The JAviator: Time-Portable Programming in Java

Christoph Kirsch
Universität Salzburg

Sun Microsystems
September 2008

javiator.cs.uni-salzburg.at[#]

- Silviu Craciunas* (Control Systems)
- Harald Röck (Operating Systems)
- Rainer Trummer (Frame, Electronics)

[#]Supported by a 2007 IBM Faculty Award and the EU ArtistDesign Network of Excellence on Embedded Systems Design
*Supported by Austrian Science Fund Project P18913-N15

The JAviator

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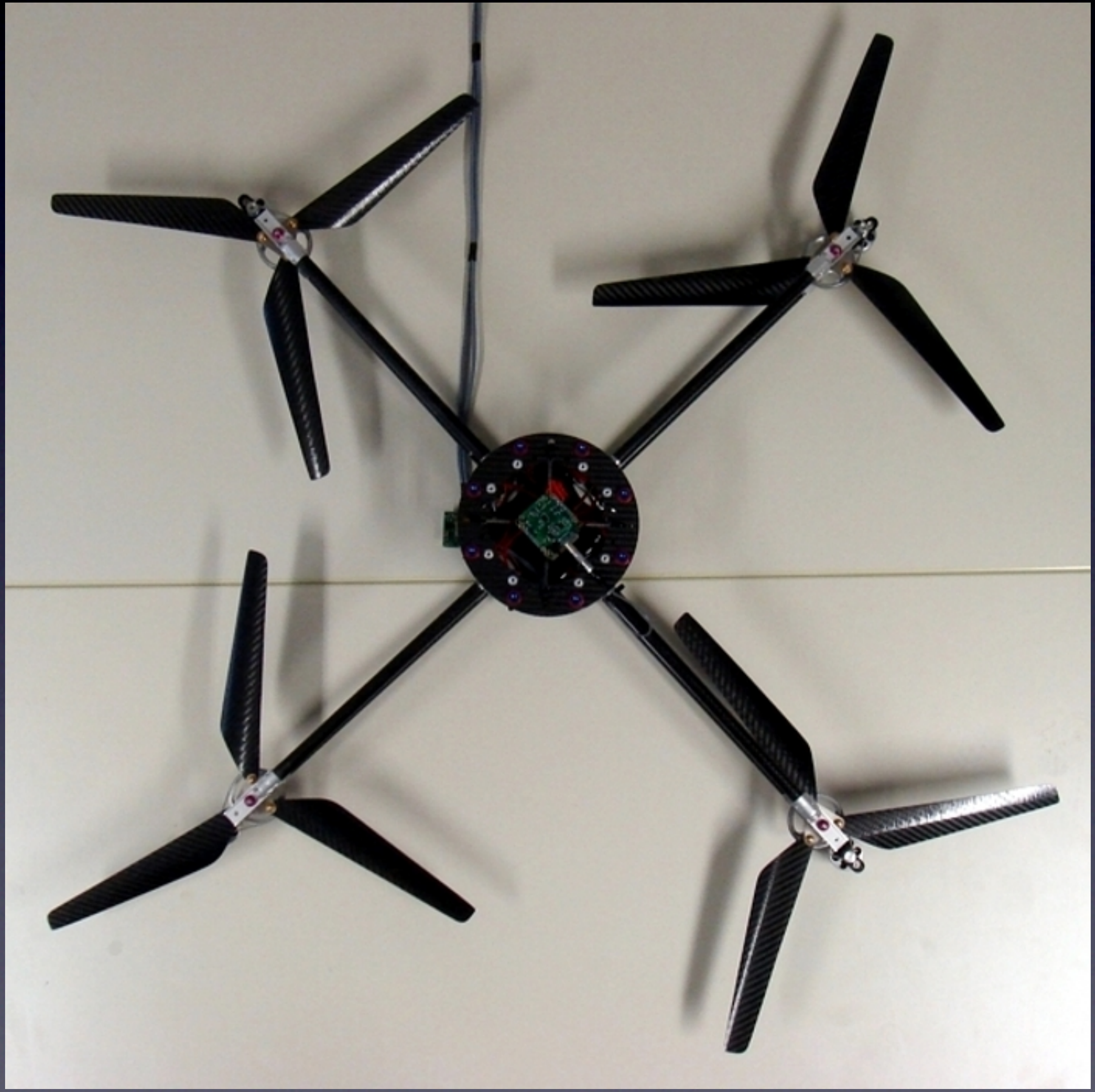
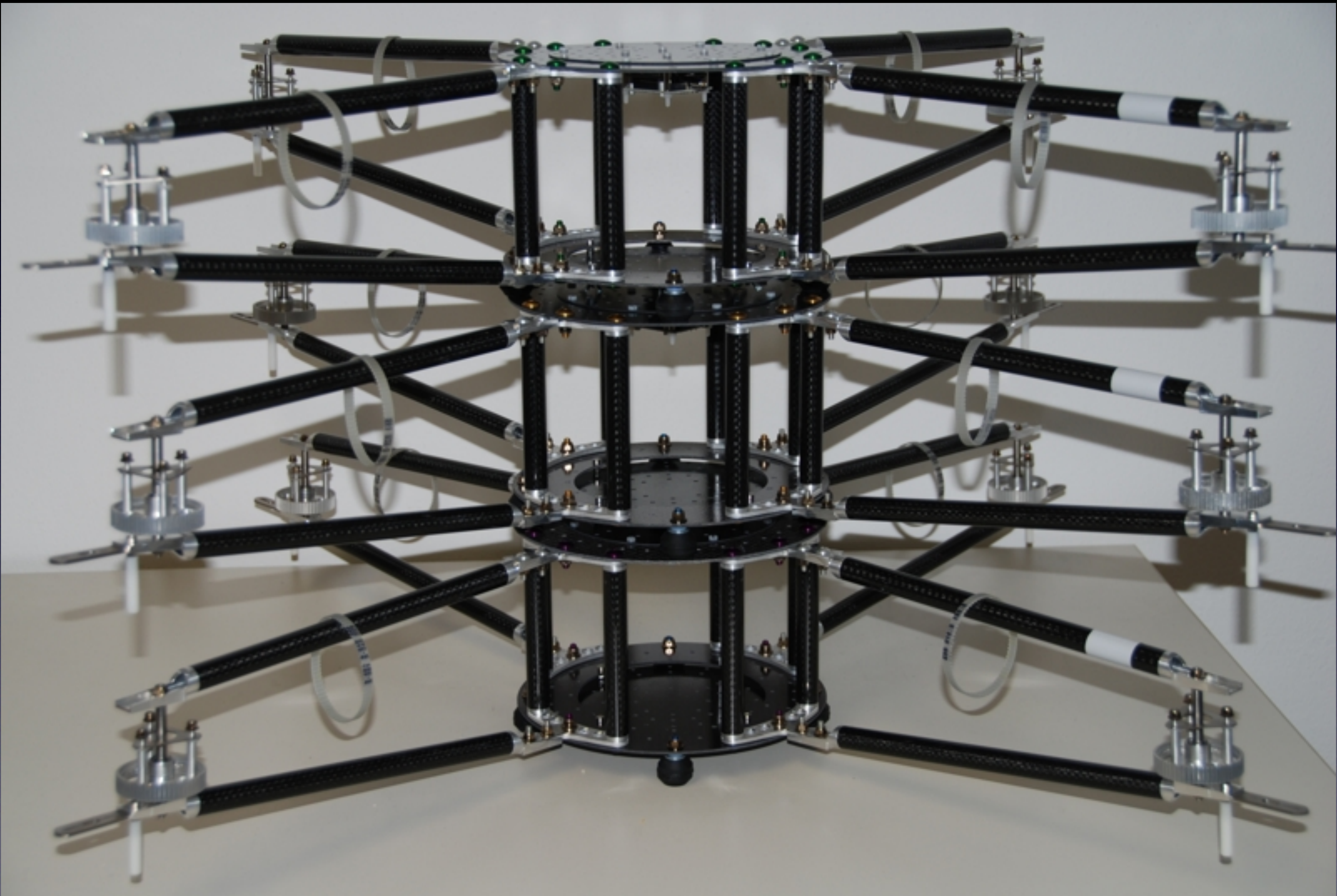
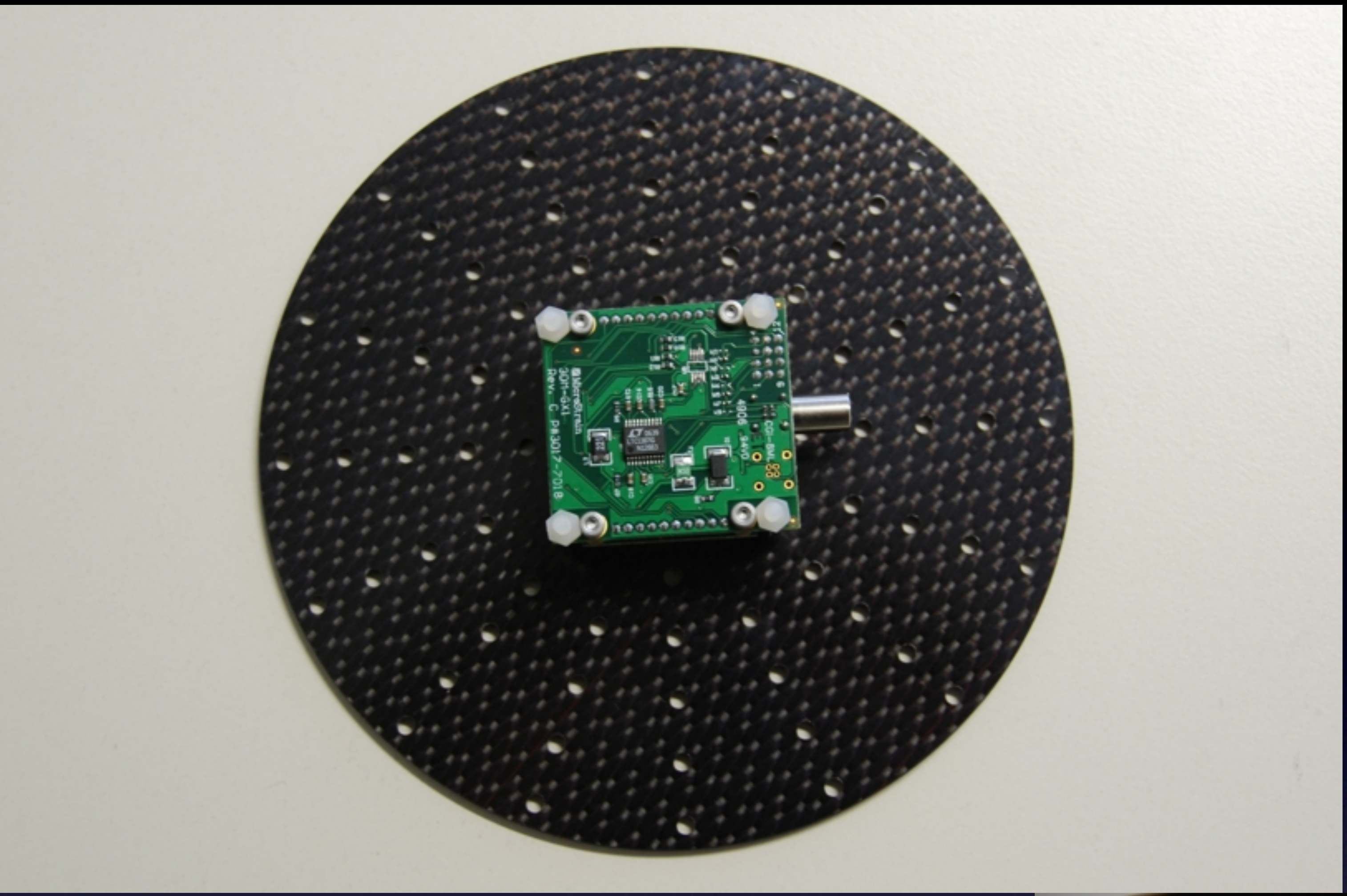
Quad-Rotor Helicopter

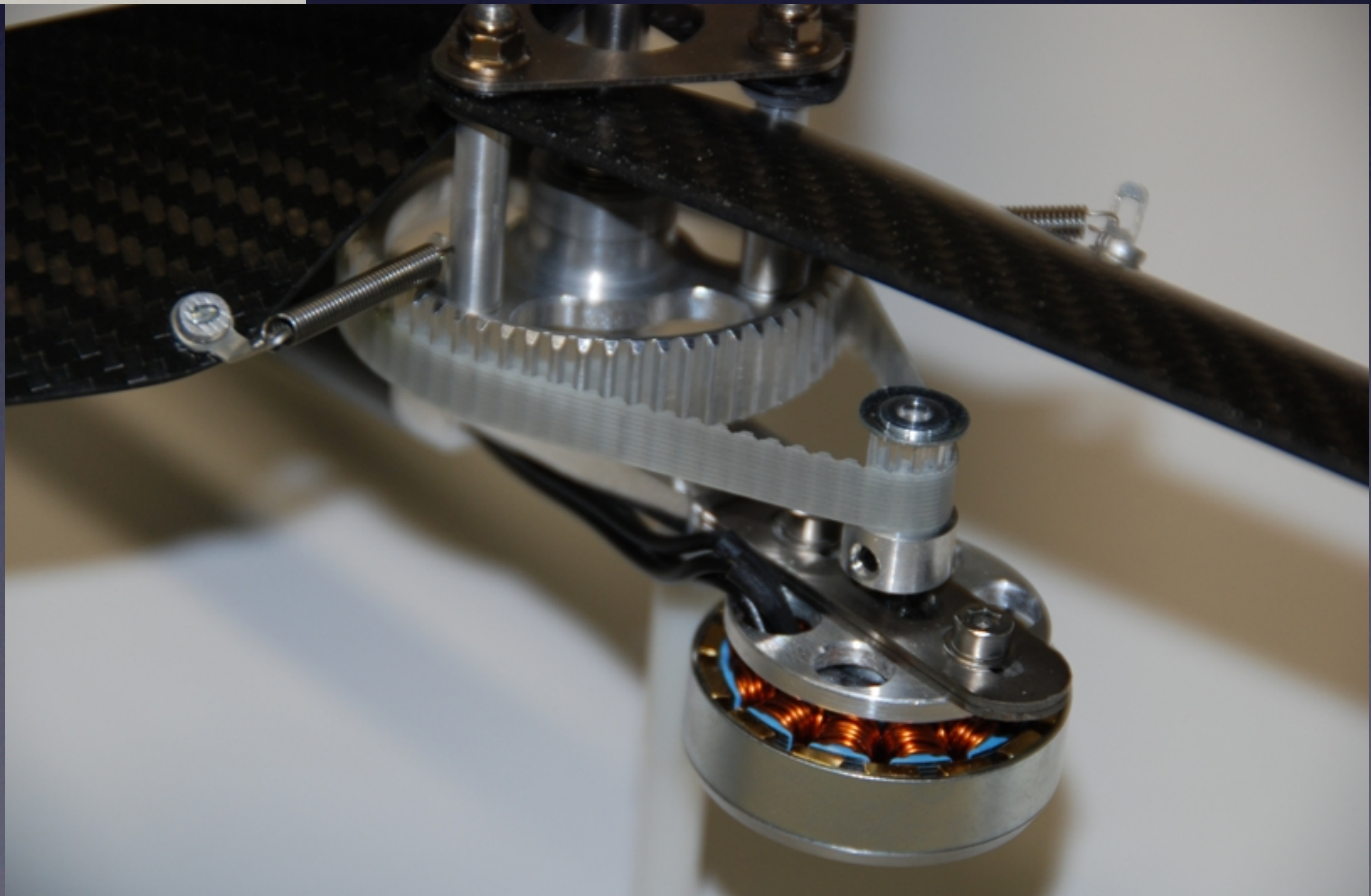




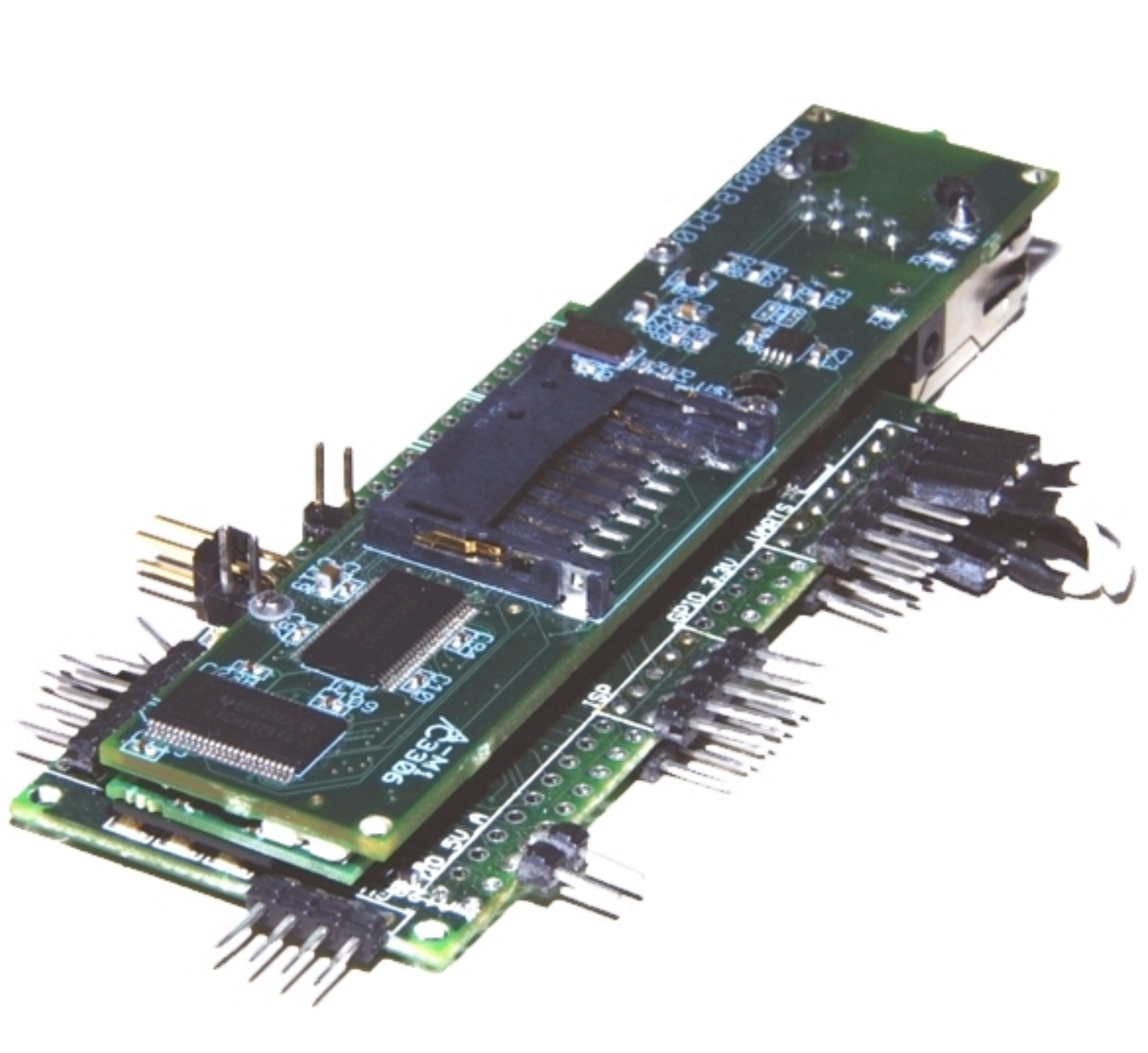


Gyro

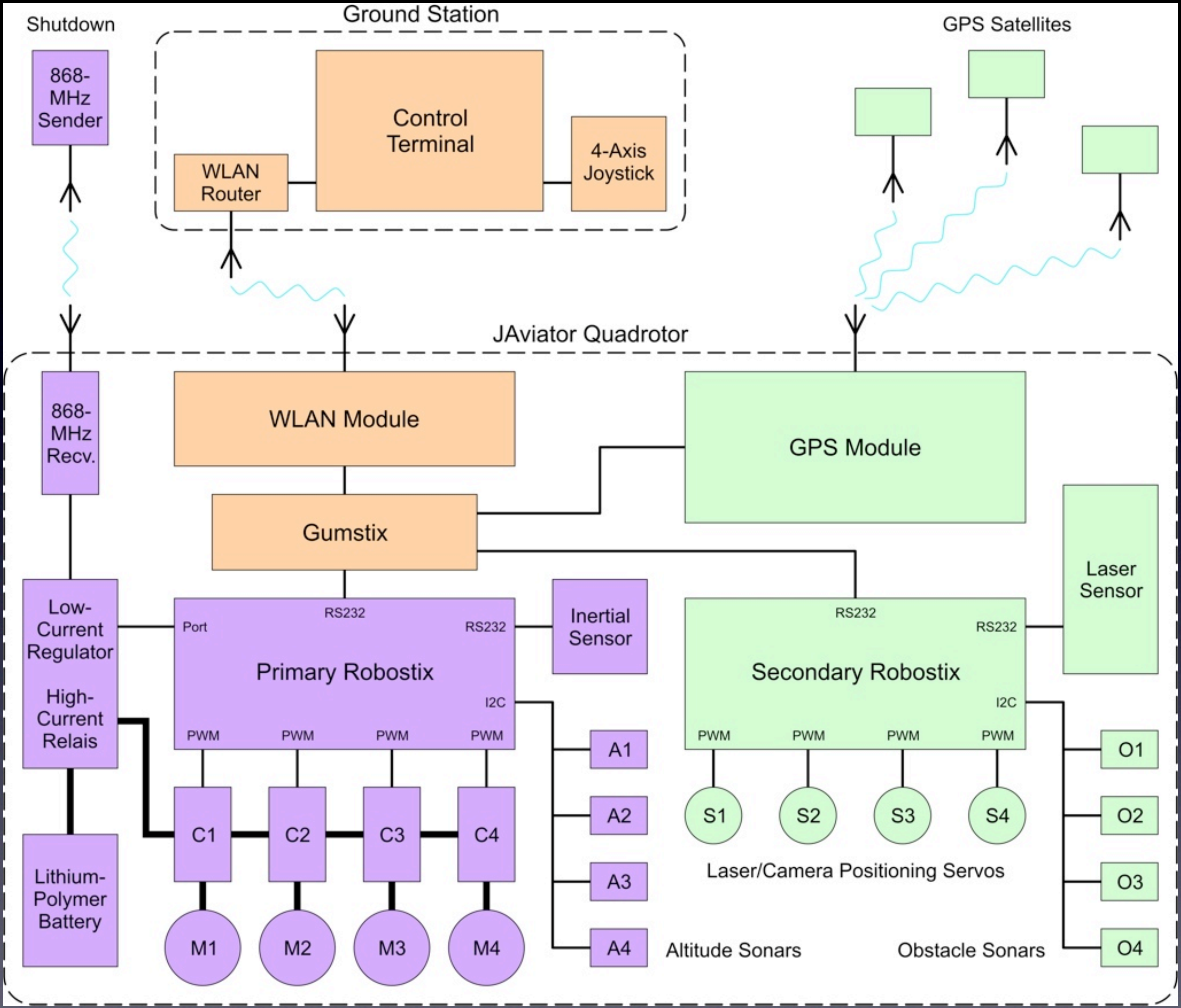
Propulsion

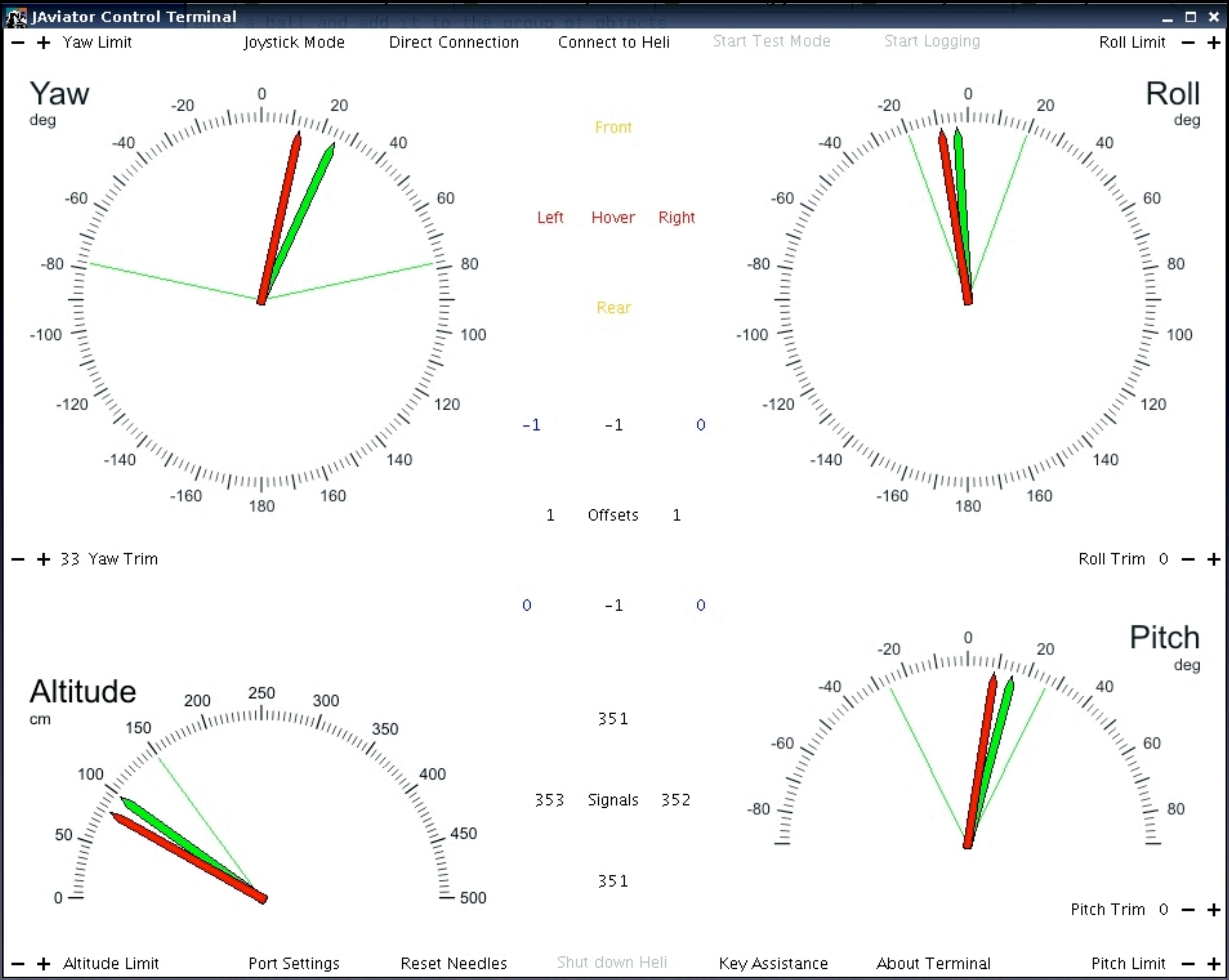


Gumstix



600MHz XScale, 128MB RAM, WLAN, Atmega uController


Shutdown
868-MHz Sender
Ground Station
WLAN Router
Control Terminal
4-Axis Joystick
GPS Satellites
JAviator Quadrotor
868-MHz Recv.
WLAN Module
GPS Module
Gumstix
Laser Sensor
Low-Current Regulator
High-Current Relais
RS232
Port
RS232
Primary Robostix
I2C
PWM
PWM
PWM
PWM
Inertial Sensor
RS232
RS232
Secondary Robostix
I2C
PWM
PWM
PWM
PWM
Lithium-Polymer Battery
C1
C2
C3
C4
M1
M2
M3
M4
A1
A2
A3
A4
Altitude Sonars
S1
S2
S3
S4
Laser/Camera Positioning Servos
O1
O2
O3
O4
Obstacle Sonars



− + 33 Yaw Trim

Roll Trim 0 − +

Pitch Trim 0 − +

-1 -1 0

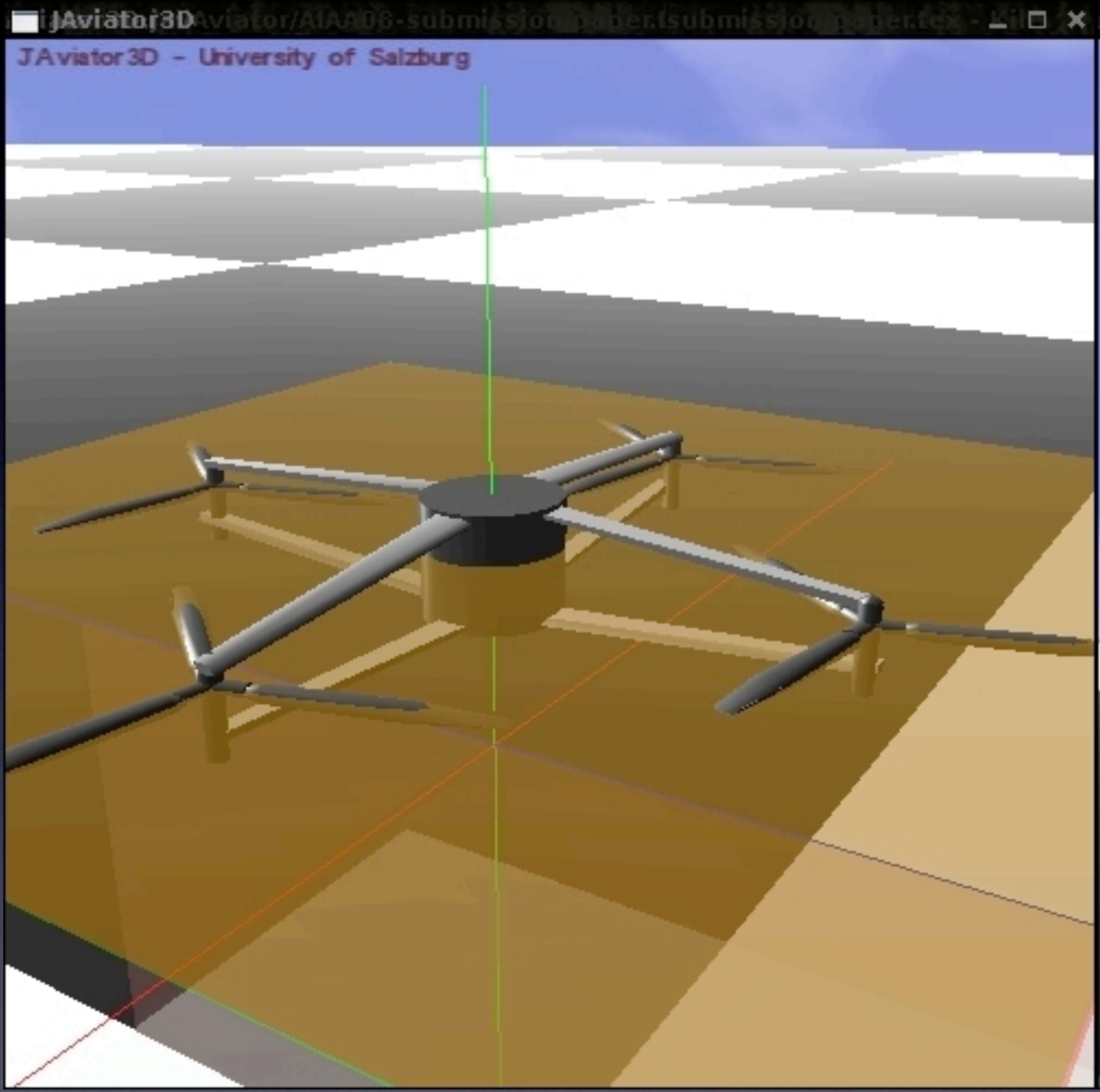
1 Offsets 1

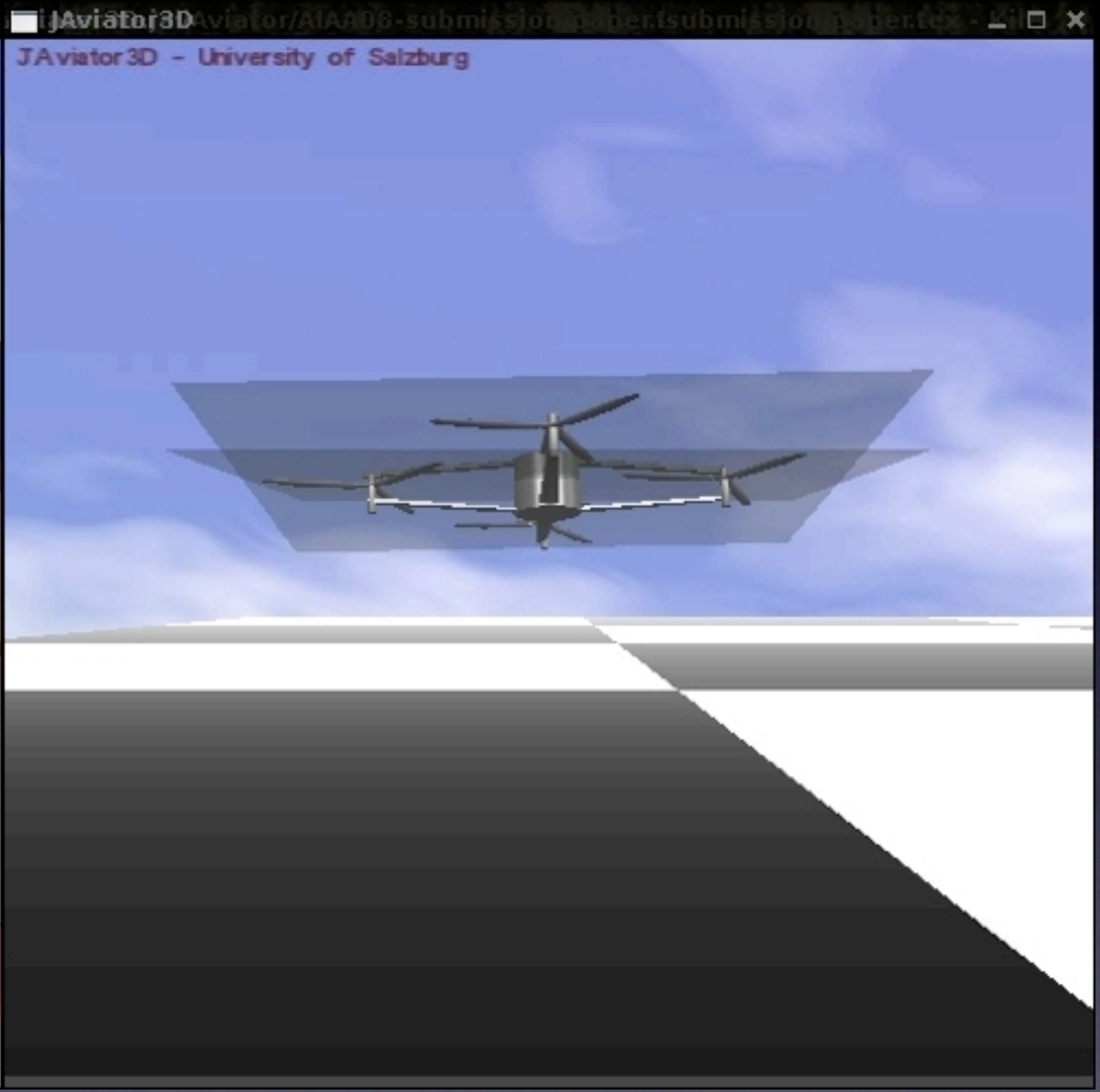
0 -1 0

351

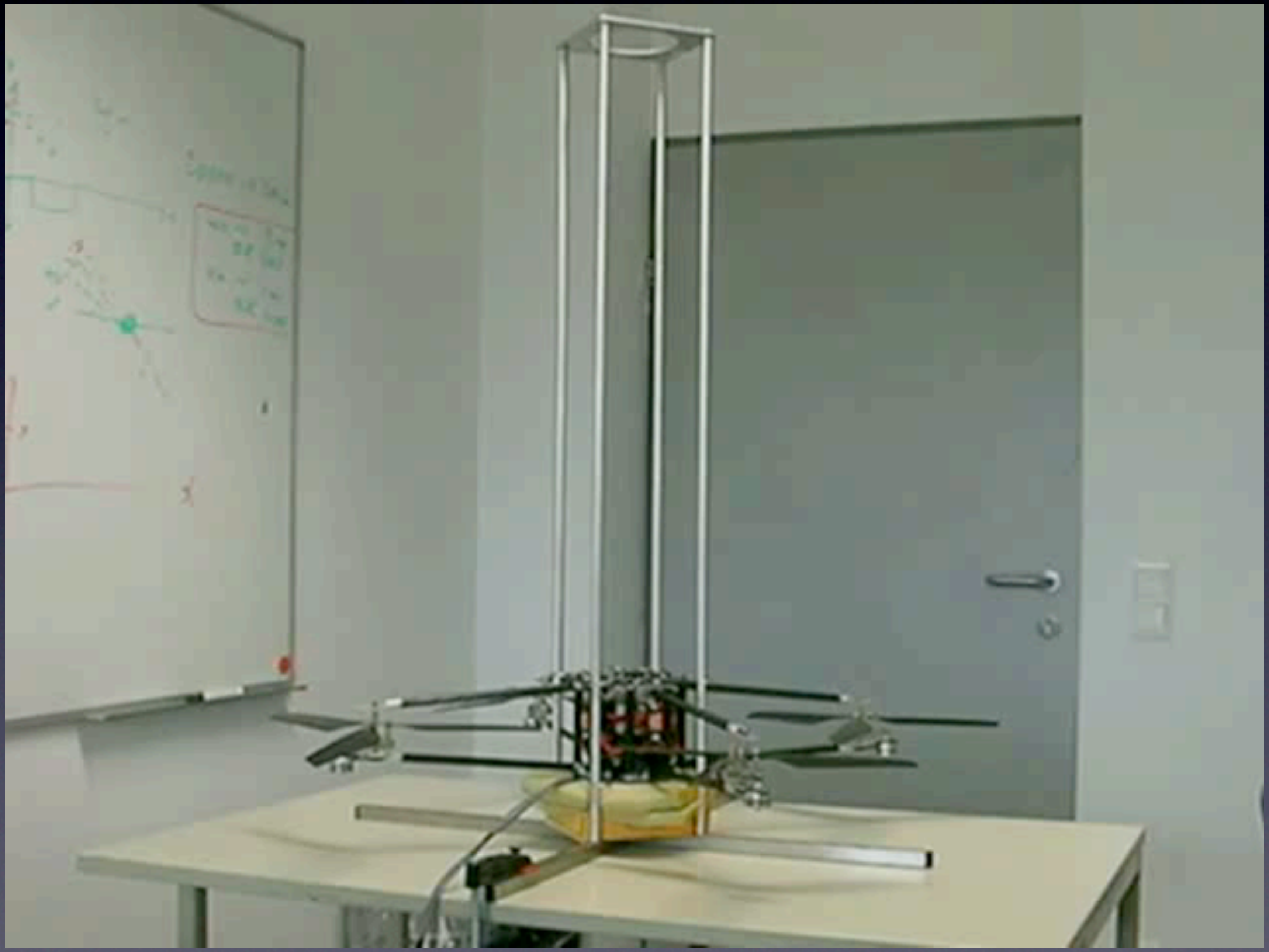
353 Signals 352

351

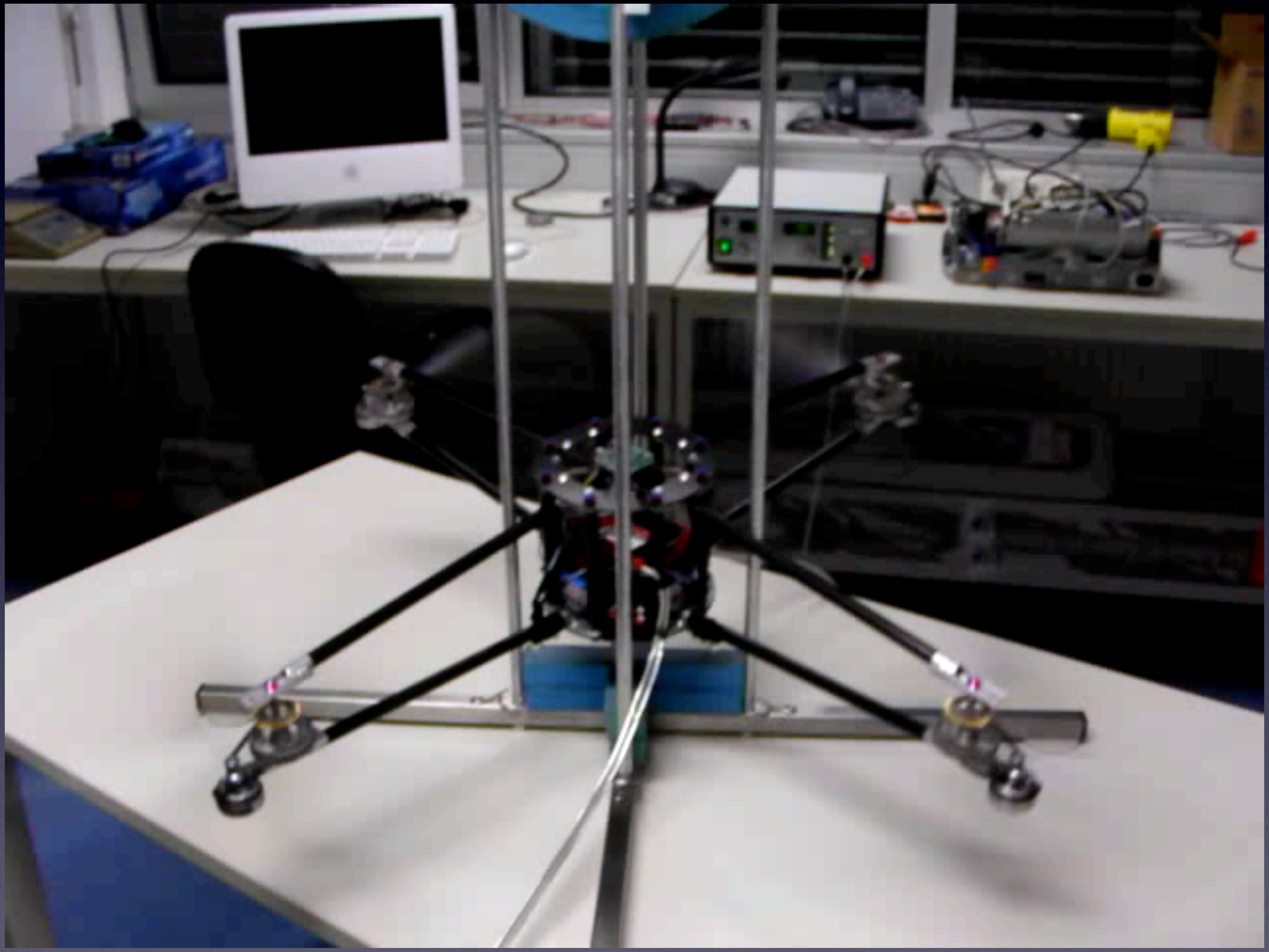

JAviator3D
JAviator3D - University of Salzburg


JAviator3D
JAviator3D - University of Salzburg

Oops

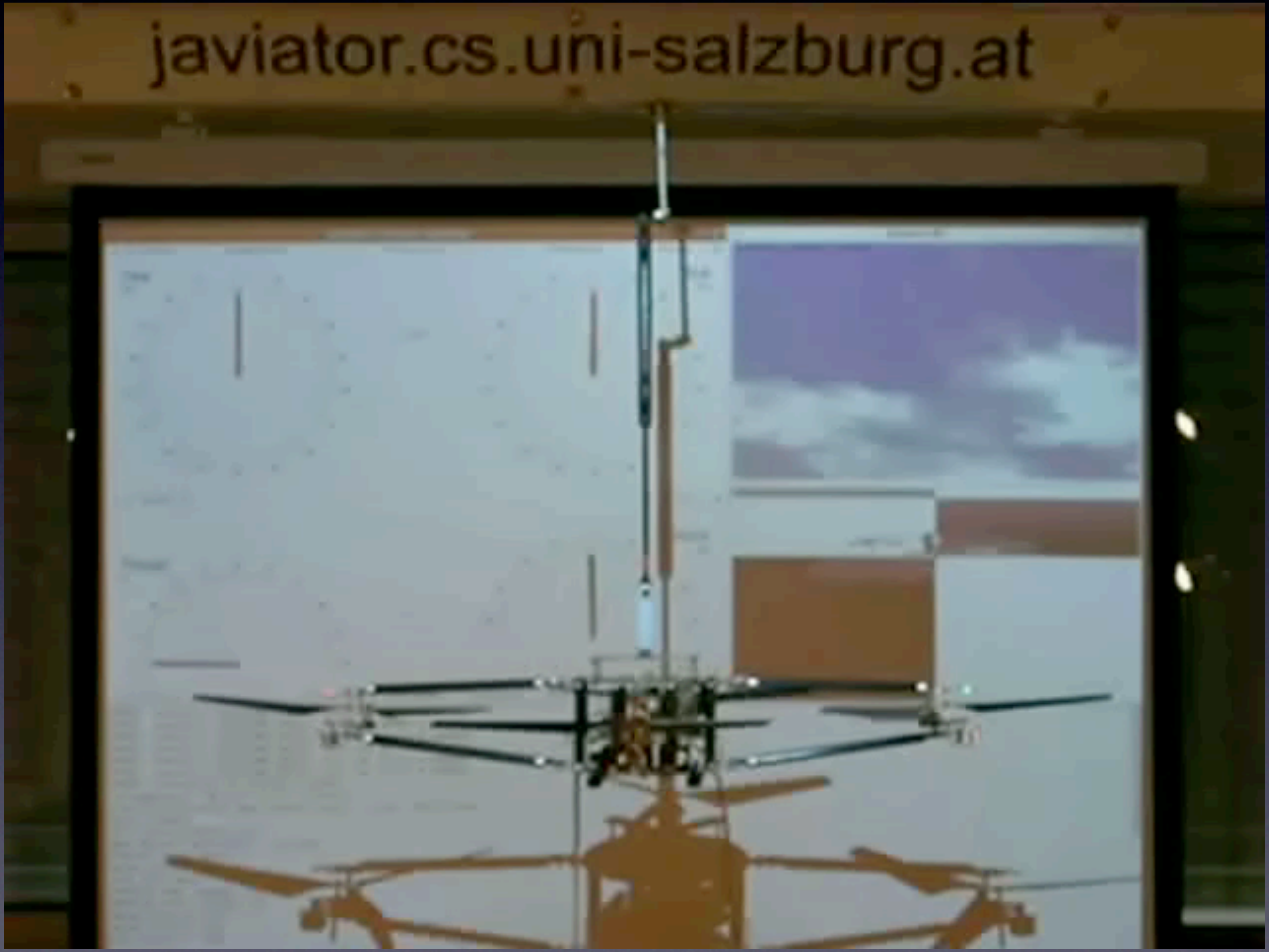


Flight Control

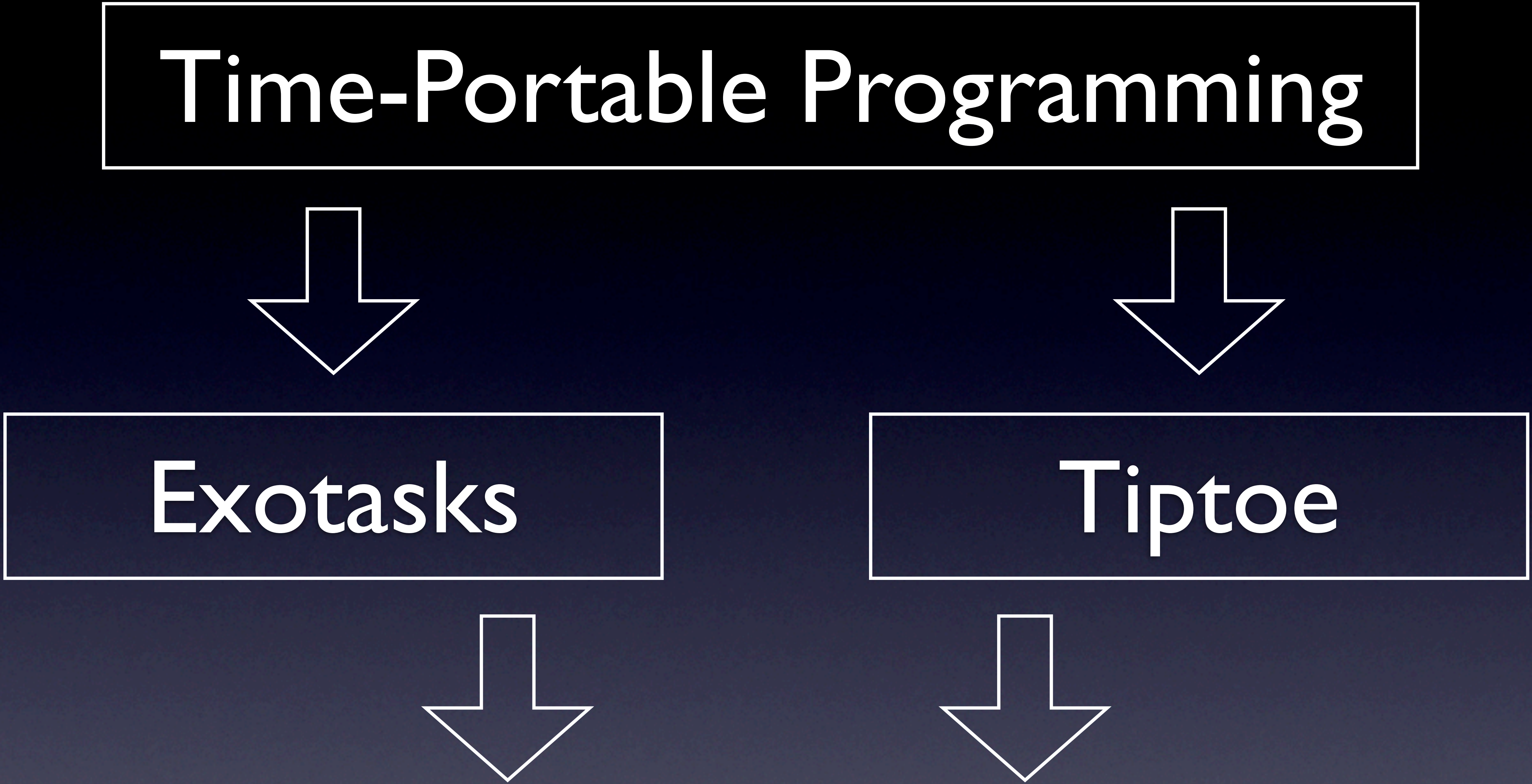


Free Flight

Yaw Control



[AIAA GNC 2008]



Time-Portable Programming

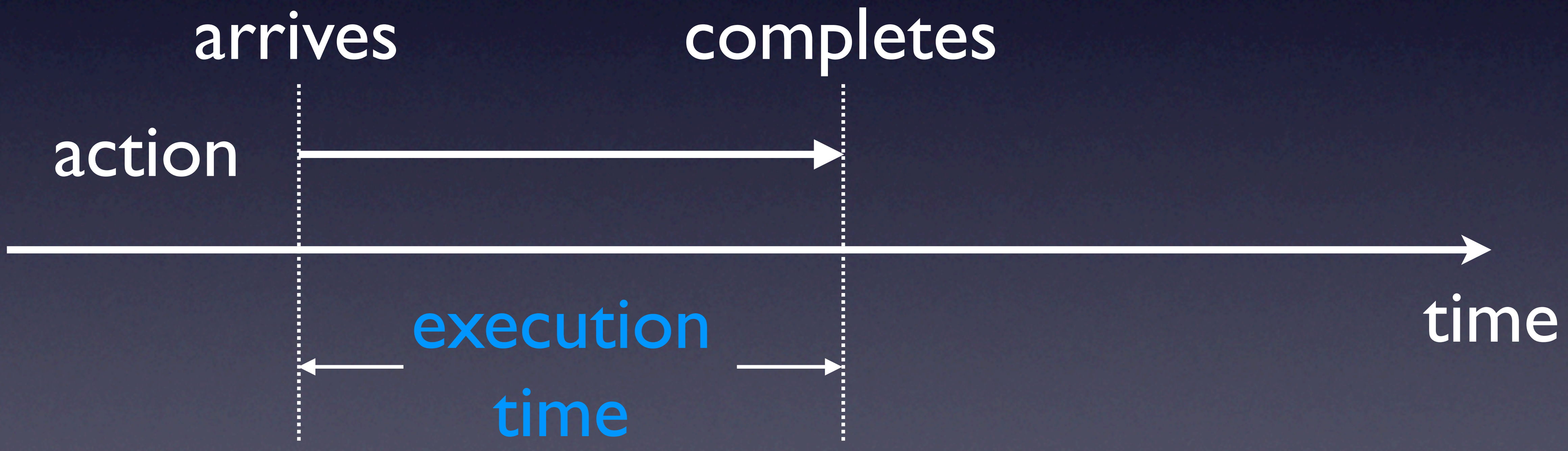
Exotasks

Tiptoe

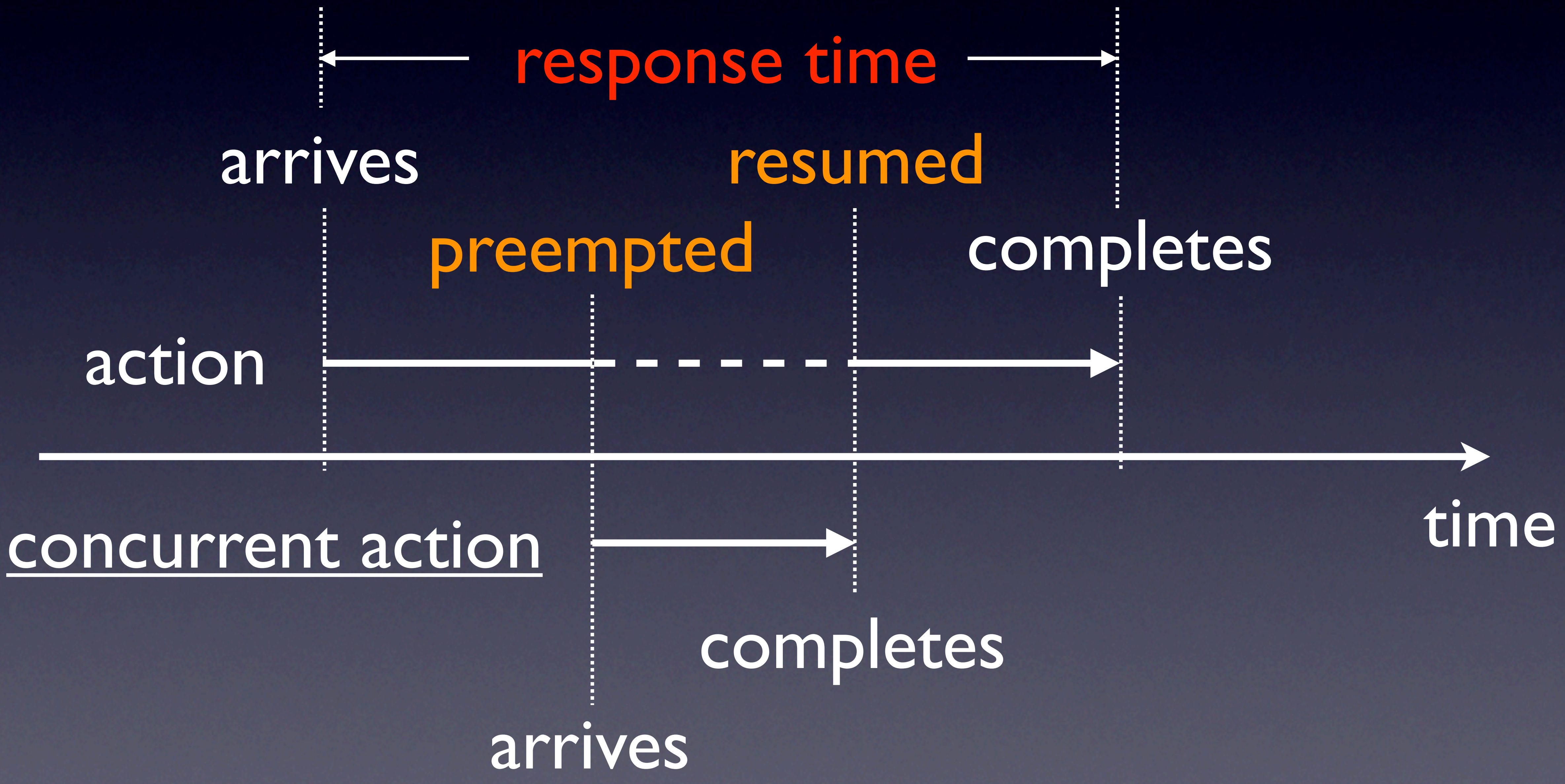
Outline

1. Time-Portable Programming
2. Exotasks
3. Tiptoe

Process Action



Concurrency



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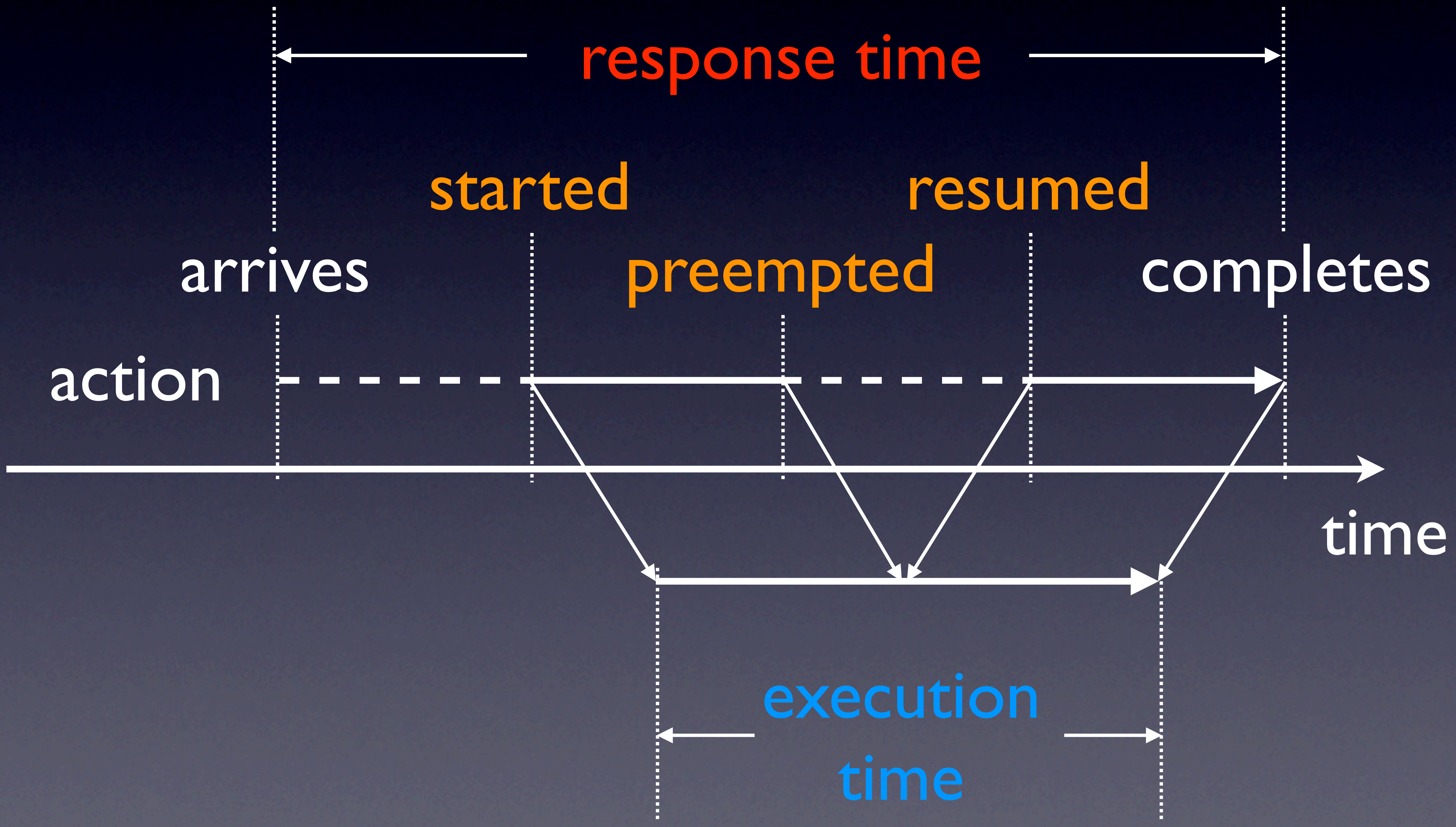
Execution and Response



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Time

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- The temporal behavior of a process action is characterized by its execution time and its response time

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- If the response times of the process actions of a program are maintained across different hardware platforms (execution) and software workloads (concurrency), we say that the program is time-portable
- Time-portable programming specifies and implements upper AND lower bounds on response times of process actions

Correctness

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1. The execution time of a process action is determined by the process action and the executing processor.

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    - Worst-case execution time (WCET) analysis

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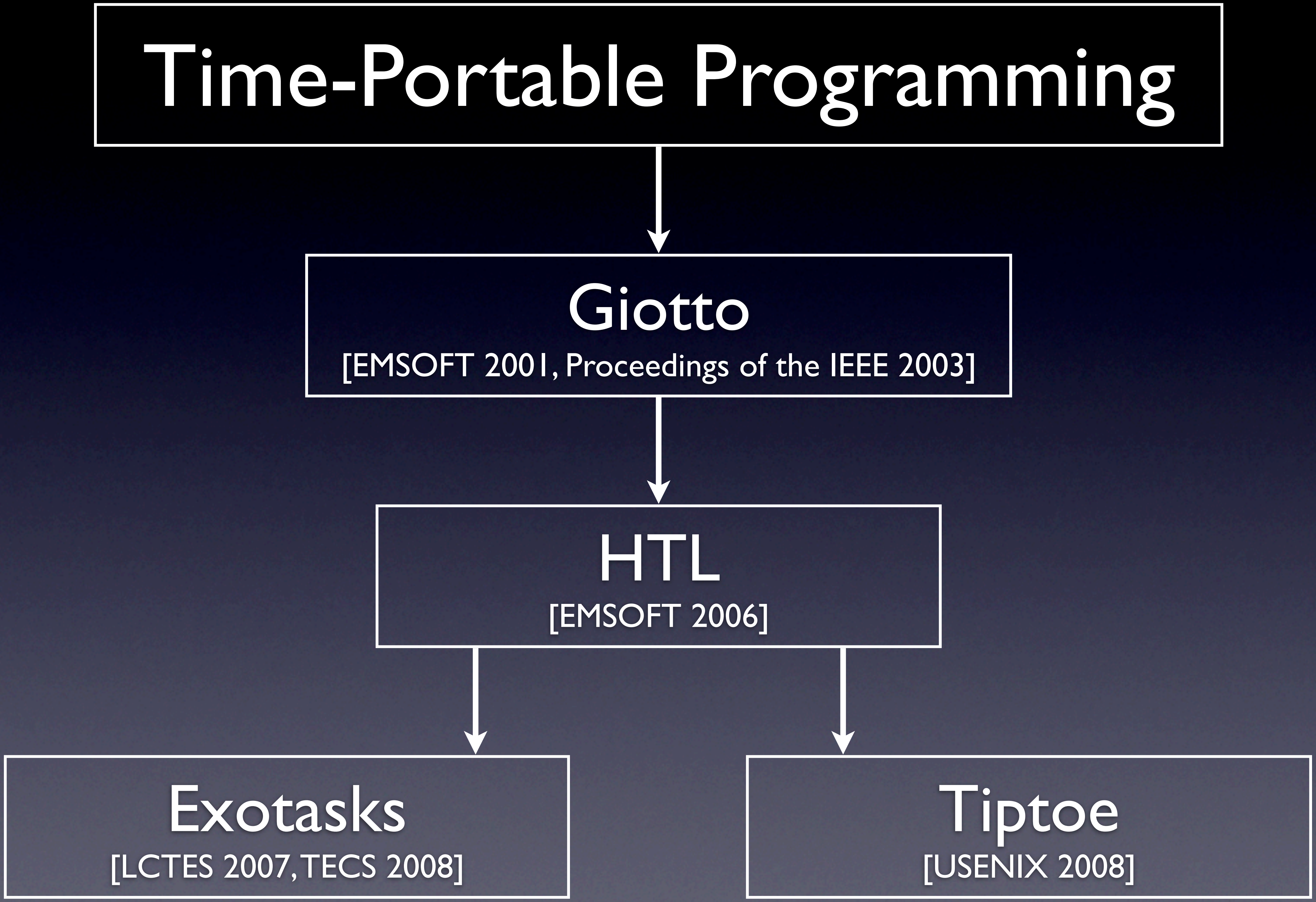
    - Worst-case execution time (WCET) analysis

2. The response time of a process action is determined by the entire system of processes executing on a processor.

    - Real-time scheduling theory



Time-Portable Programming

Giotto

[EMSOFT 2001, Proceedings of the IEEE 2003]

HTL

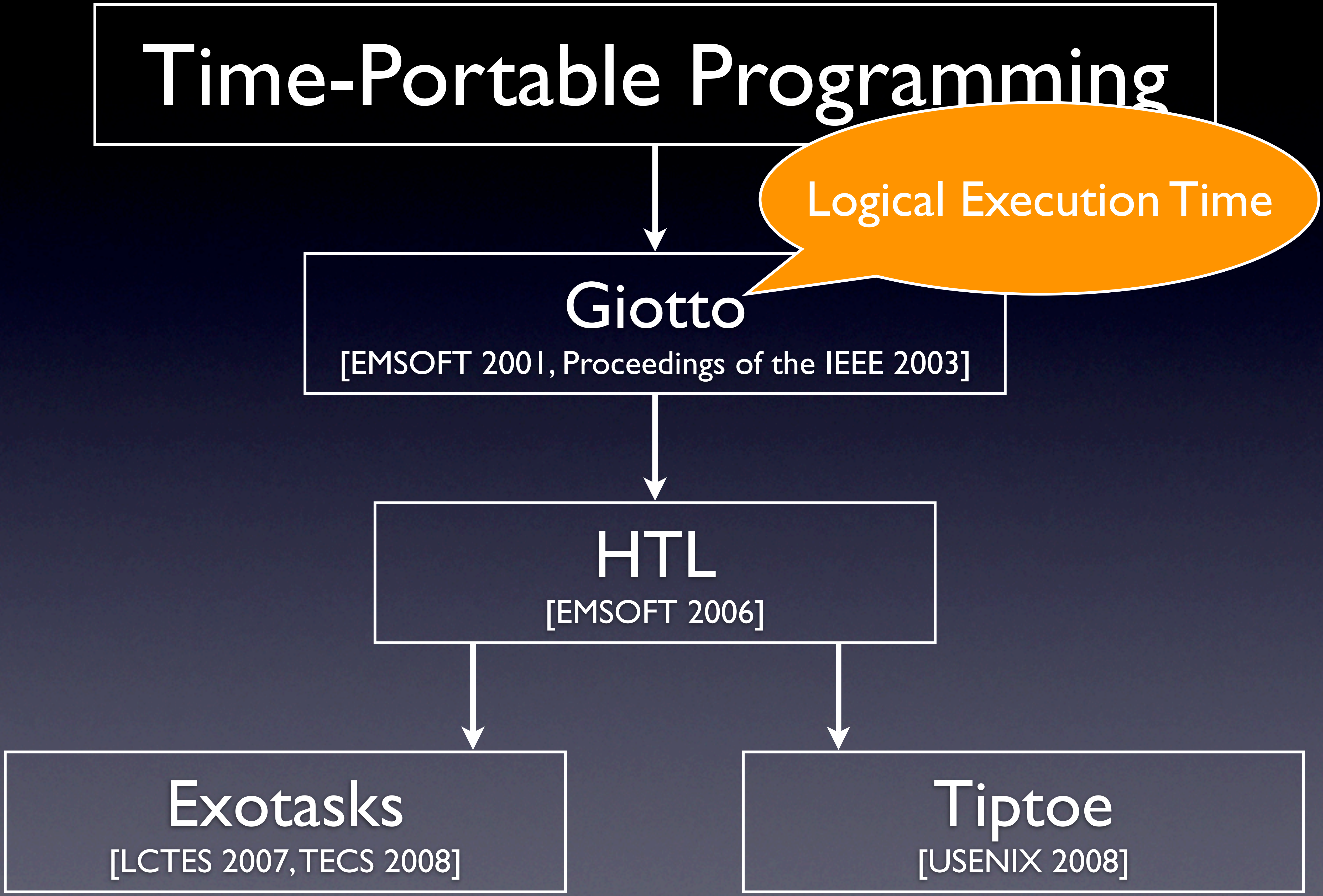
[EMSOFT 2006]

Exotasks

[LCTES 2007, TECS 2008]

Tiptoe

[USENIX 2008]



Time-Portable Programming

Logical Execution Time

Giotto

[EMSOFT 2001, Proceedings of the IEEE 2003]

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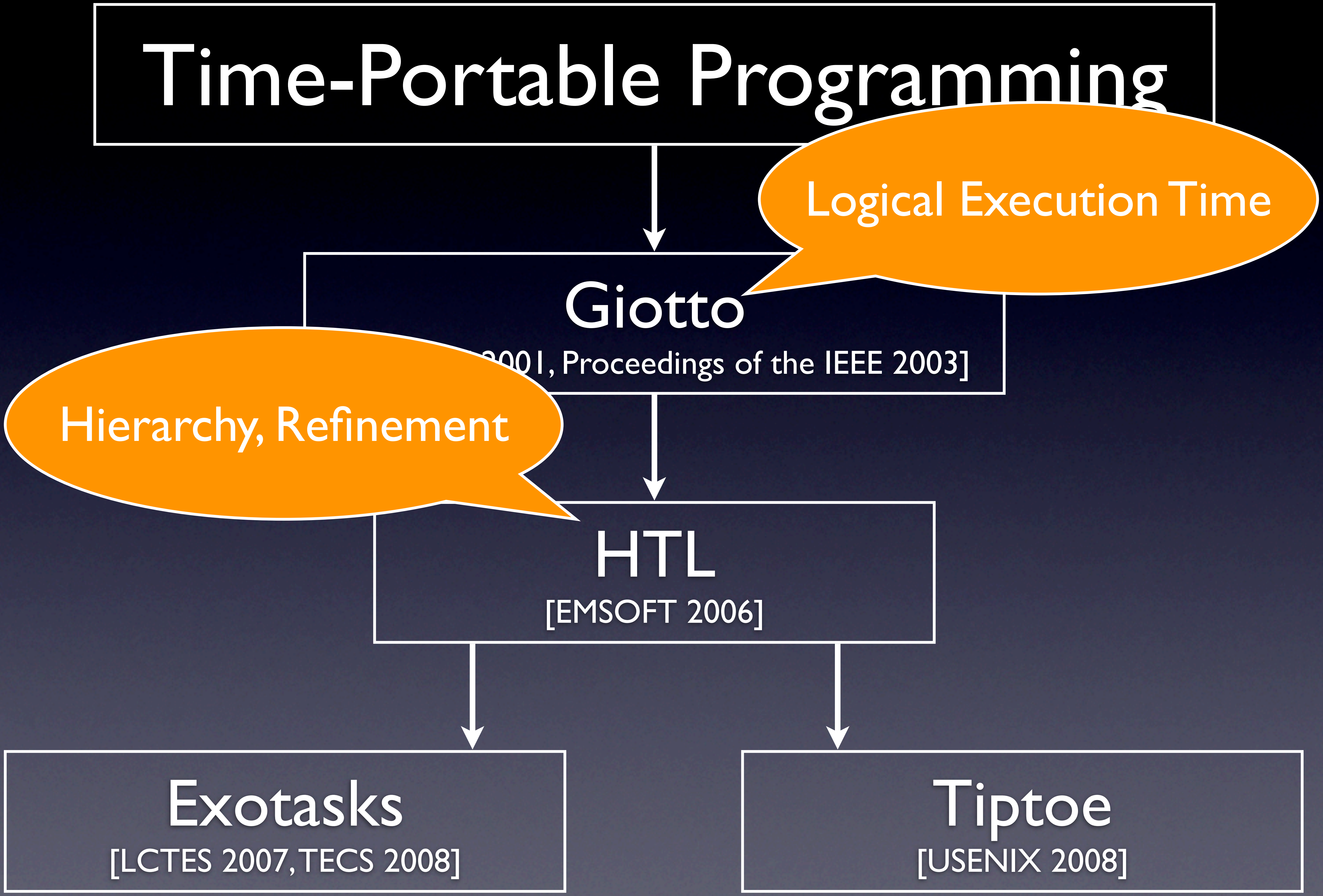

Time-Portable Programming

Logical Execution Time

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2001, Proceedings of the IEEE 2003]

Hierarchy, Refinement

HTL

[EMSOFT 2006]

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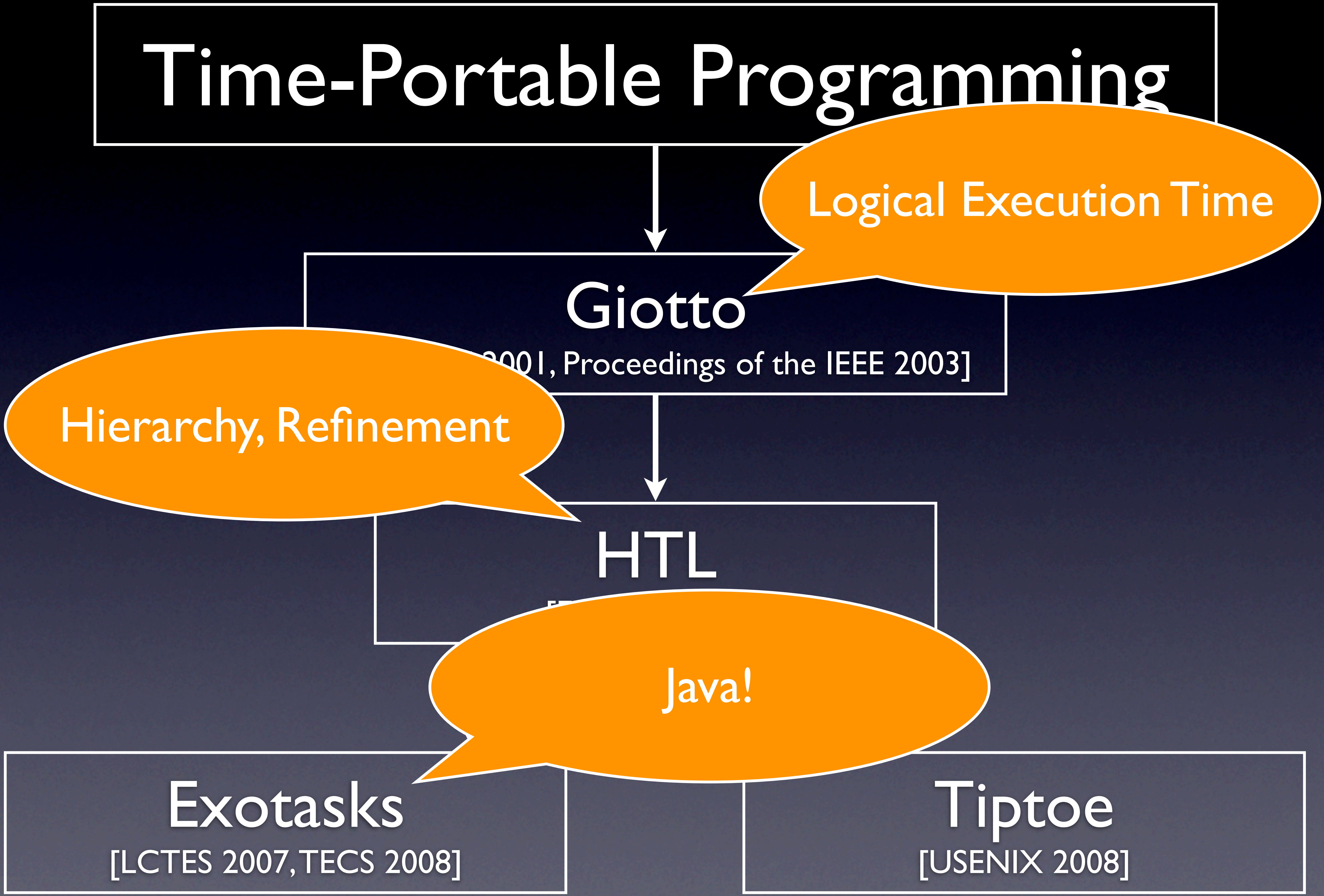
[USENIX 2008]



Time-Portable Programming

Logical Execution Time

Giotto

2001, Proceedings of the IEEE 2003]

Hierarchy, Refinement

HTL

[

Java!

Exotasks

[LCTES 2007, TECS 2008]

Tiptoe

[USENIX 2008]

Outline

1. Time-Portable Programming
2. Exotasks
3. Tiptoe

Exotask Team#

- J. Auerbach, D.F. Bacon, V.T. Rajan (IBM Research)
- Daniel Iercan (TU Timisoara, Romania)

- Silviu Craciunas* (Univ. of Salzburg, Austria)
- Harald Röck (Univ. of Salzburg, Austria)
- Rainer Trummer (Univ. of Salzburg, Austria)

#Supported by a 2007 IBM Faculty Award and the EU ArtistDesign Network of Excellence on Embedded Systems Design
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Exotasks

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- Alternative to Java threads

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- Single-threaded code: validated Java subset

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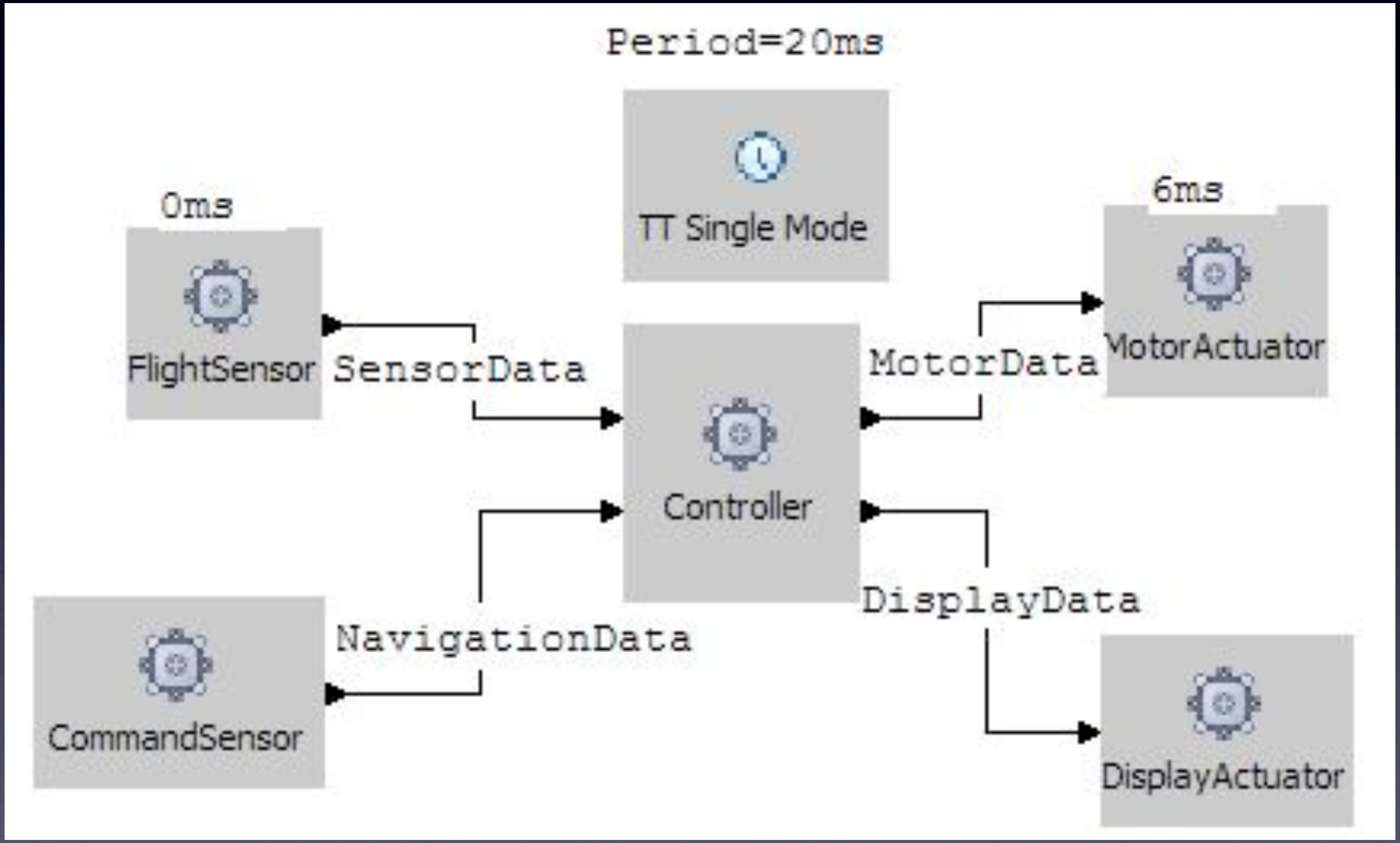
- Alternative to Java threads
- Single-threaded code: validated Java subset
- Isolated in space: private heaps, individual GC
- Communicate by message-passing Java objects
- Isolated in time: HTL semantics
- Other semantics are possible: scheduler plugins

Visual Syntax



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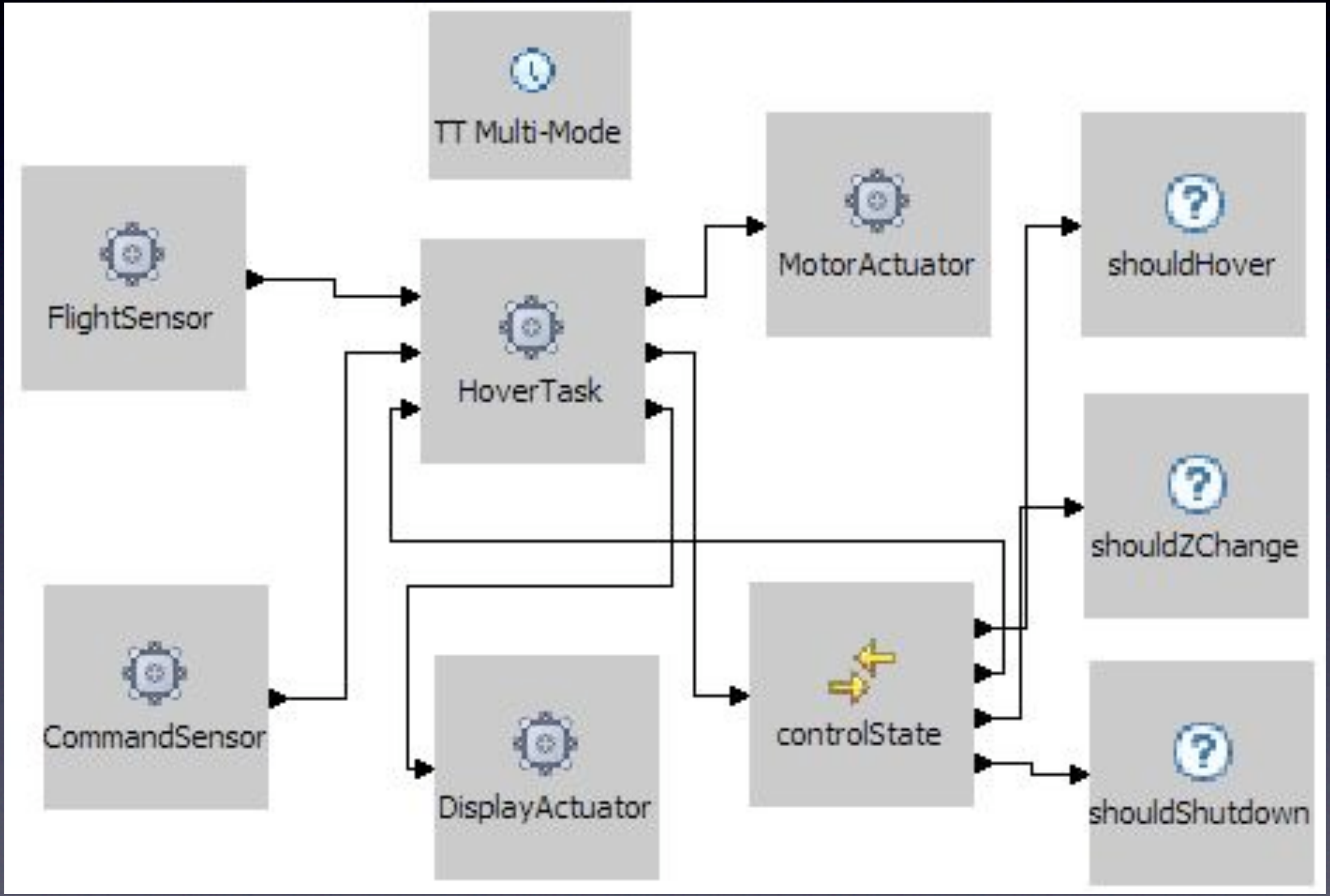
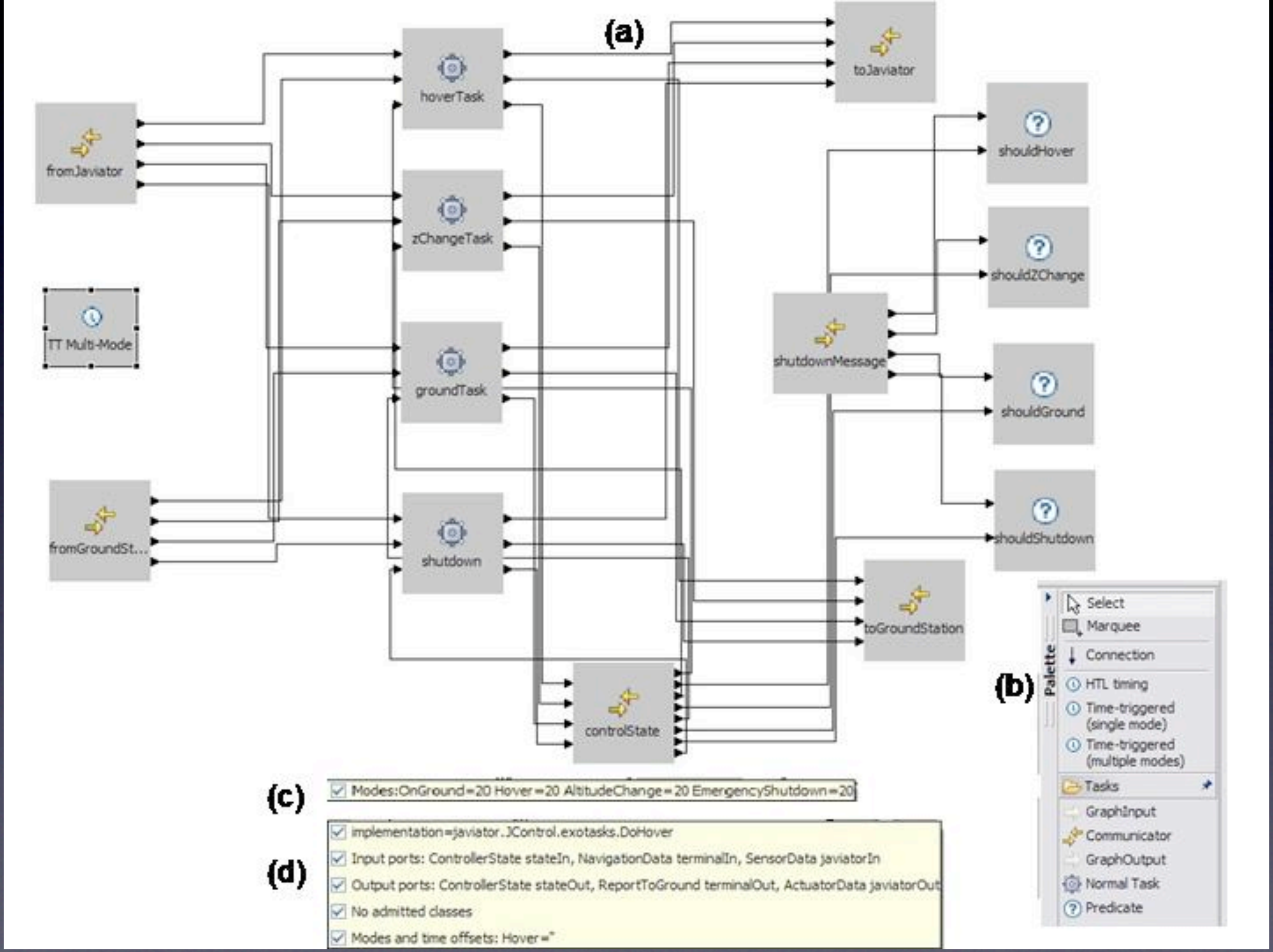
Multi-Mode Programming



Eclipse Plugin



☑ Modes:OnGround=20 Hover=20 AltitudeChange=20 EmergencyShutdown=20

☑ implementation=javiator.JControl.exotasks.DoHover

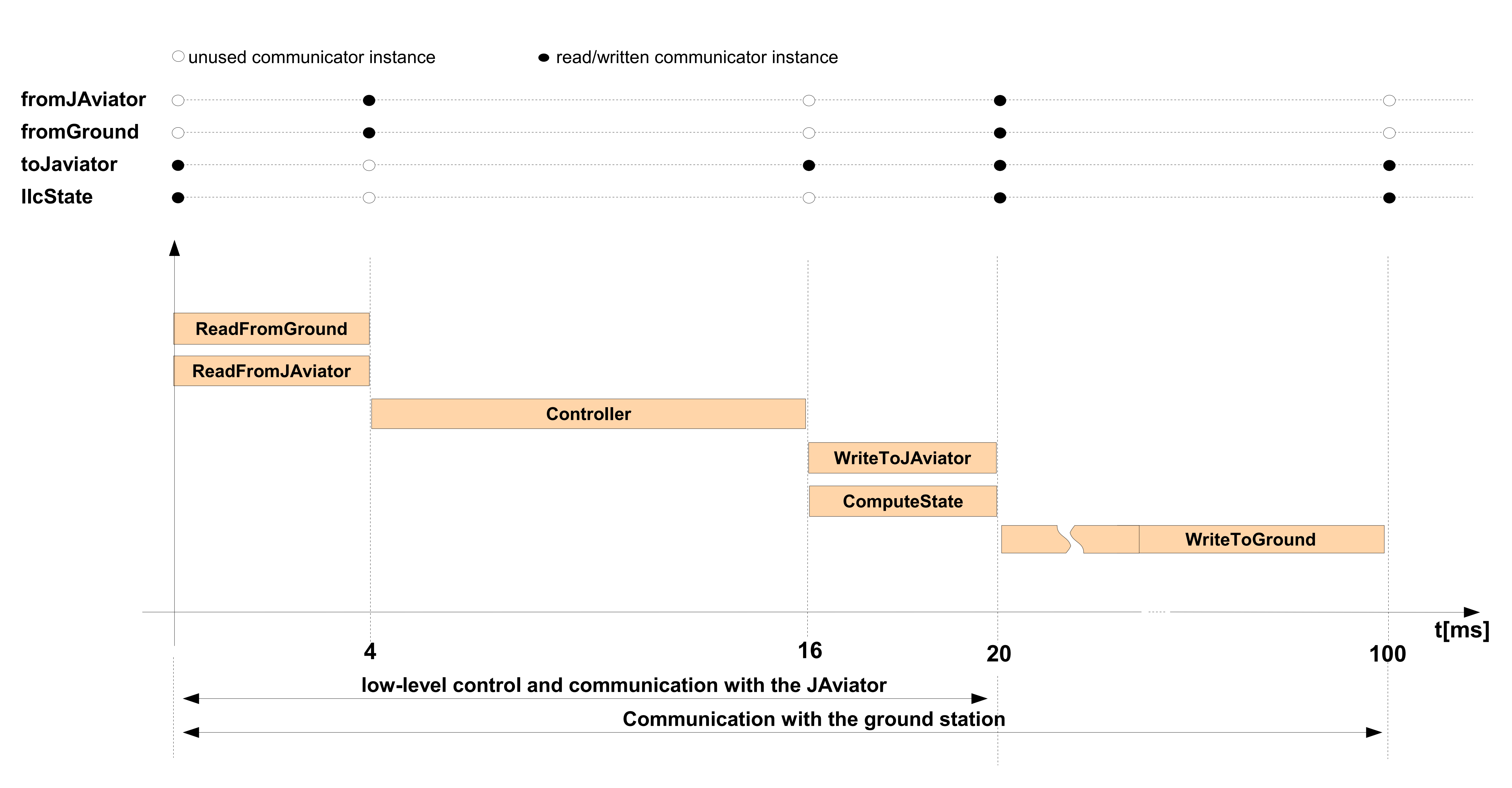
☑ Input ports: ControllerState stateIn, NavigationData terminalIn, SensorData javiatorIn

☑ Output ports: ControllerState stateOut, ReportToGround terminalOut, ActuatorData javiatorOut

☑ No admitted classes

☑ Modes and time offsets: Hover="

HTL Semantics


○ unused communicator instance
● read/written communicator instance
fromJAviator
fromGround
toJaviator
llcState
ReadFromGround
ReadFromJAviator
Controller
WriteToJAviator
ComputeState
WriteToGround
t[ms]
4
16
20
100
low-level control and communication with the JAviator
Communication with the ground station

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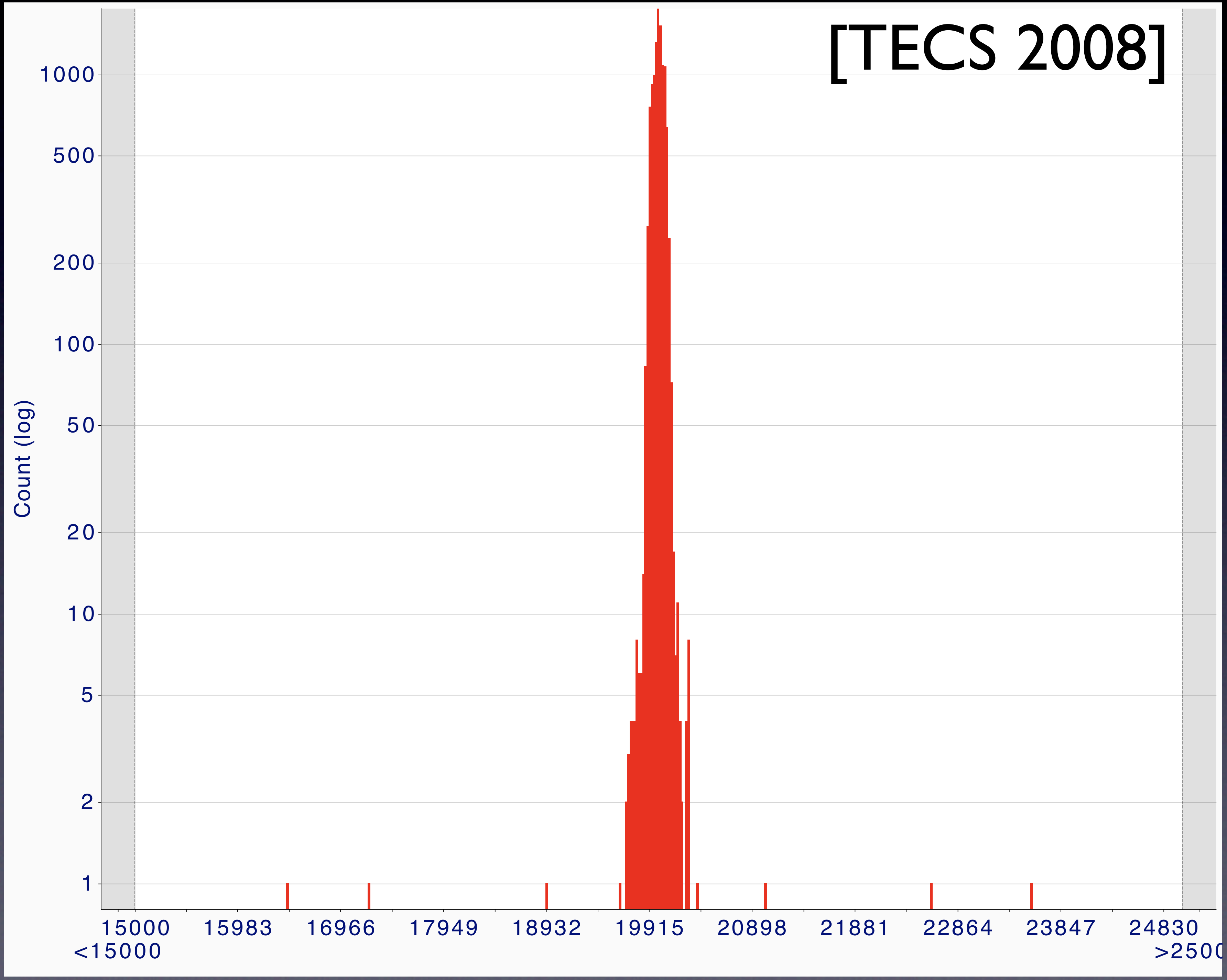
Performance Histogram



@256KB/s

~1ms

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1. Time-Portable Programming
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3. Tiptoe

tiptoe.cs.uni-salzburg.at#

- Silviu Craciunas* (Programming Model)
- Hannes Payer* (Memory Management)
- Harald Röck (VM, Scheduling)
- Ana Sokolova* (Theoretical Foundation)
- Horst Stadler (I/O Subsystem)

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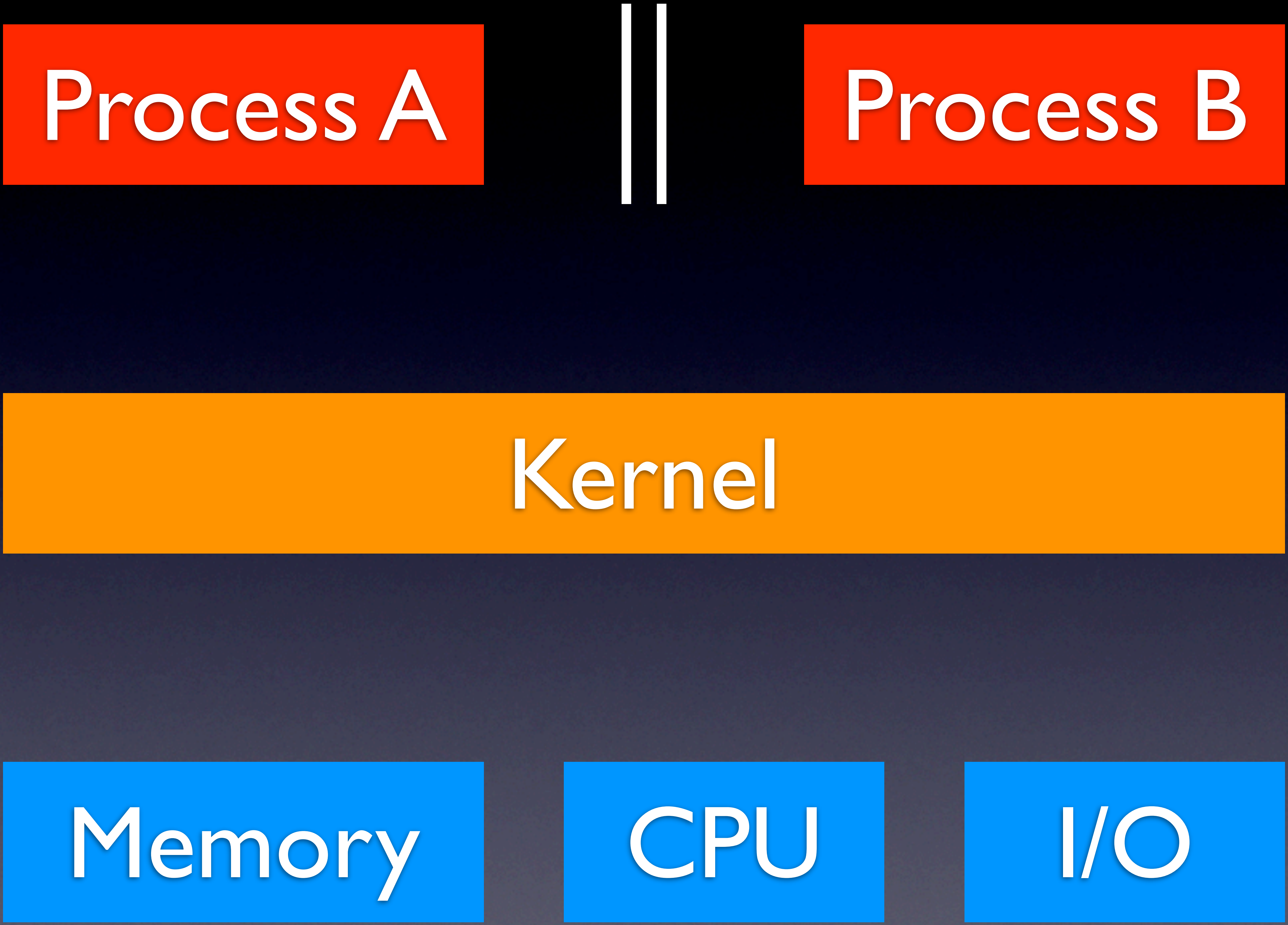

Process A || Process B

Kernel

Memory

CPU

I/O

Example

Example

- Consider a process that reads a video stream from a network connection, compresses it, and stores it on disk, all in real time

Example

- Consider a process that reads a video stream from a network connection, compresses it, and stores it on disk, all in real time
- The process periodically adapts the frame rate, allocates memory, receives frames, compresses them, writes the result to disk, and finally deallocates memory to prepare for the next iteration

Pseudo Code

```
loop {
  int number_of_frames = determine_rate();

  allocate_memory(number_of_frames);
  read_from_network(number_of_frames);

  compress_data(number_of_frames);

  write_to_disk(number_of_frames);
  deallocate_memory(number_of_frames);
} until (done);
```

Pseudo Code

Workload Parameter

```
                 ames = determine_rate();

   allocate_memory(number_of_frames);
   read_from_network(number_of_frames);

   compress_data(number_of_frames);

   write_to_disk(number_of_frames);
   deallocate_memory(number_of_frames);
} until (done);
```

[USENIX 2008]

- malloc(n) takes O(1)
- free(n) takes O(1) (or O(n) if compacting)
- access takes one indirection

- memory fragmentation is bounded and predictable in constant time

Tiptoe Programming Model

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- Process actions are characterized by their execution time and response time in terms of their workload parameters

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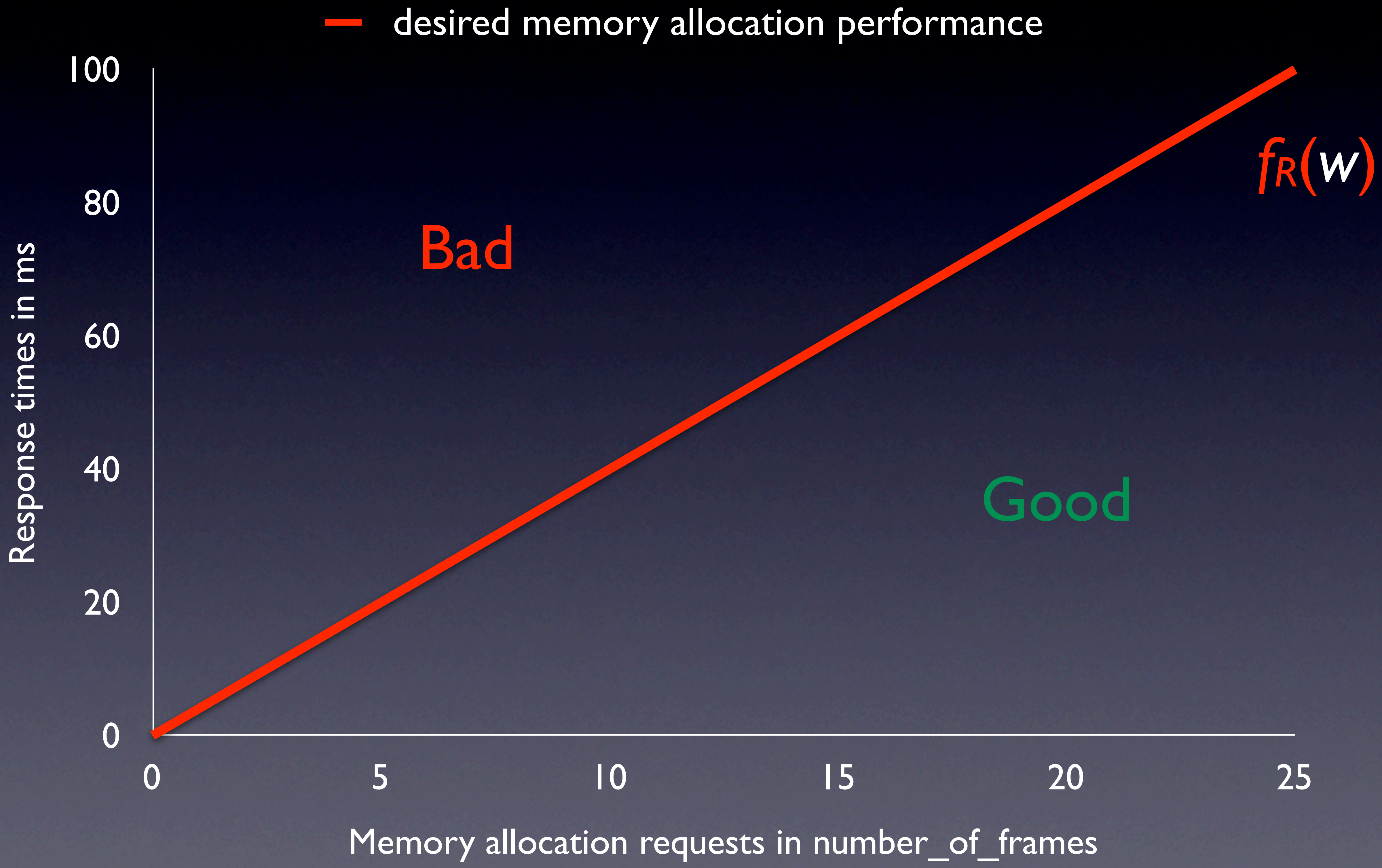
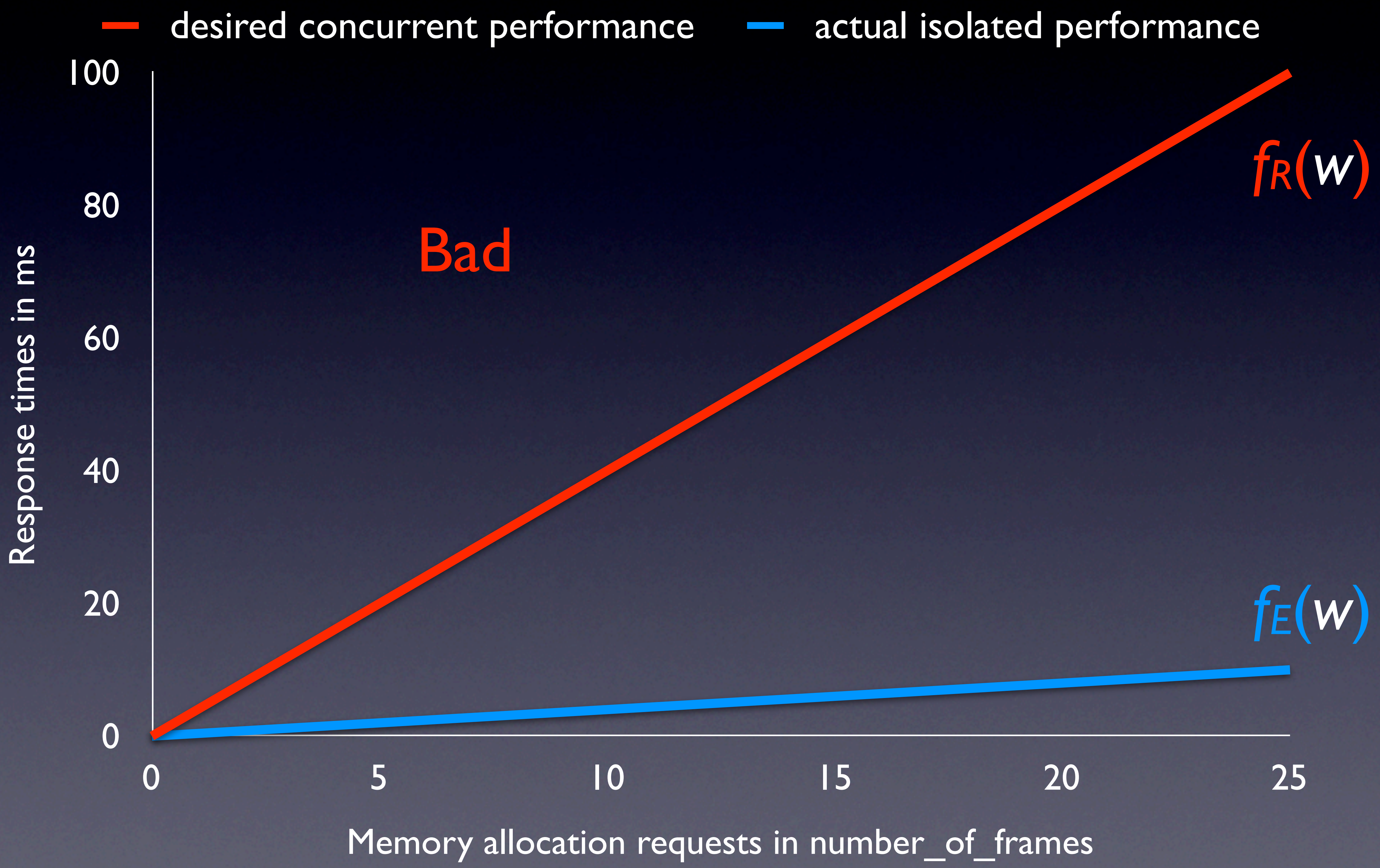
Response-Time Function



Execution-Time Function



Utilization Function:

$$f_U(w) = \frac{f_E(w)}{f_R(w)}$$

here, we have:

$f_U(w)$ = 10% (for w>0)

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Throughput

f_R(1 frame) = 4ms (250fps)

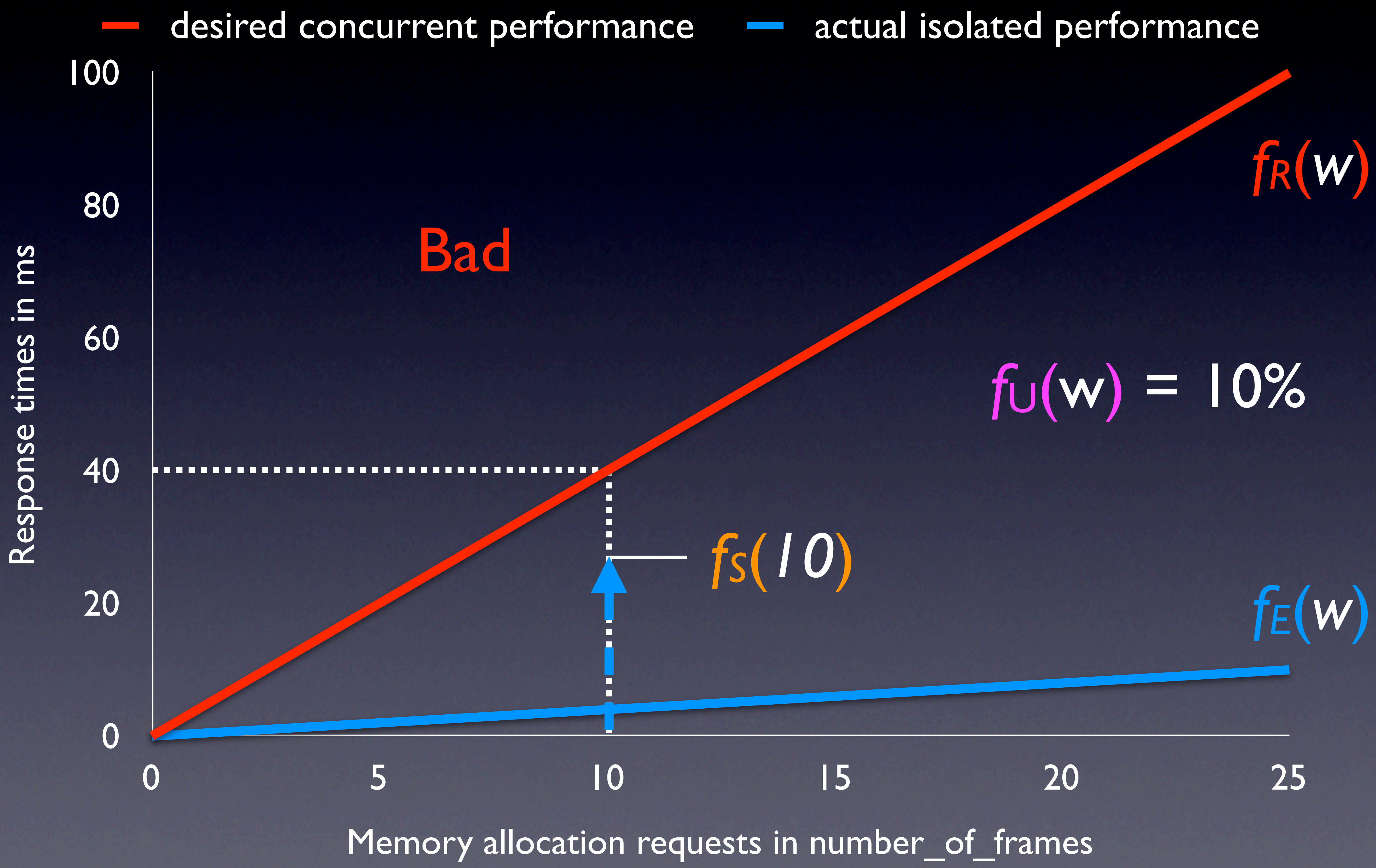
...

f_R(10 frames) = 40ms (250fps)

...

f_R(25 frames) = 100ms (250fps)

Scheduled Response Time



$$\forall w.\ f_S(w) \leq f_R(w)\ ?$$

Scheduling and Admission

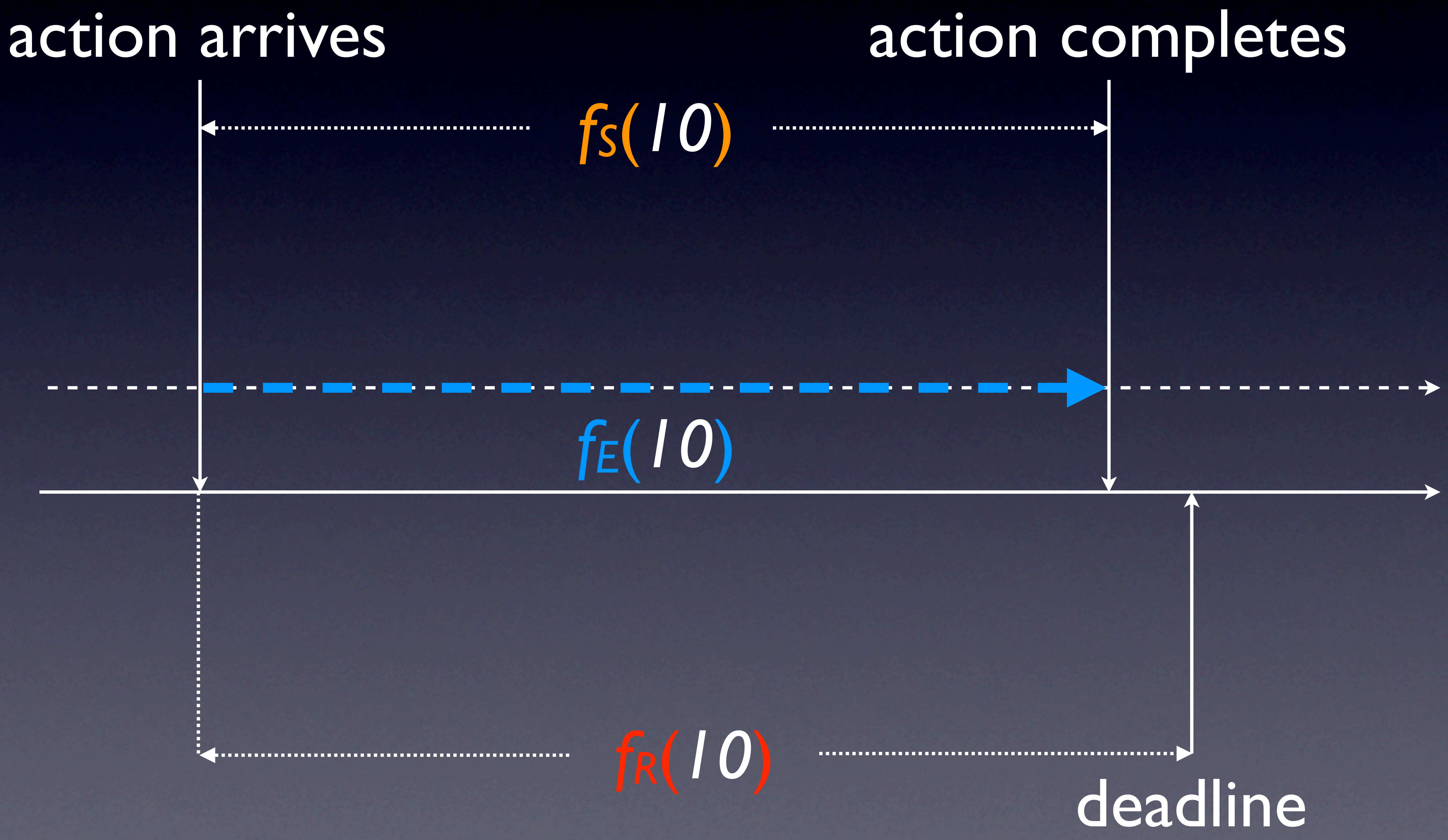
Scheduling and Admission

- Process scheduling:
  - How do we efficiently schedule processes on the level of individual process actions?

Scheduling and Admission

- Process scheduling:
  - How do we efficiently schedule processes on the level of individual process actions?
- Process admission:
  - How do we efficiently test schedulability of newly arriving processes

Just use EDF, or not?

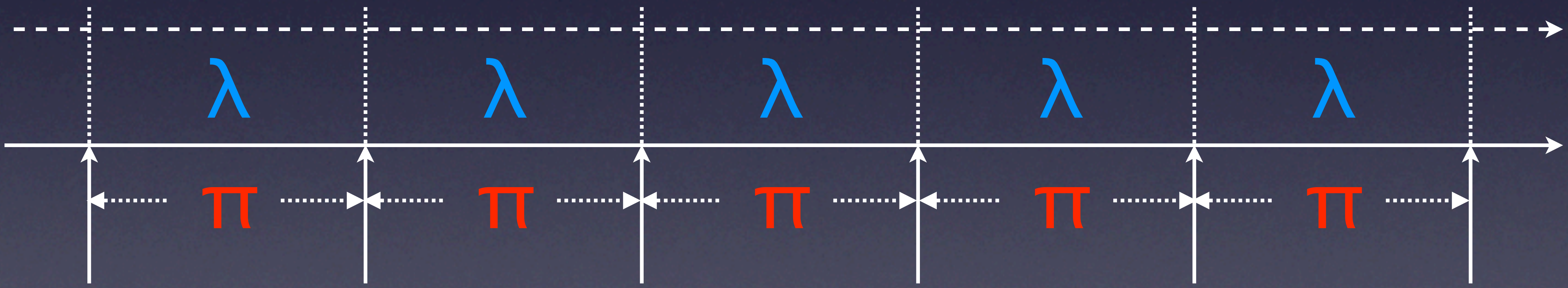


Virtual Periodic Resource

limit: λ

period: π

utilization: λ / π



Tiptoe Process Model

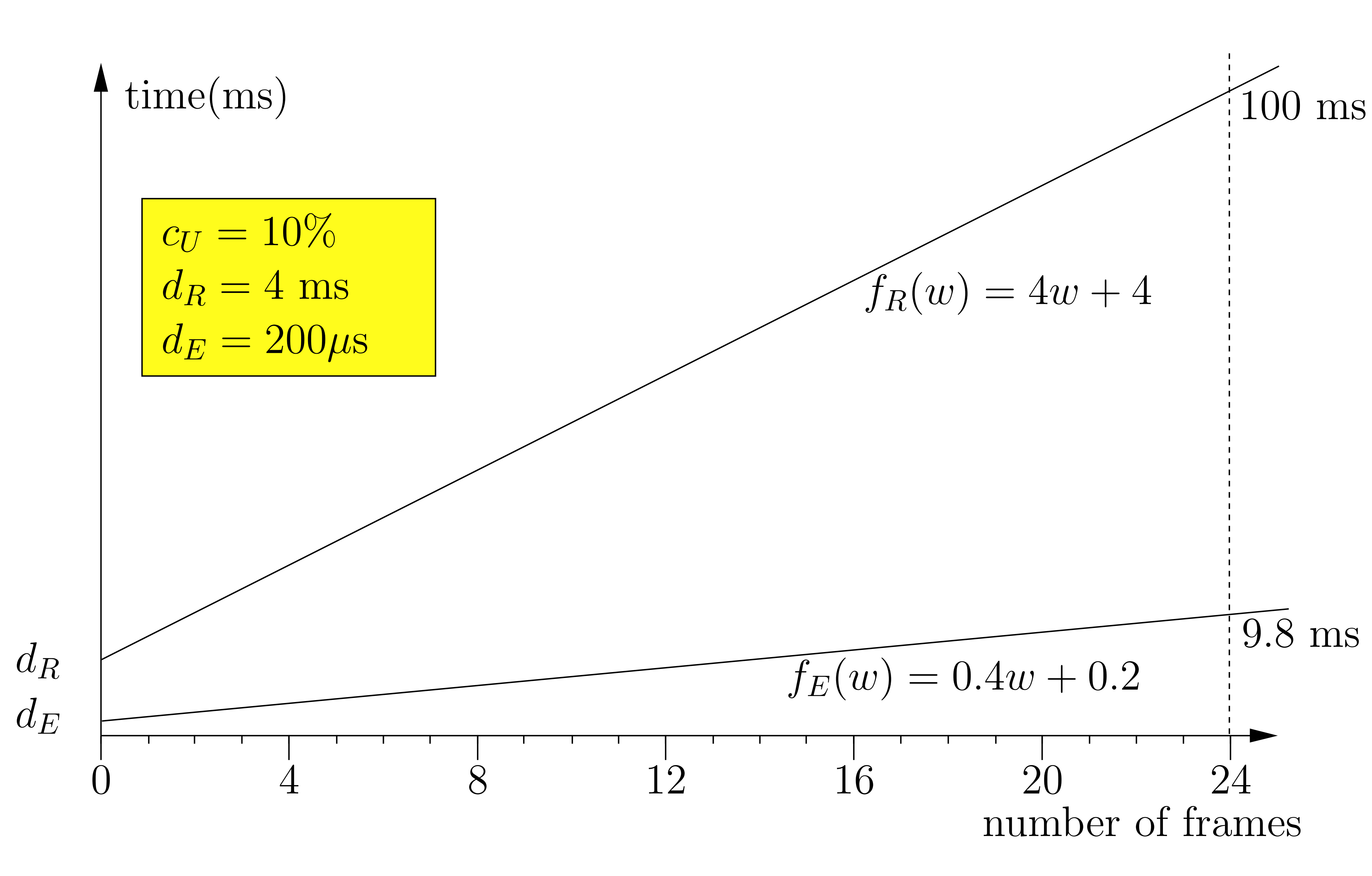
Tiptoe Process Model

- Each Tiptoe process declares a finite set of virtual periodic resources

Tiptoe Process Model

- Each Tiptoe process declares a finite set of virtual periodic resources
- Each process action of a Tiptoe process uses exactly one virtual periodic resource declared by the process

Refined Example



Here, we have again

$f_U(w) = 10\%$ (for $w>0$)

f_R(1 frame) = 8ms but only 125fps

...

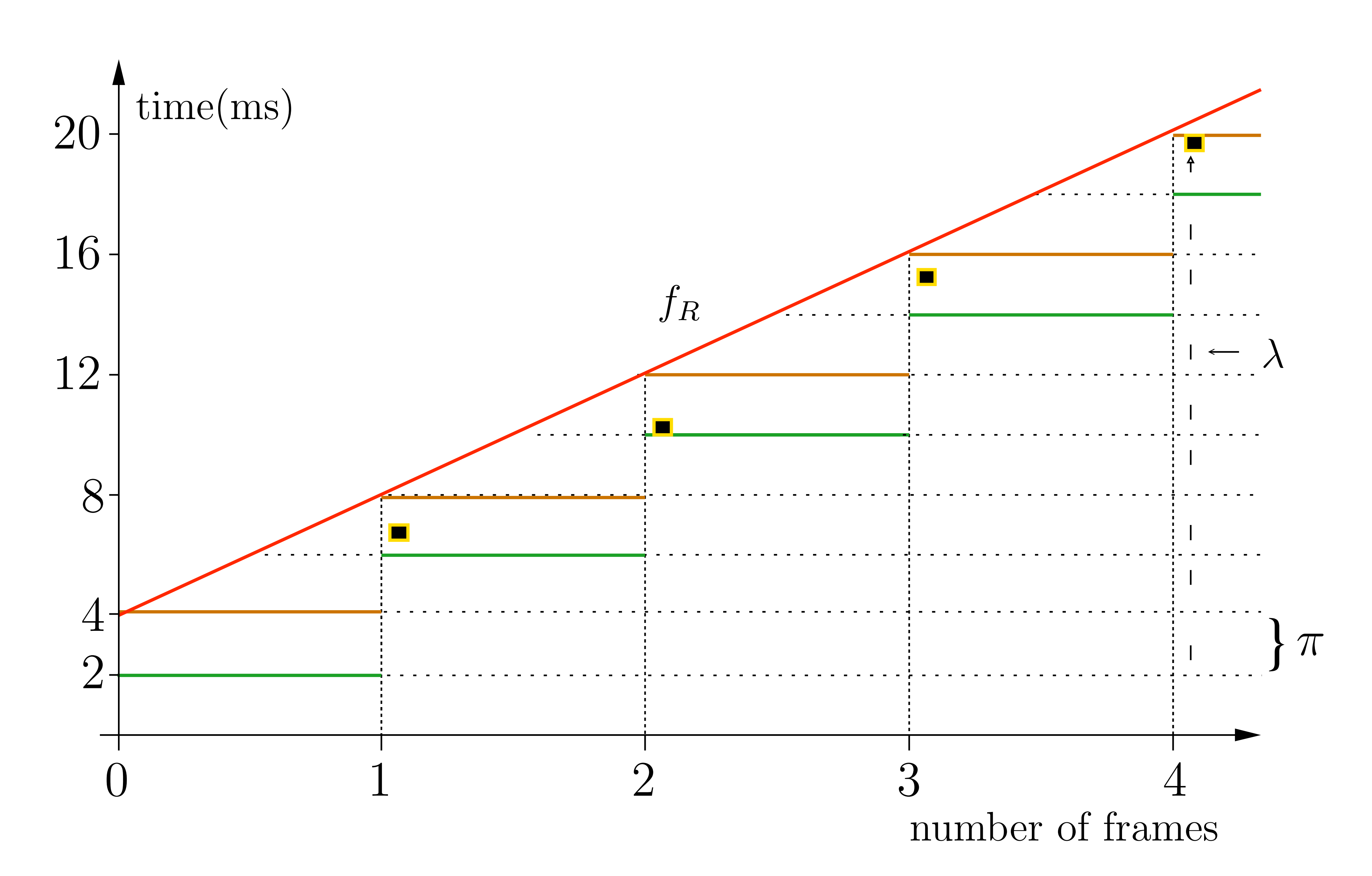
f_R(4 frames) = 20ms yields 200fps

...

f_R(24 frames) = 100ms yet 240fps

f_R(4 frames) = 20ms

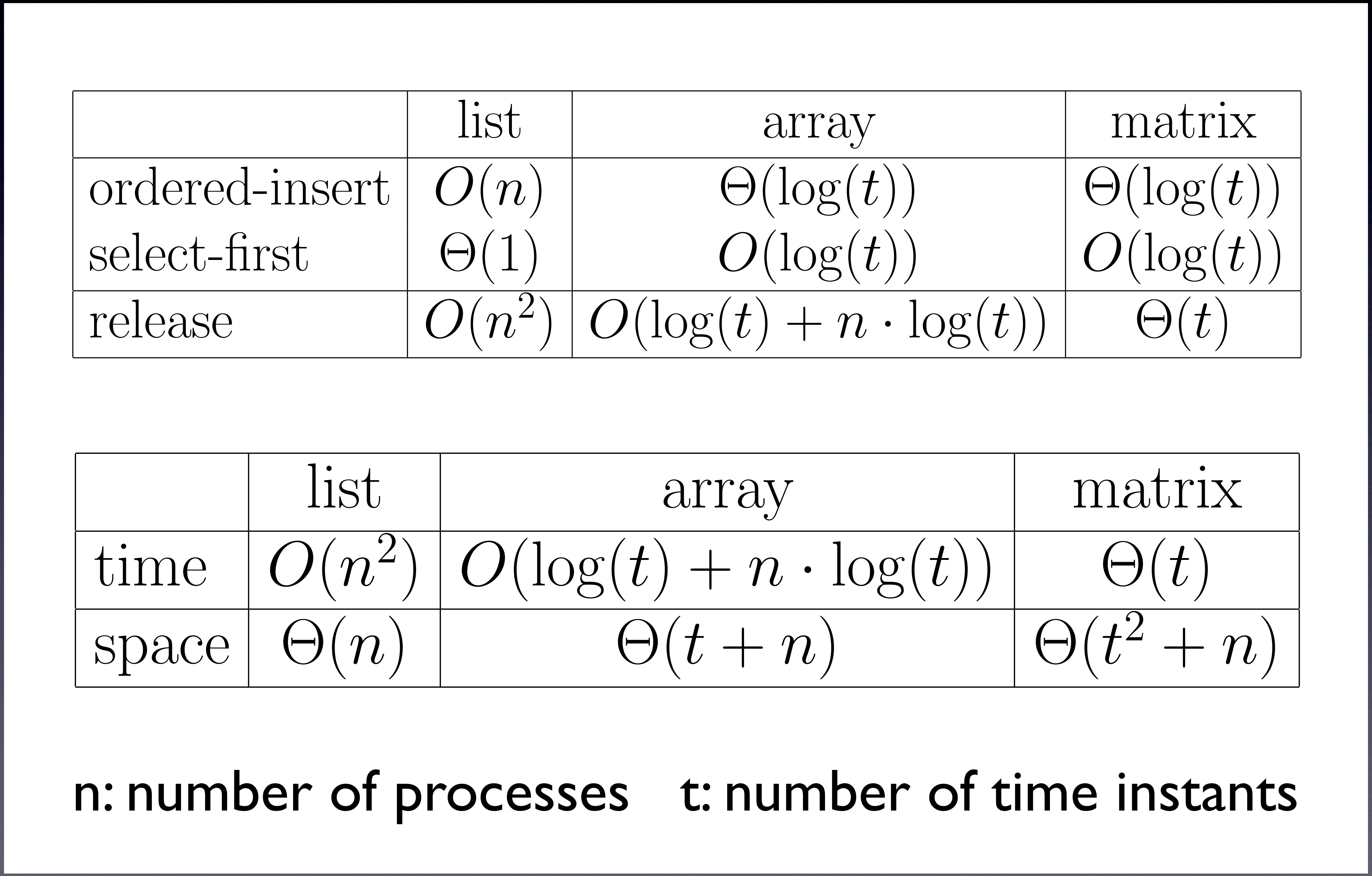
λ = 200µs; π = 2ms



Scheduling Algorithm

- maintains a queue of ready processes ordered by deadline and a queue of blocked processes ordered by release times
- ordered-insert processes into queues
- select-first processes in queues
- release processes by moving and sorting them from one queue to another queue

Time and Space

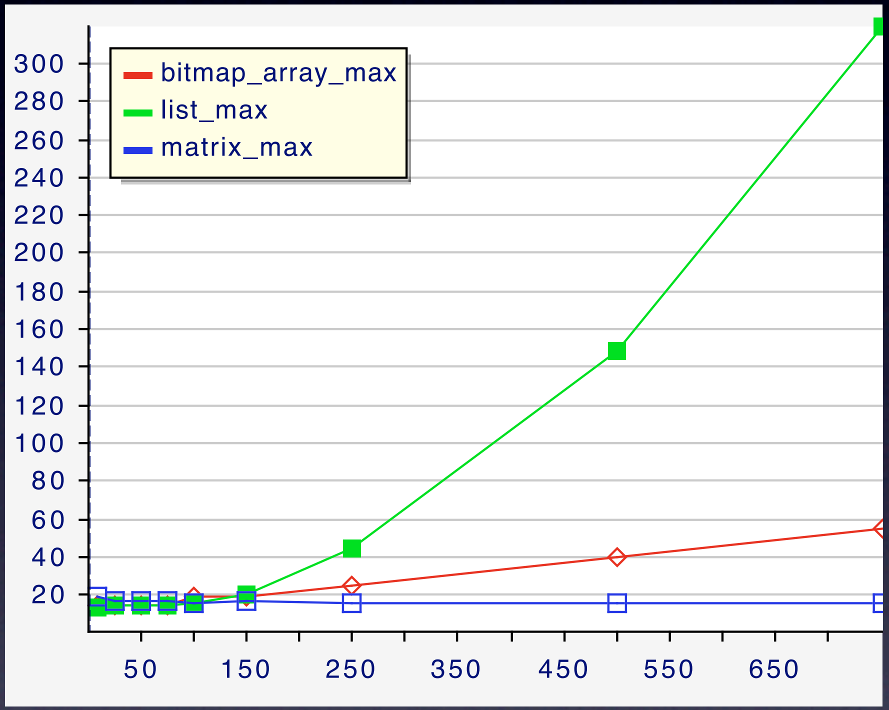


	list	array	matrix
ordered-insert	$O(n)$	$\Theta(\log(t))$	$\Theta(\log(t))$
select-first	$\Theta(1)$	$O(\log(t))$	$O(\log(t))$
release	$O(n^2)$	$O(\log(t) + n \cdot \log(t))$	$\Theta(t)$

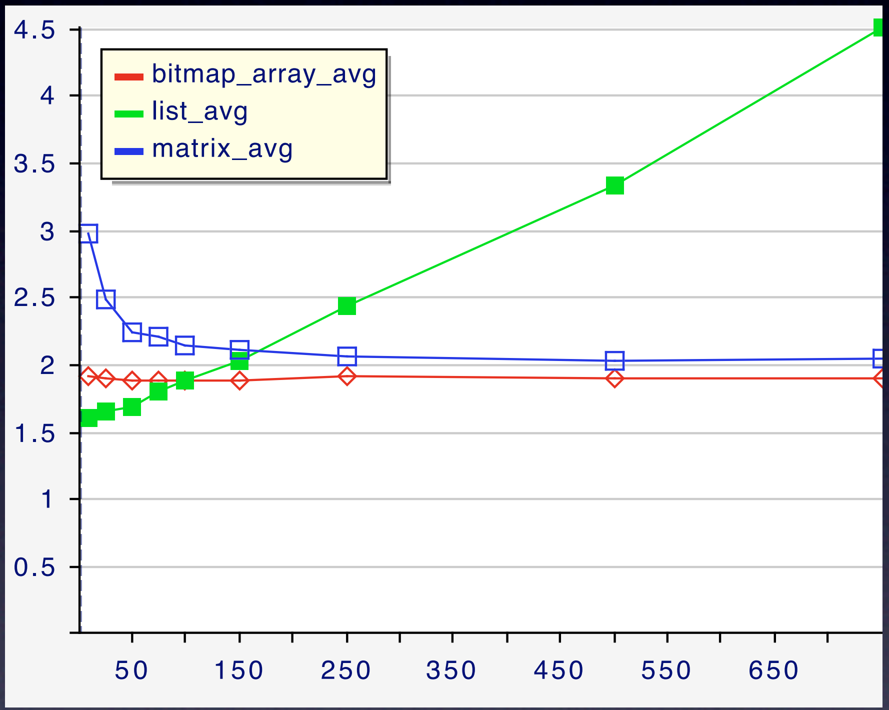
	list	array	matrix
time	$O(n^2)$	$O(\log(t) + n \cdot \log(t))$	$\Theta(t)$
space	$\Theta(n)$	$\Theta(t + n)$	$\Theta(t^2 + n)$

n: number of processes   t: number of time instants

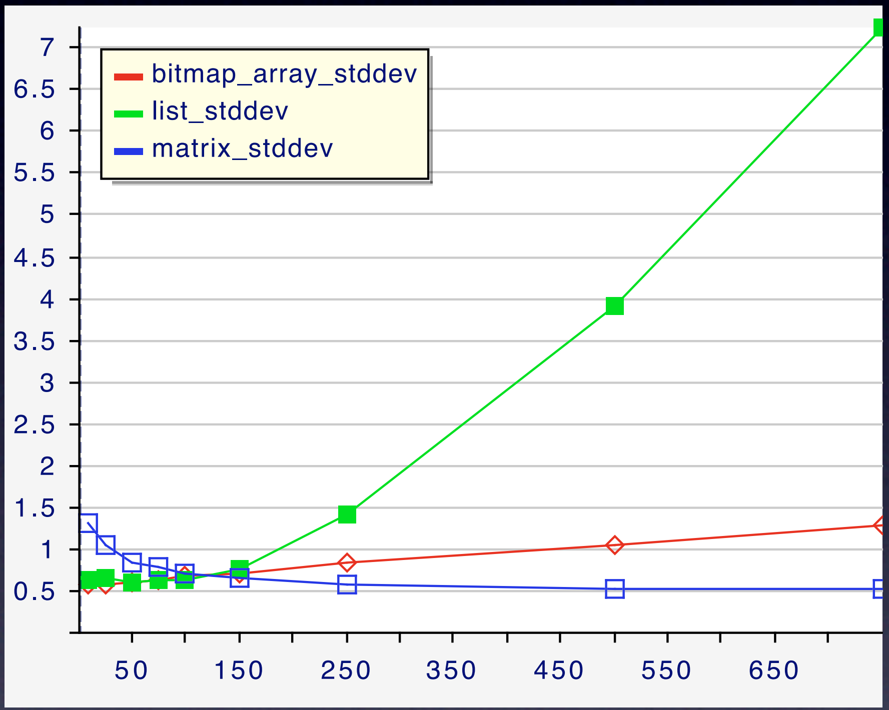
Scheduler Overhead



Max

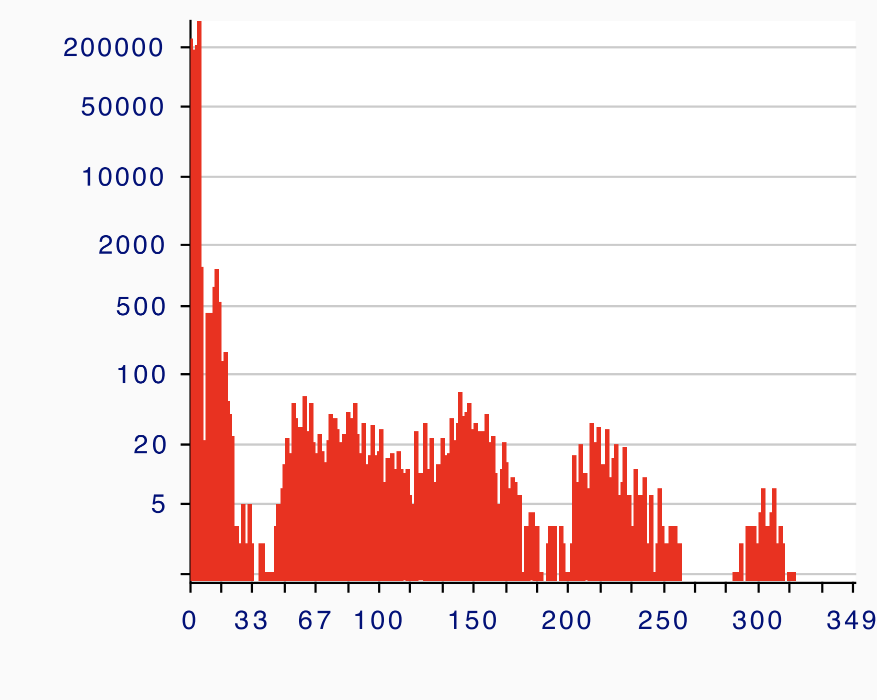


Average

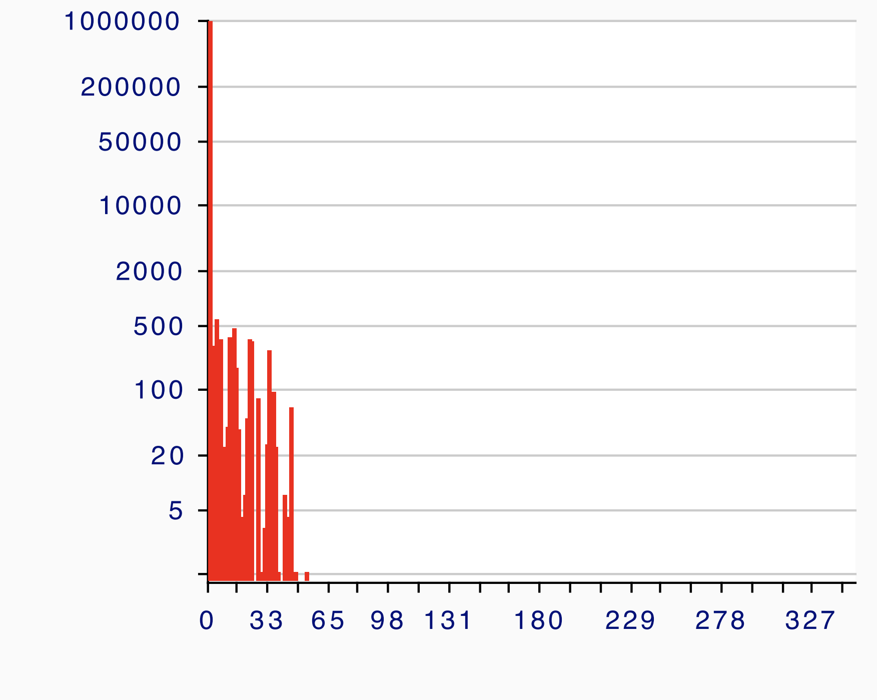


Jitter

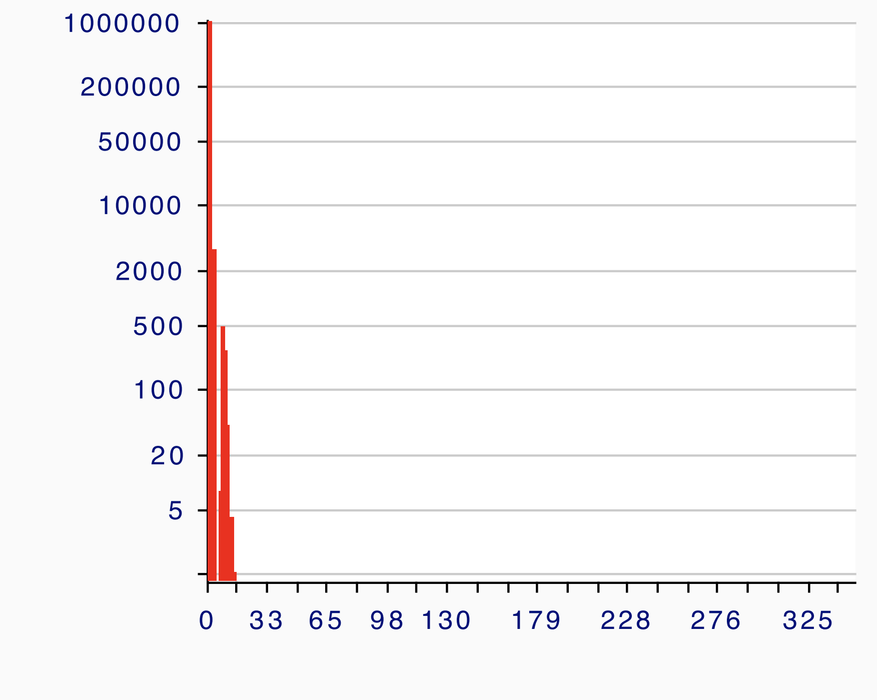
Execution Time Histograms



List

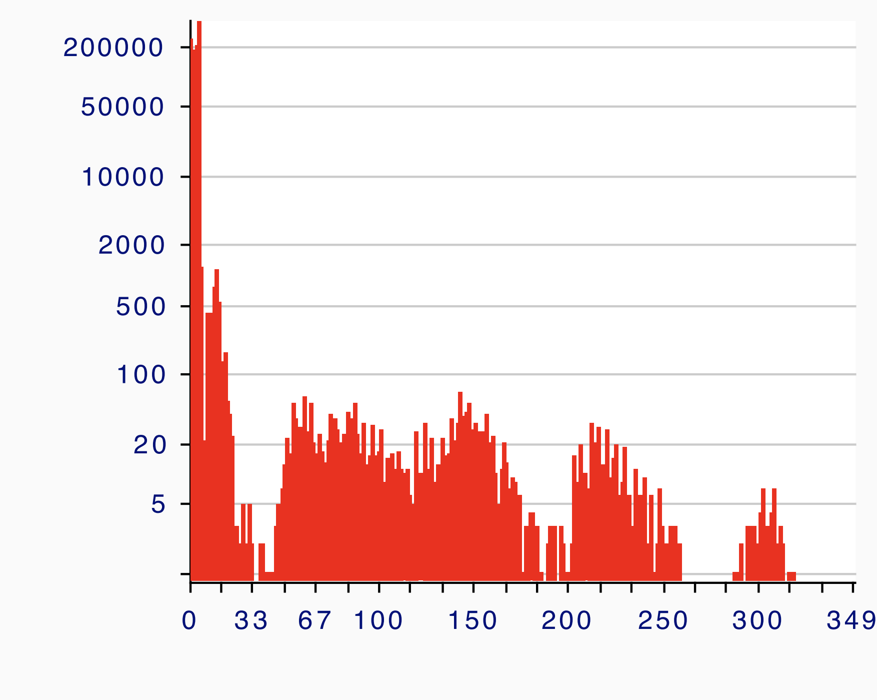


Array

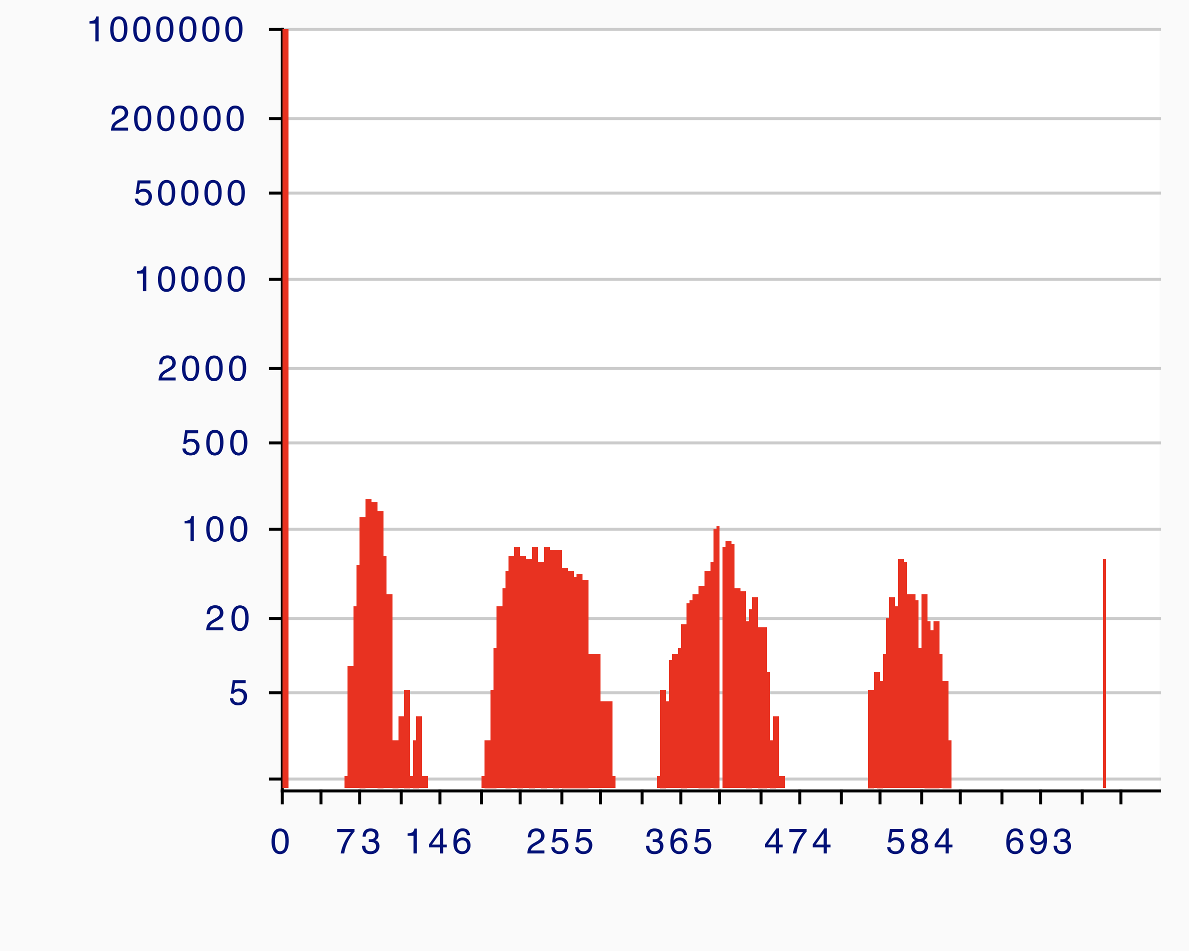


Matrix

Process Release Dominates

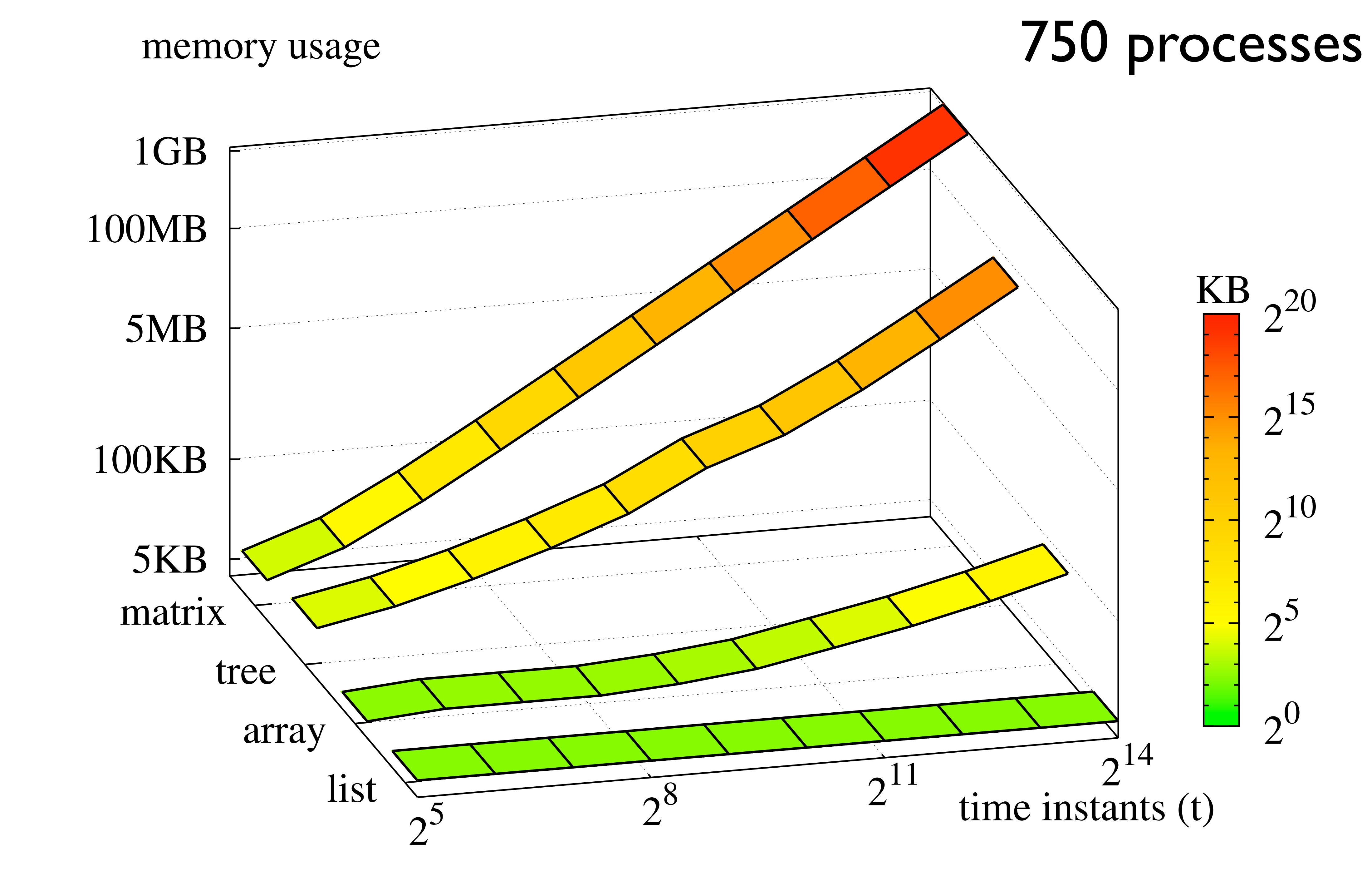


List



Releases per Instant

Memory Overhead



Current/Future Work

- Concurrent memory management
- Process management
- I/O subsystem

Thank you