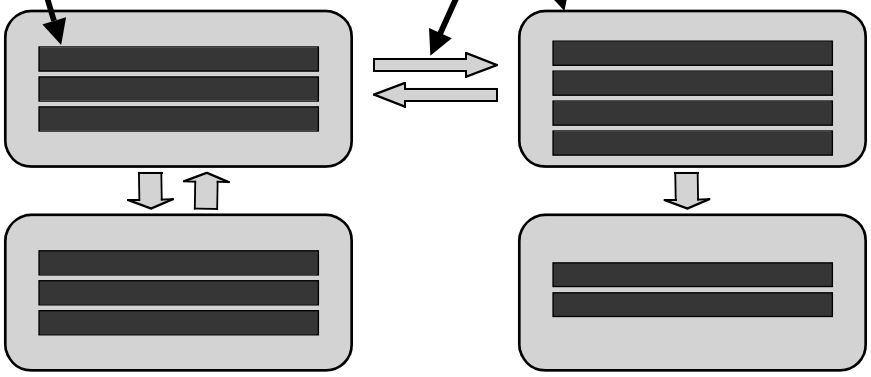
Platform-independent Software Model

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.

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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:

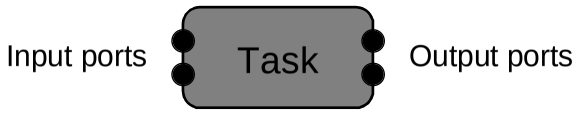
Compiler must maintain programmer's fiction:

-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

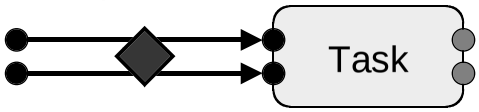
The Giotto Programmer's Model

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



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

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

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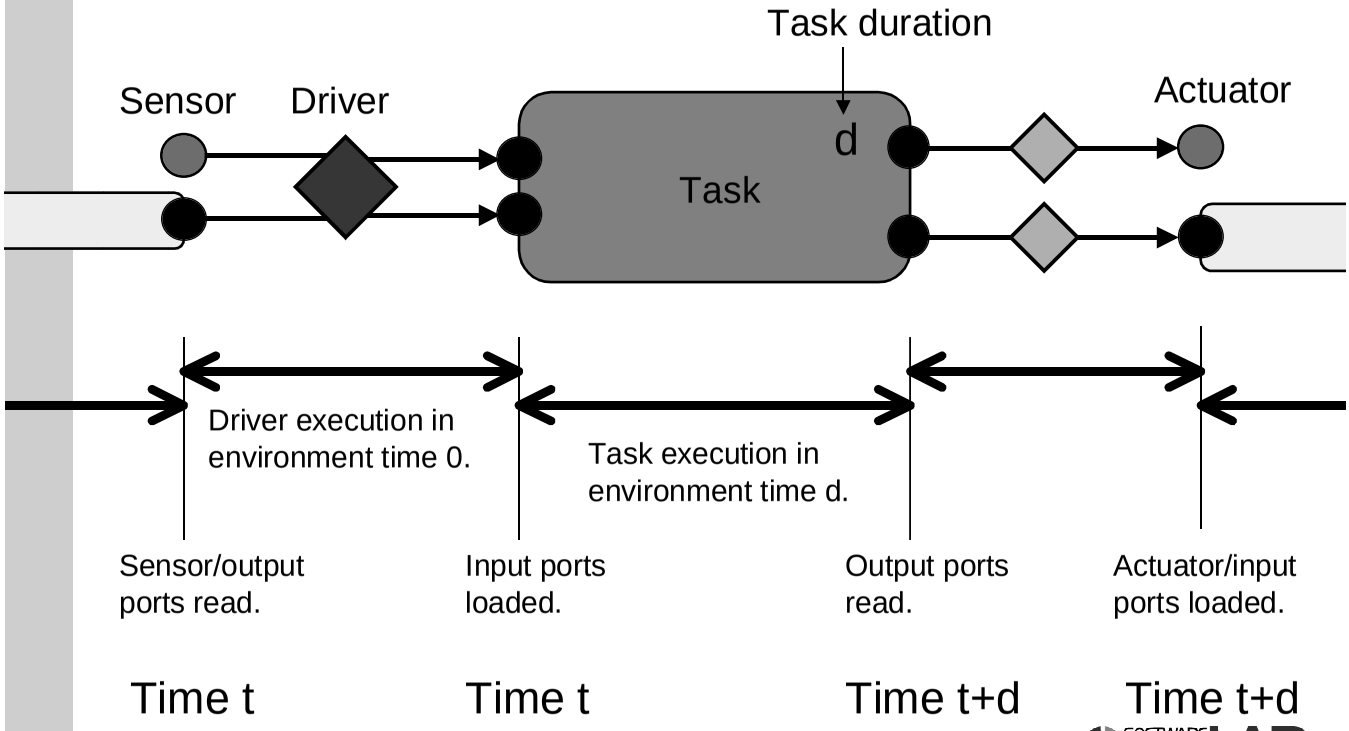
Environment Timeline (defined by Giotto semantics)



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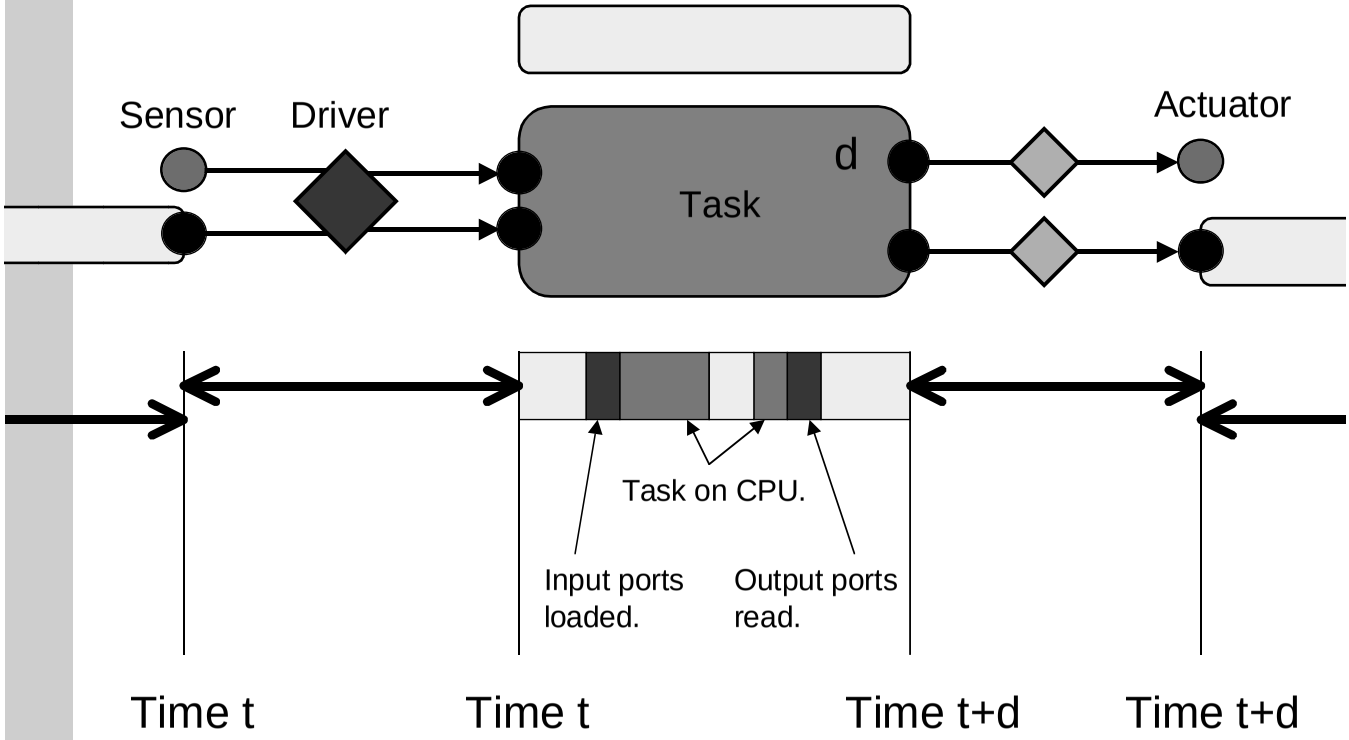
Platform Timeline (chosen by Giotto compiler)



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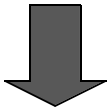
Platform Independence ensures Predictability

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).

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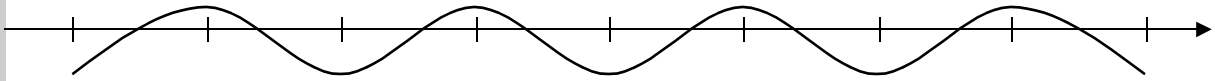
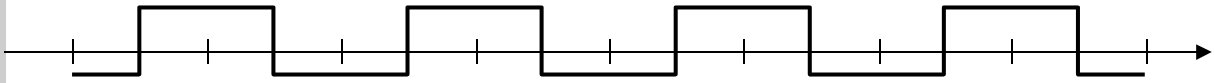
Environment



Environment Processes: environment time

Software Processes: platform time



Software

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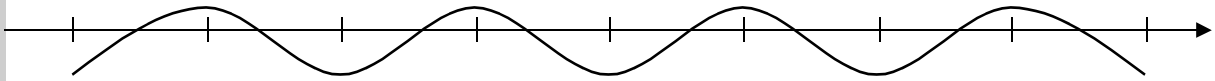
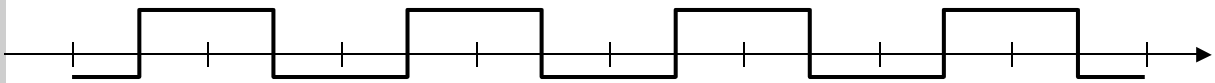
Environment



Reactivity

The Art of Embedded Programming

Schedulability



Software

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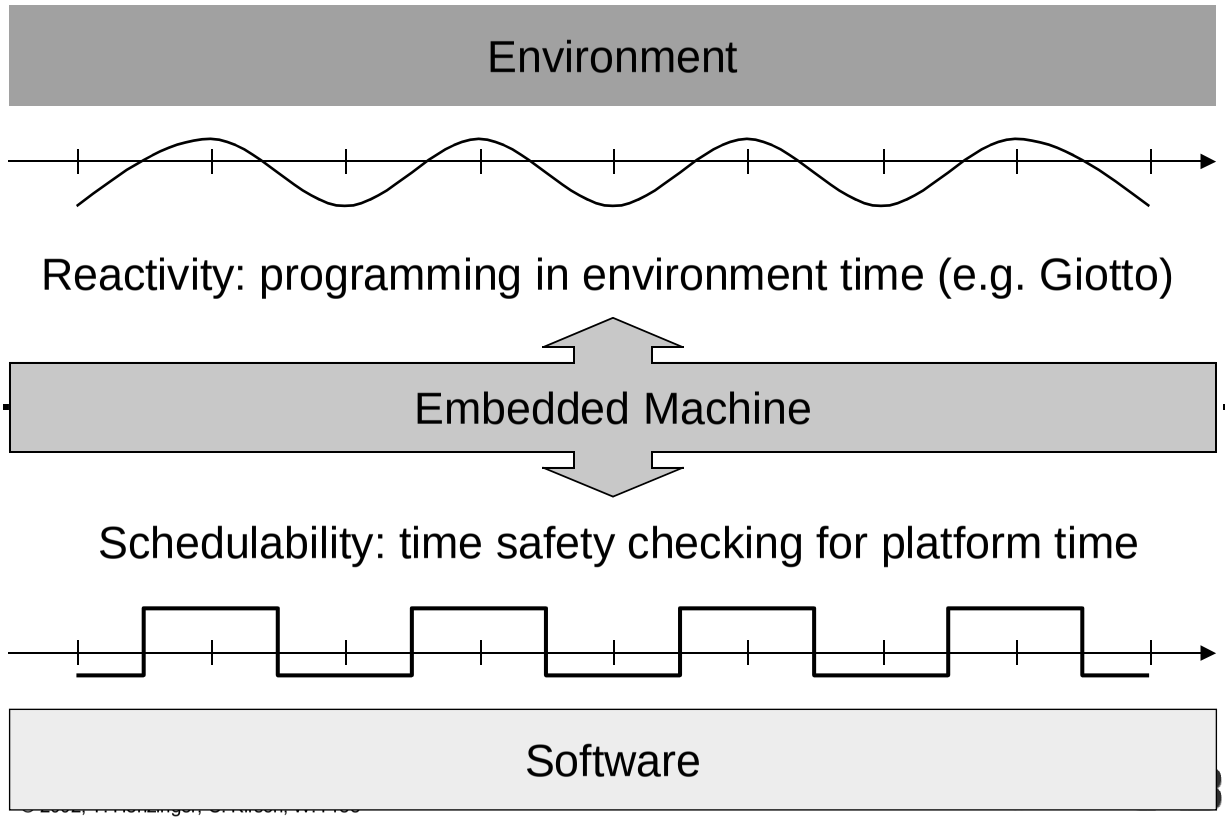
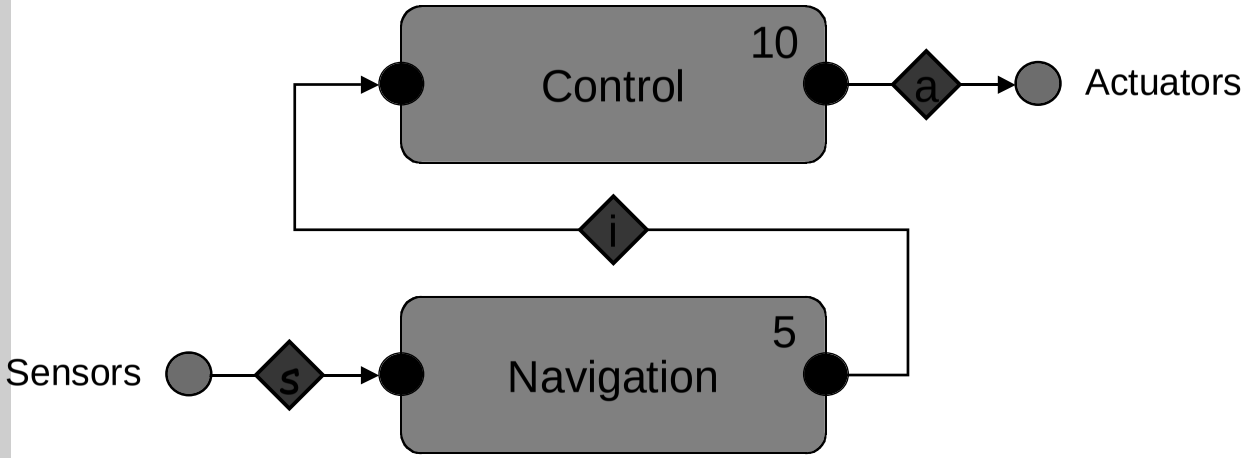
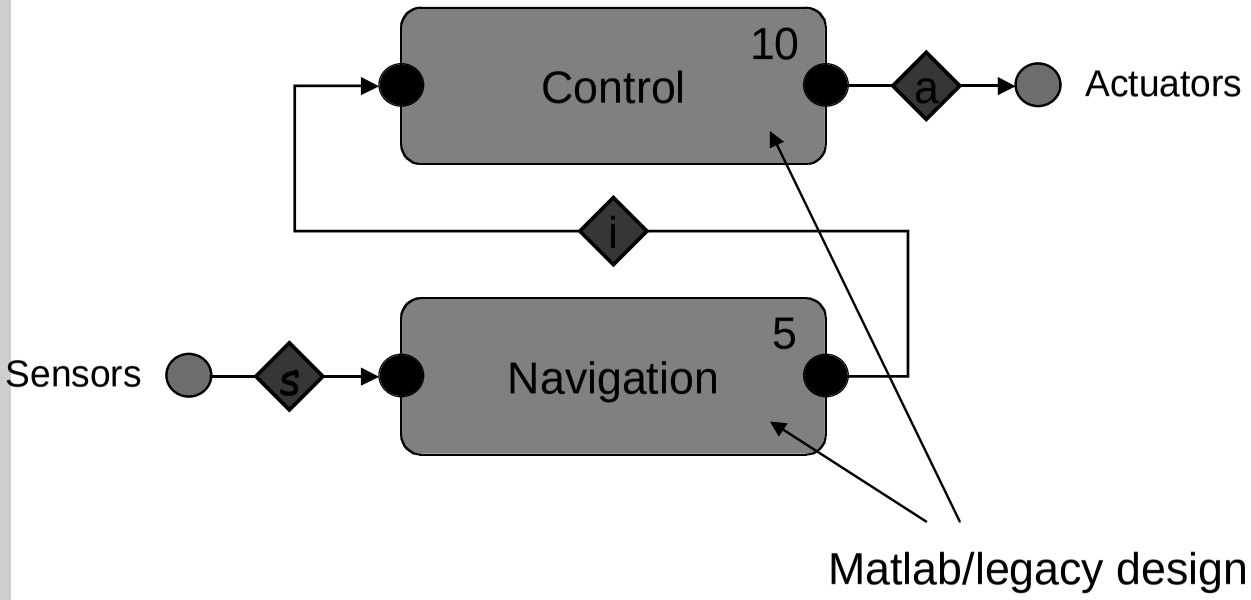
The Embedded Machine: Time is like Memory



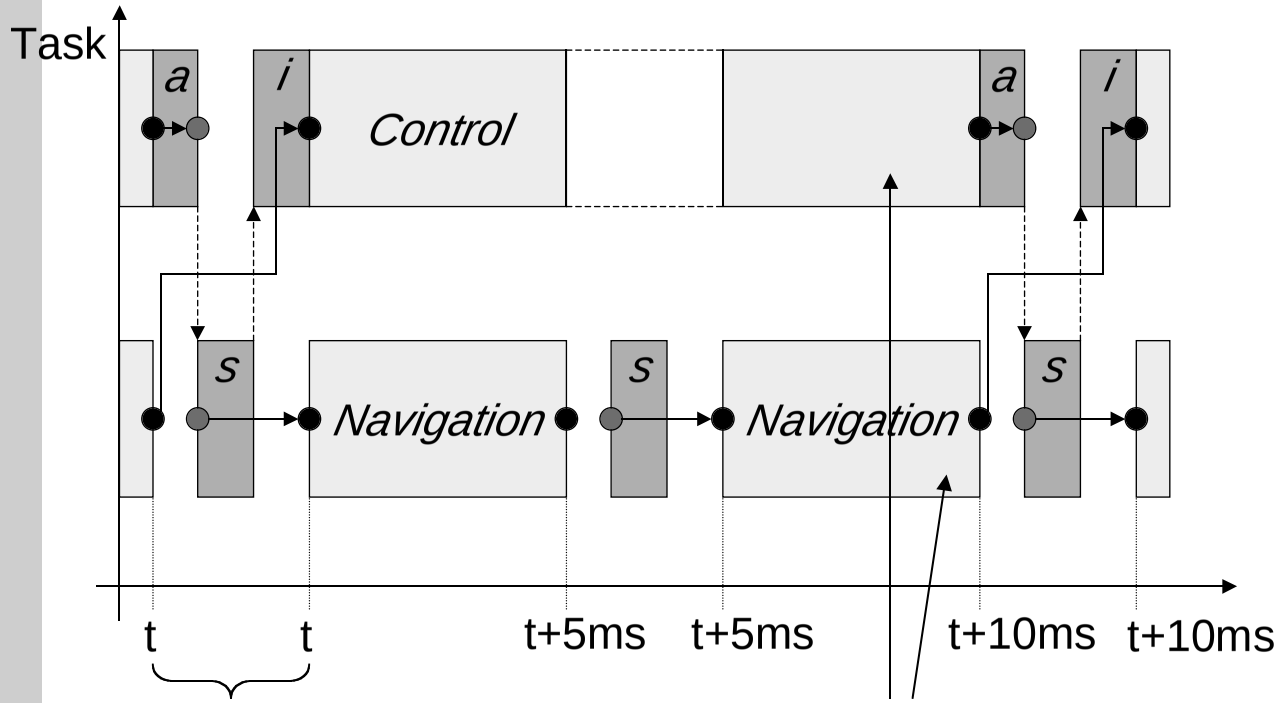
Simplified Helicopter Software



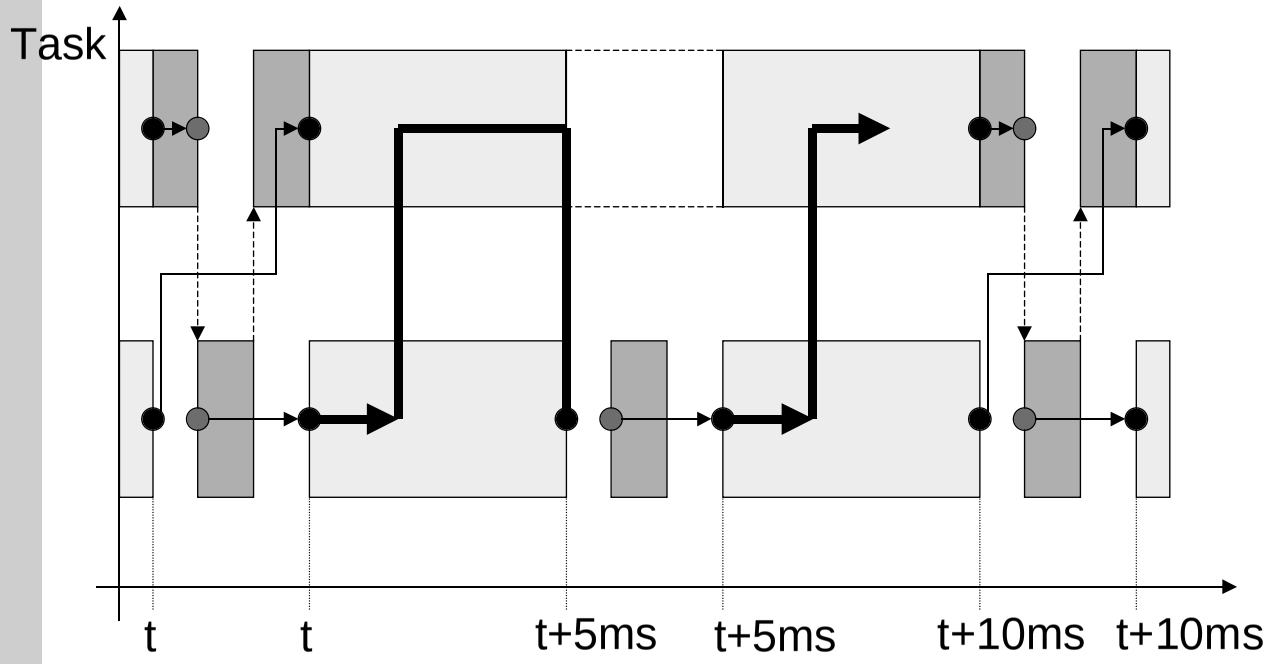
Simplified Helicopter Software



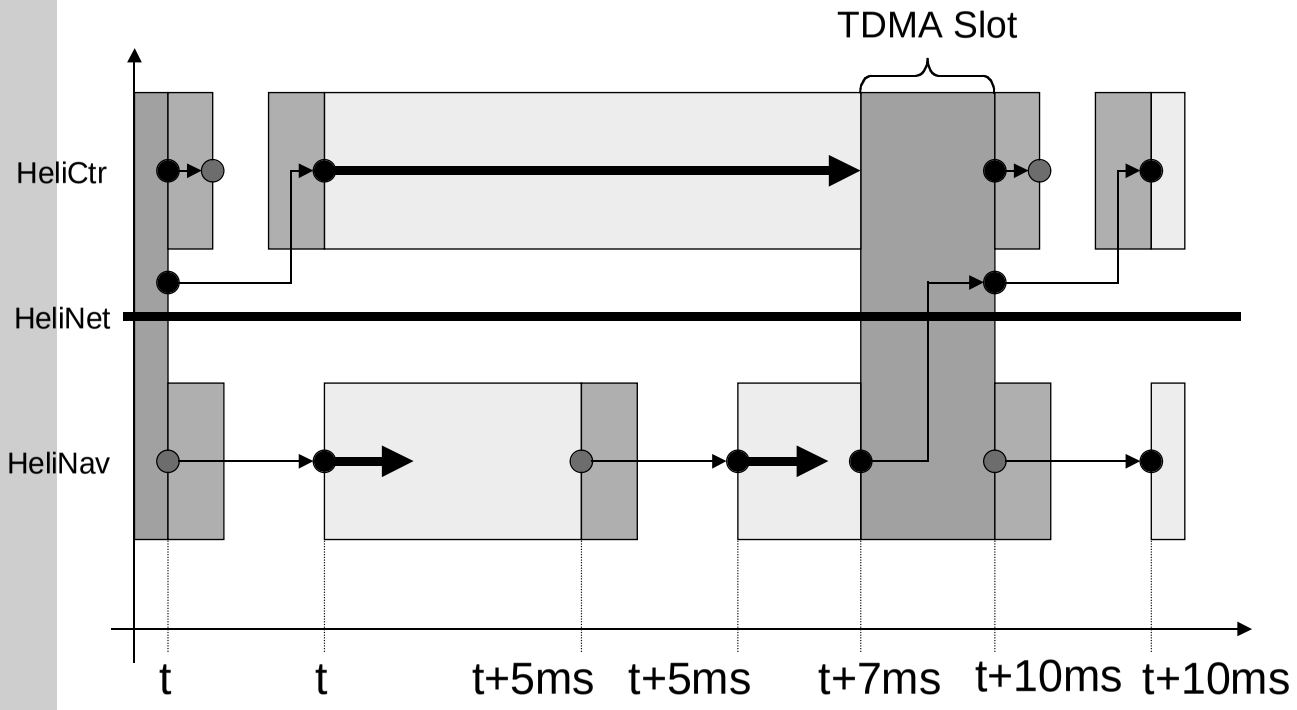
Helicopter Software: Environment Timeline



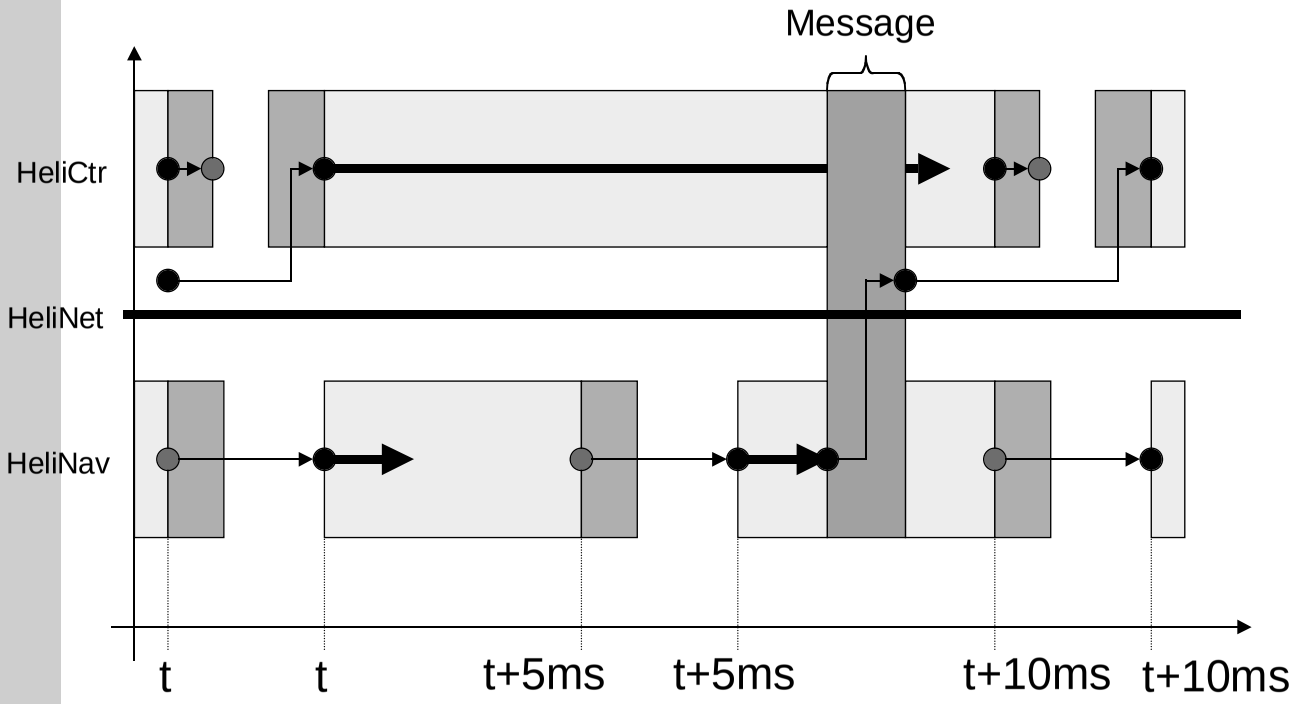
Single-CPU Helicopter: Platform Timeline (EDF)



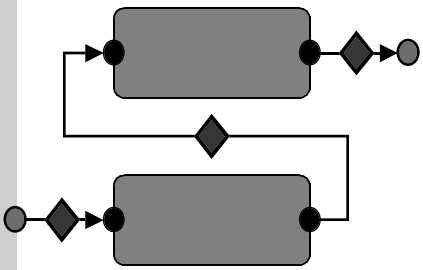
Two-CPU Helicopter: Platform Timeline (Time-triggered Communication)



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

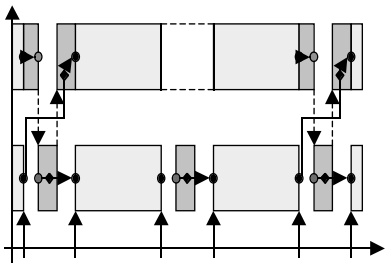


Helicopter Software: Giotto Syntax (Functionality)



```
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 ) ;
  }
...
```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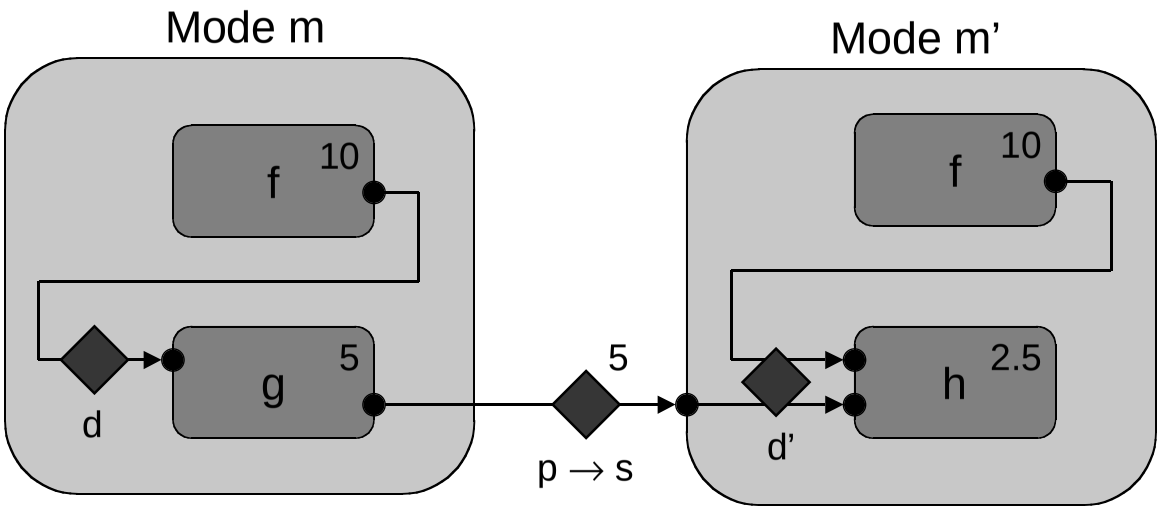
Mode Switch



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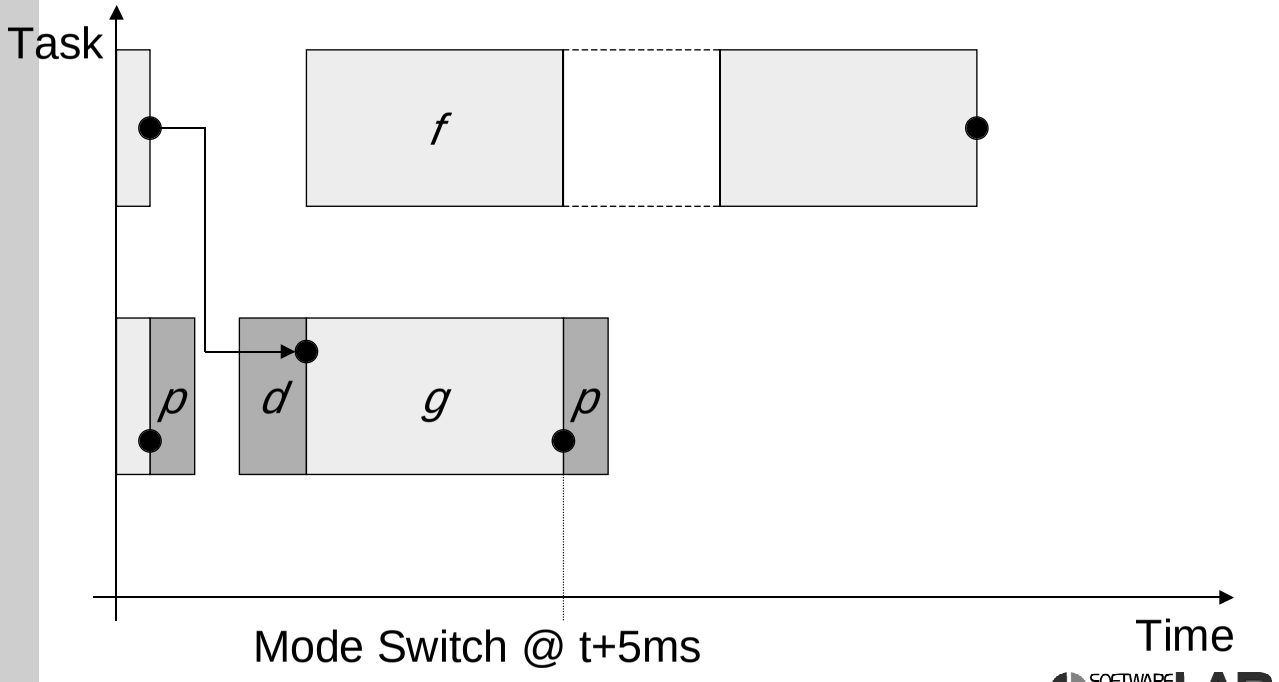
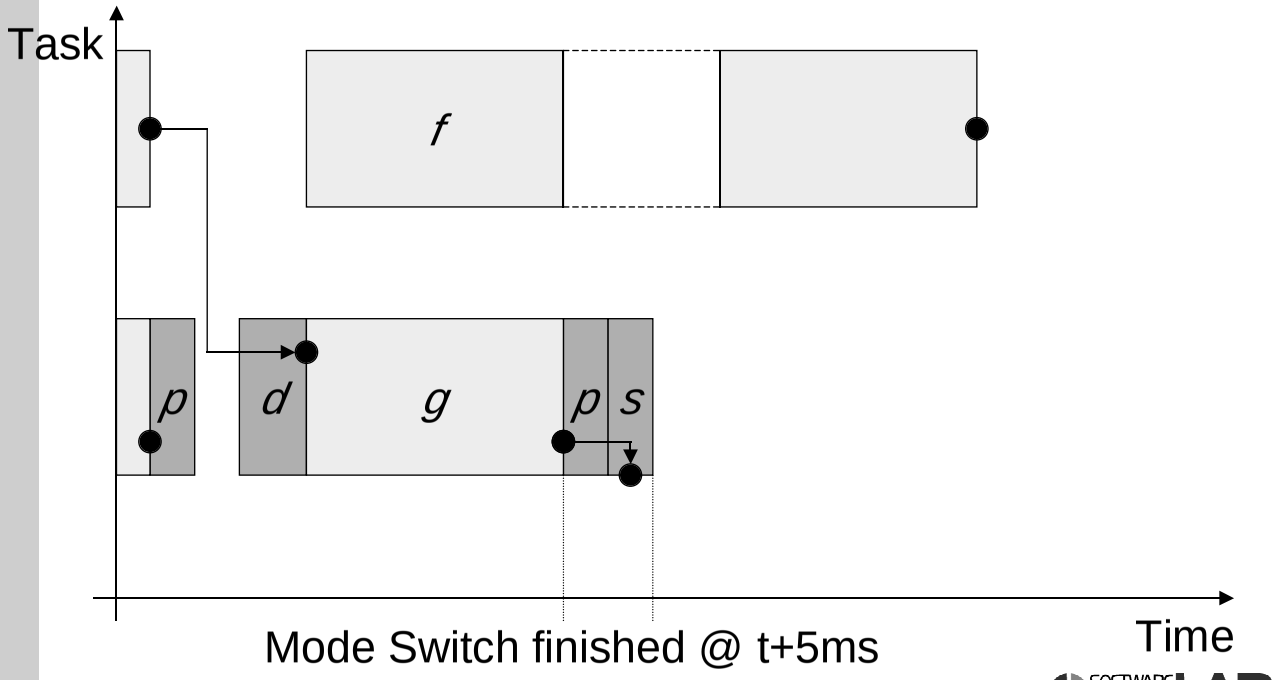
Mode Switch: Environment Timeline



Mode Switch: Environment Timeline



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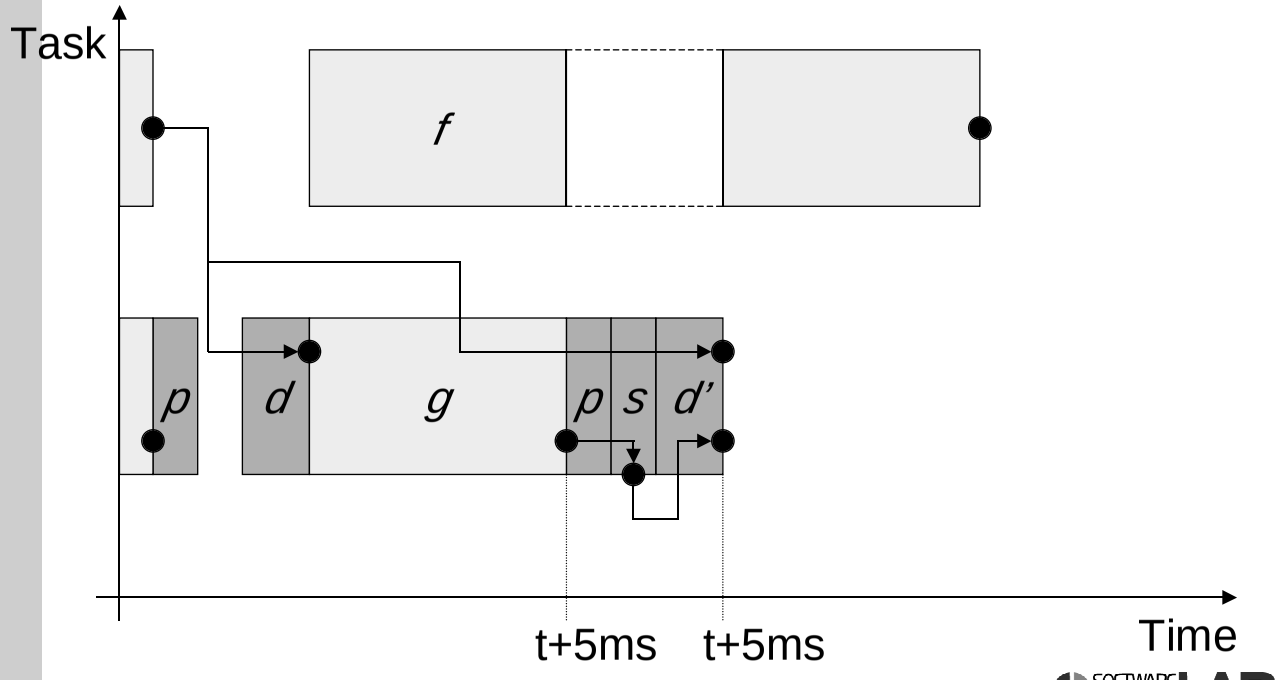

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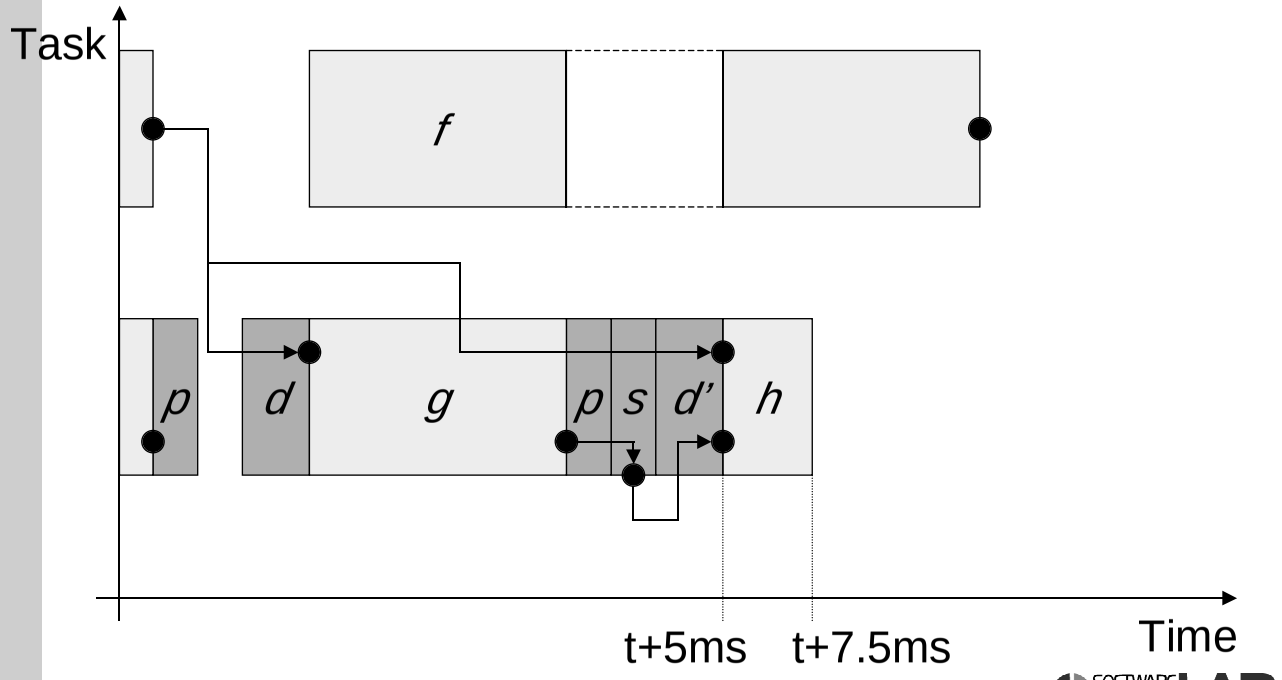

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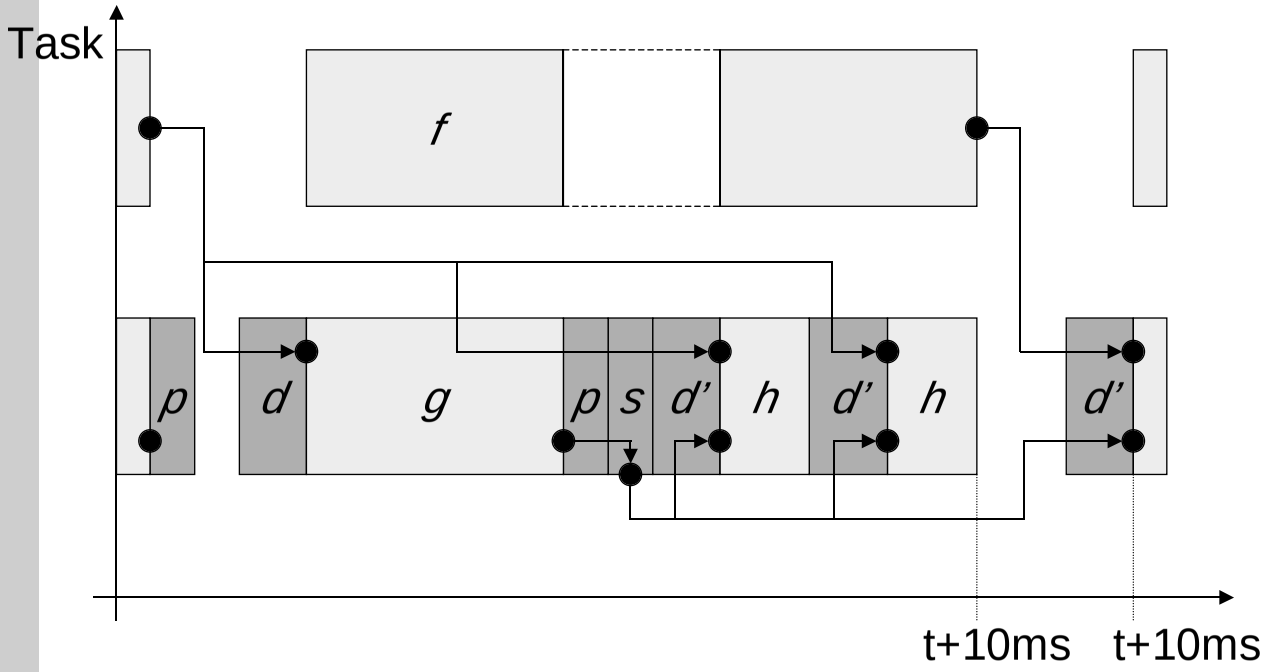


The Giotto Compiler

Functionality — Native Code — Tasks and Drivers

Timing 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

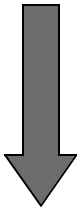
Timing Interaction — Giotto Program

Platform — Giotto-P

Map — Giotto-PM

-topology (CPUs, nets)
-performance (WCETs, latencies)
-APIs (RTOSs, protocols)
-assign tasks to CPUs
-assign connections to nets

Giotto Compiler



Executables or "Failure"

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

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Closing the Gap: Annotated Giotto

Functionality — Native Code — Tasks and Drivers

Timing Interaction — Giotto Program

Platform — Giotto-P

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

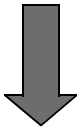
Map — Giotto-PM

-assign tasks to CPUs
-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)

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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.

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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) ] ;
  }
...
```


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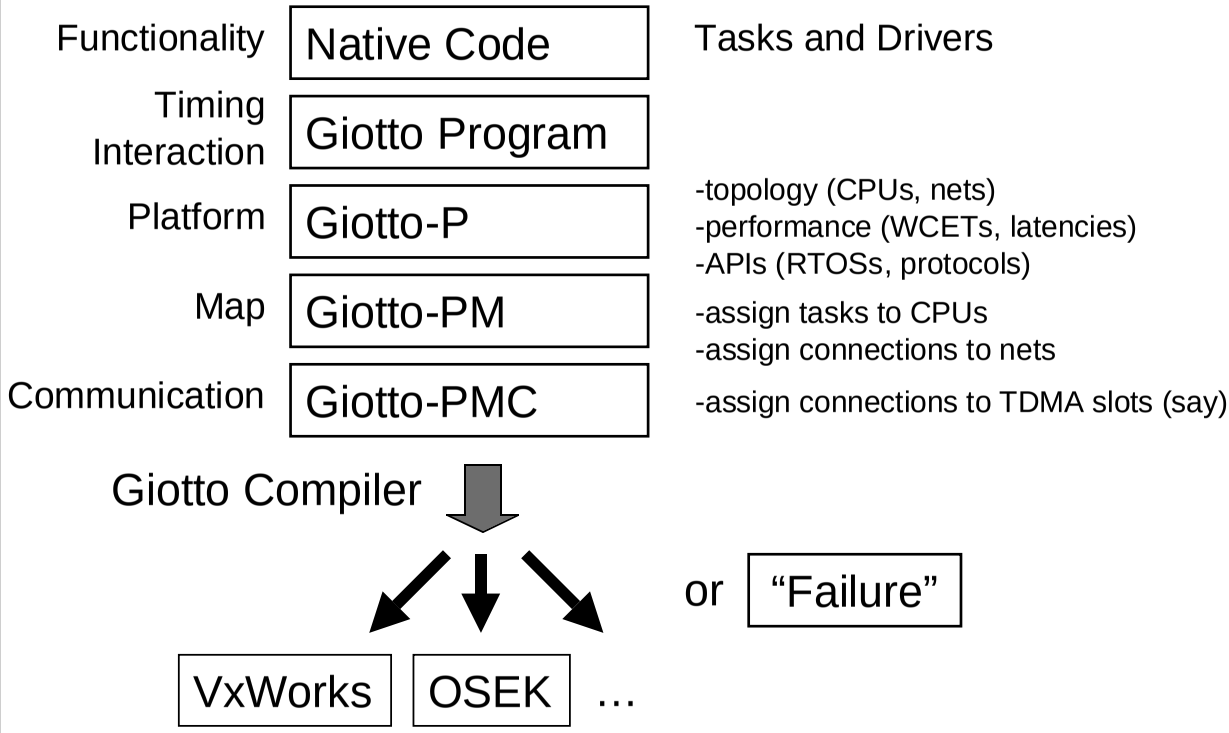
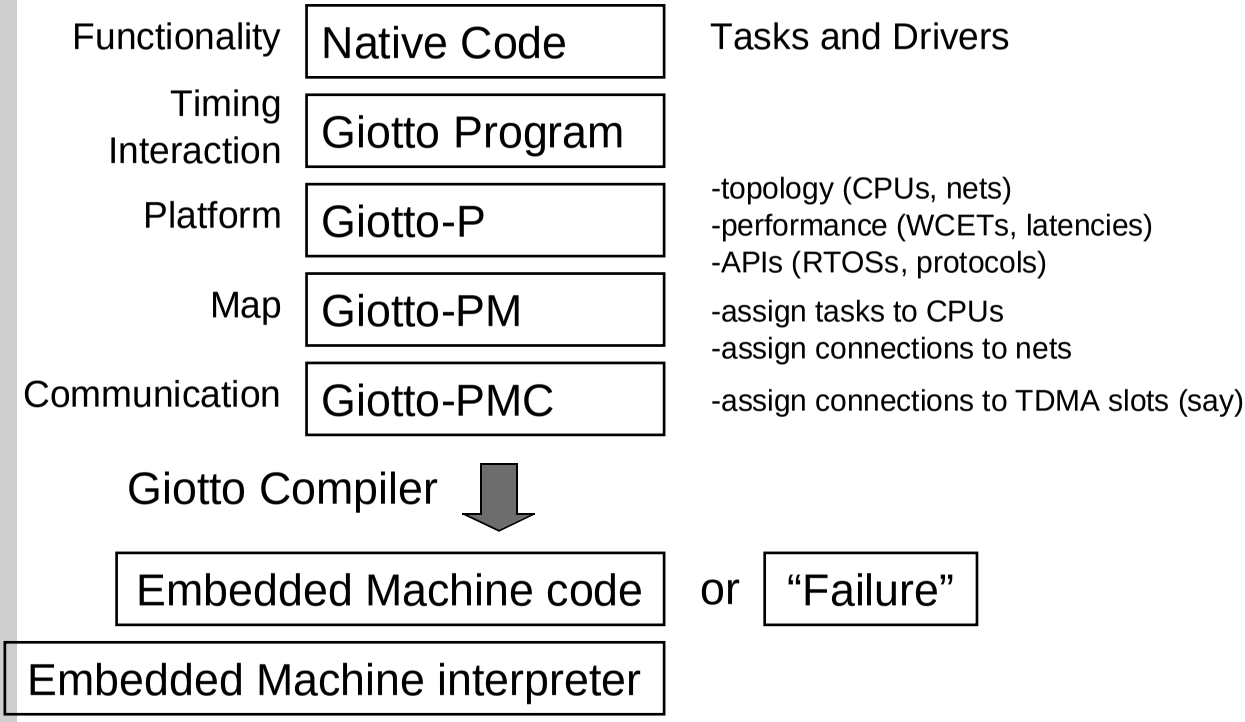
Code Generation



Code Generation: The Embedded Machine



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

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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)

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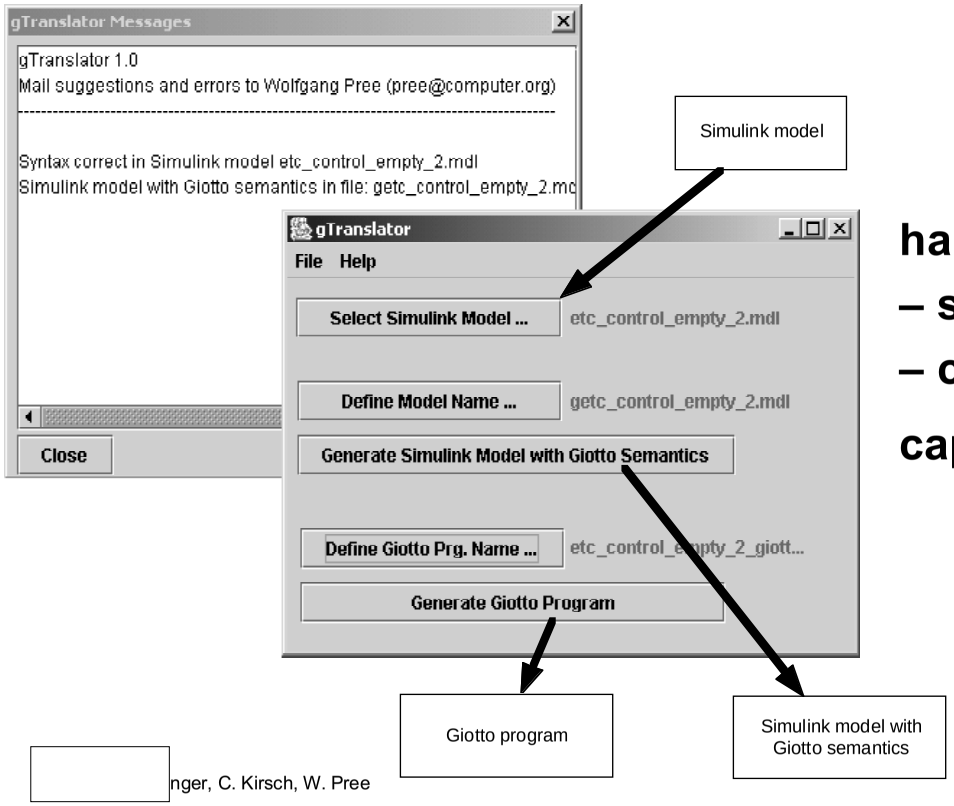
gTranslator tool: seamless integration of Giotto and Simulink



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

nger, C. Kirsch, W. Pree

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Framework components (ESA)

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Attitude and Orbit Control System

The AOCS is typically the most complex satellite subsystem

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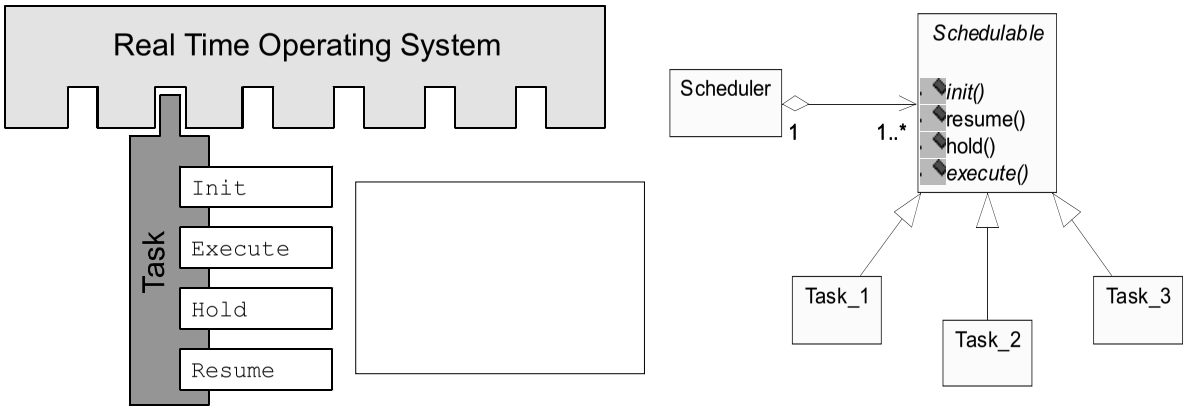
Reuse in a RT-OS

RTOS's are examples of reuse in the RT field
→ inspiration for AOCS f/w



Task *management* is separated from task *implementation* through an abstract class/interface

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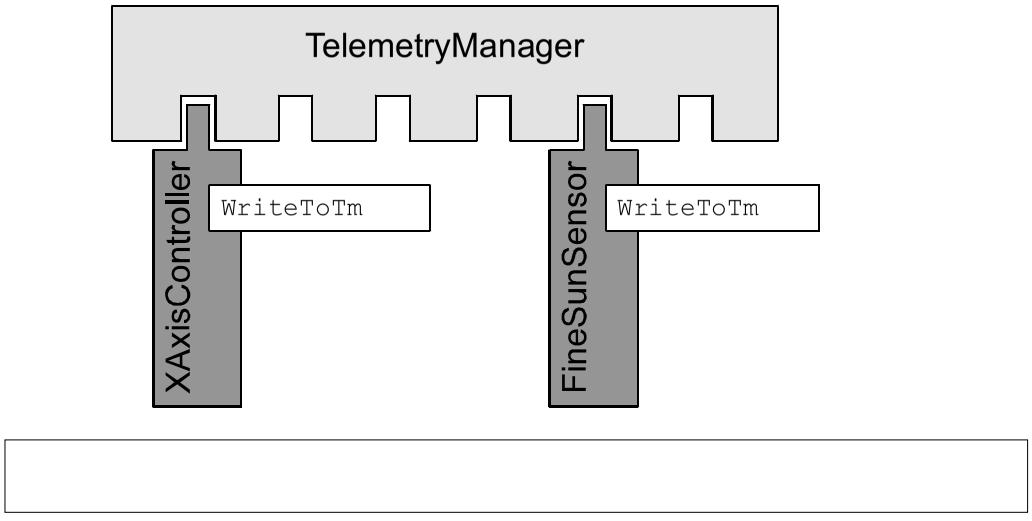
Telemetry Management

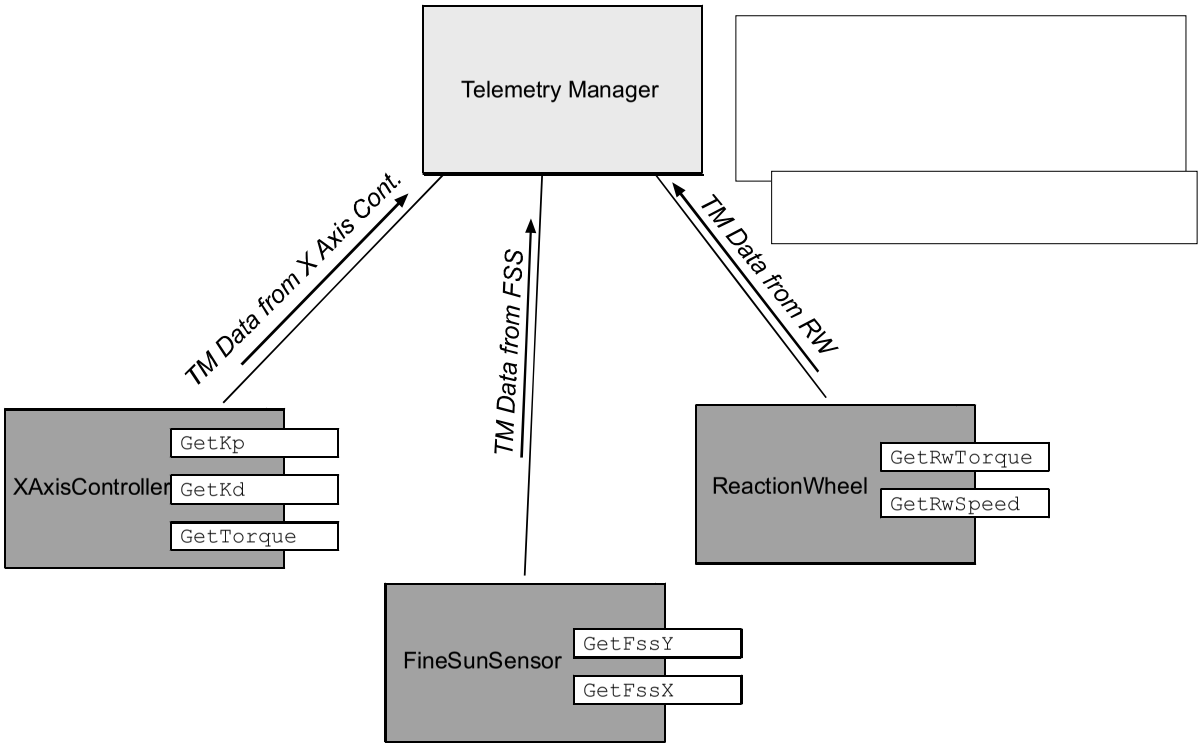
- AOCS periodically sends telemetry (TM) to the ground representing (a subset of) the state of the AOCS objects
- Problem: how can the management of the telemetry functionality be decoupled from the format and content of the telemetry data?
  - Note: We want to design a generic framework, not just a single application
- Proposed solution can be applied to any embedded system where housekeeping data need to be logged on a periodic basis

TM Manager – schematic view




```
Telemeterable* list[N];
TmStream* tmStream;
. . .
for ( i=0; i<N; i++ )
     list[i]->writeToTelemetry(tmStream);
```

Conventional, non-reusable solution



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The end

Thank you for your attention!

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