Flexible automatic memory management for real-time and embedded systems

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Outline

- Problem statement
- Background
- Time-triggered GC
- Adaptive GC scheduling
- Priorities for memory allocation
- Summary

Problem statement

- Adding flexibility to hard real-time systems
  - The need for flexibility is increasing
  - Not all hard RT systems are safety critical
  - The gap between theory and practice
- Hard RT memory management in practice
  - Non-intrusiveness
  - GC work metrics
  - GC tuning

Problem statement

Write once — run anywhere

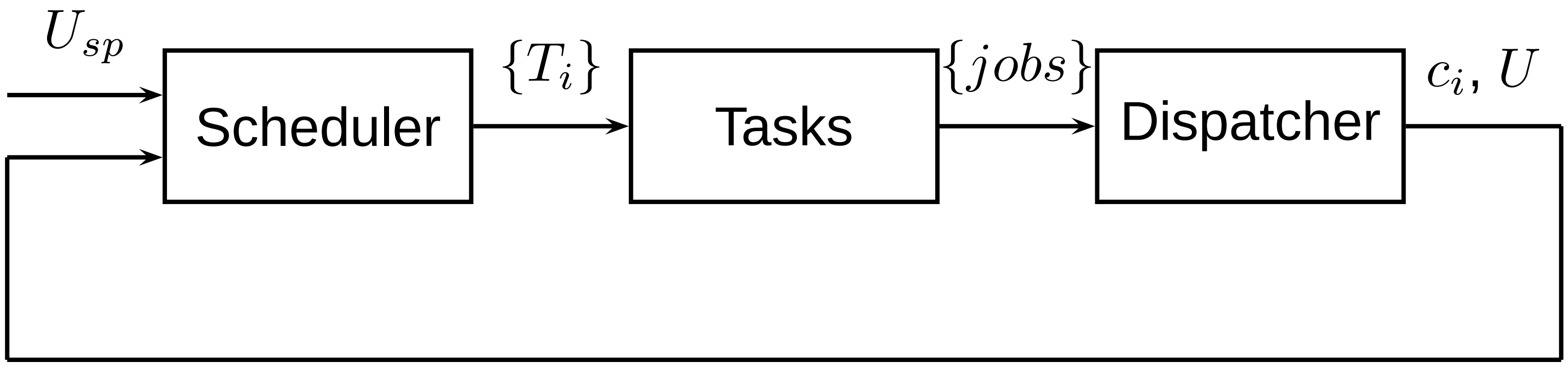
for hard real-time systems

Problem statement

Treat scheduling and schedulability analysis separately

Feedback scheduling

A simple model



Garbage Collection

- Batch GC
- Incremental GC
- Real-time GC
- Non-intrusiveness
- Practically feasible

Incremental GC

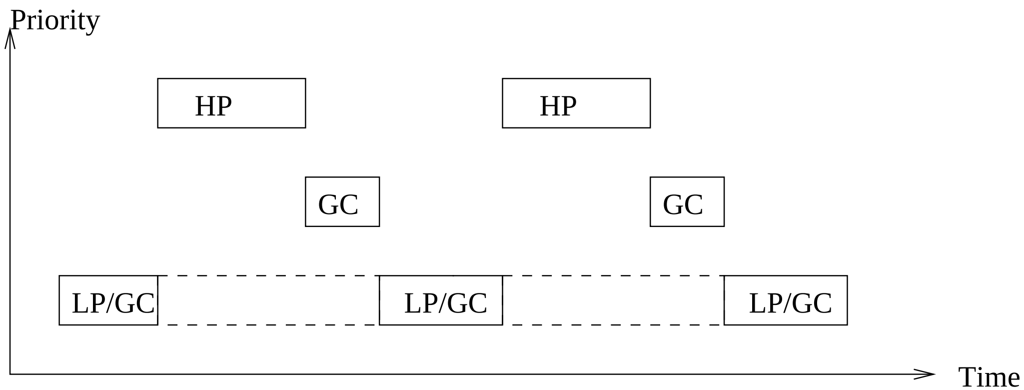
- GC work scheduled at allocations
- Increment size proportional to object size
- Ensuring sufficient progress

$$w \geq W_{max} \cdot \frac{a}{F_{min}}$$

GC performed in-line with application code may cause long delays

Semi-concurrent GC scheduling

Presented in [Henriksson 98]



- Only suitable for fixed-priority scheduling
- Requires detailed tuning

GC work metrics

How to express GC work

- Based on known quantities
- Model the temporal behaviour of the GC
- Feasible to calculate at run-time

Example

The evacuation pointer metric

$$W = \Delta B$$

$$W_{max} = E_{max}$$

Problem: A small increment of the metric may take very long time to perform

An improved metric

$$W = \alpha \cdot roots + \beta \cdot \Delta S + \Delta B + \gamma \cdot \Delta P$$

$$W_{max} = \alpha \cdot roots_{max} + \beta \cdot E_{max} + E_{max} + \gamma \cdot M_{HP}$$

Requires tuning of α, β and γ

Allocation-triggered GC

Issues:

- Bursty allocation
- Concurrent GC in EDF systems
- GC work metric concerns

Time-triggered GC

- Use time instead of allocation to trigger GC work
- Calculate GC cycle time that ensures sufficient progress
- $T_{GC} = f(H, L_{max}, \{a_p\})$

Time-triggered GC

Properties:

- GC rate independent of application behaviour
- GC can be scheduled as a normal thread
- GC scheduling independent of work metric

Adaptive GC scheduling

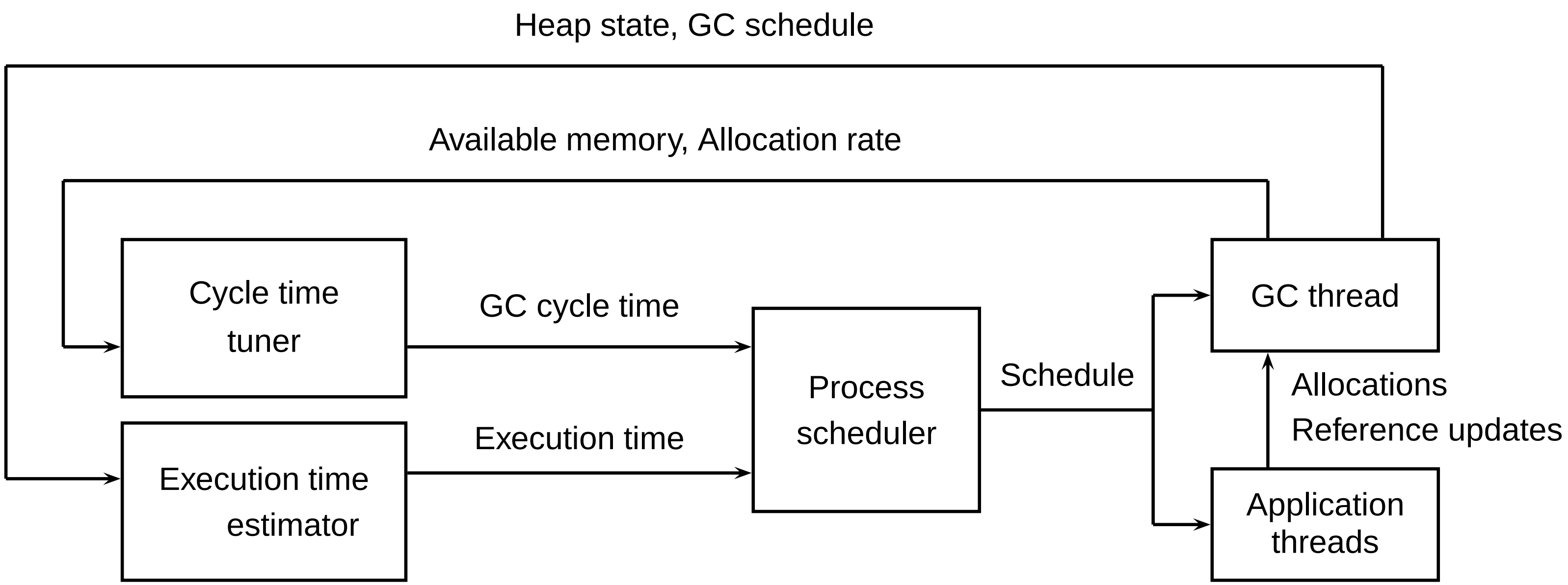
Manual tuning of GC scheduling parameters

- requires detailed analysis of both GC and application
- is based on worst case analysis
- is not possible if the run-time configuration or platform is unknown

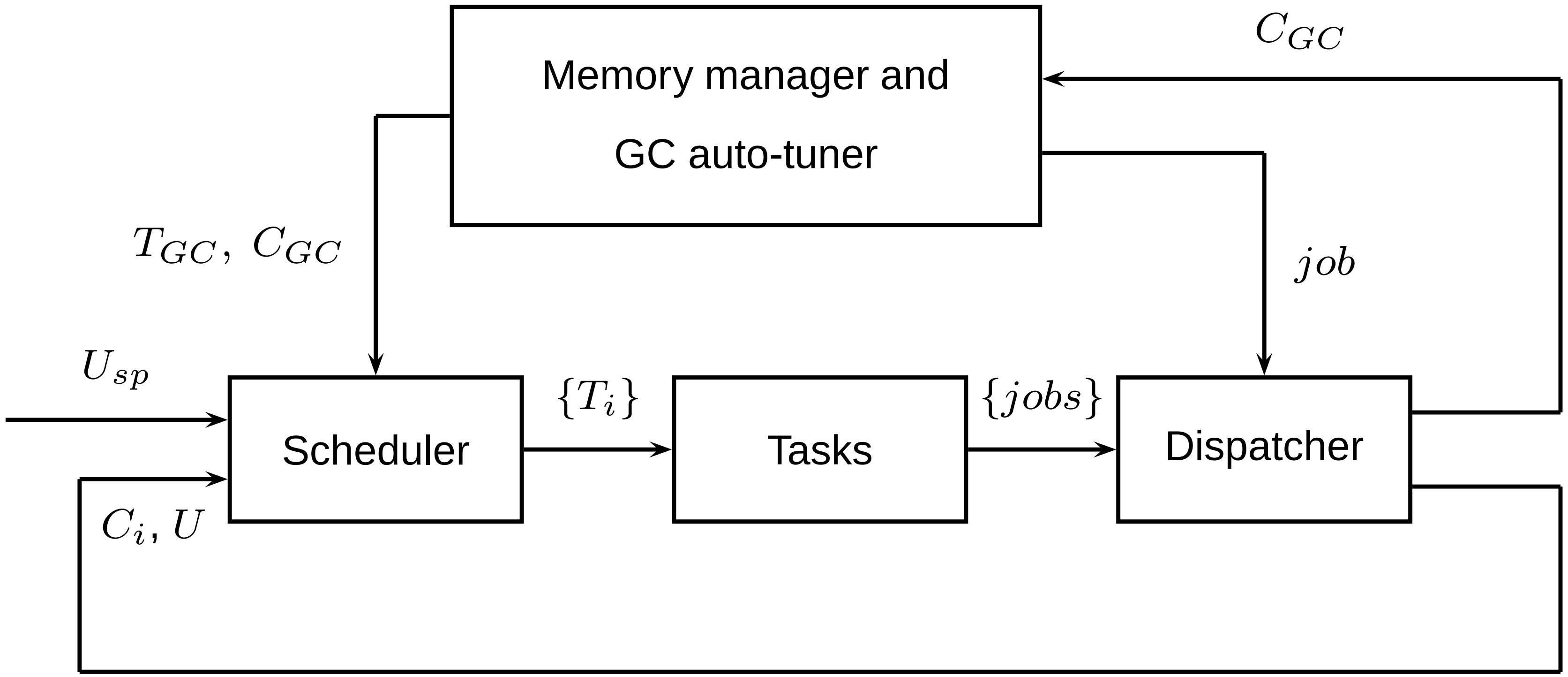
Adaptive GC scheduling

Two orthogonal problems

- Tune GC cycle time
- Estimate GC work



Feedback scheduling



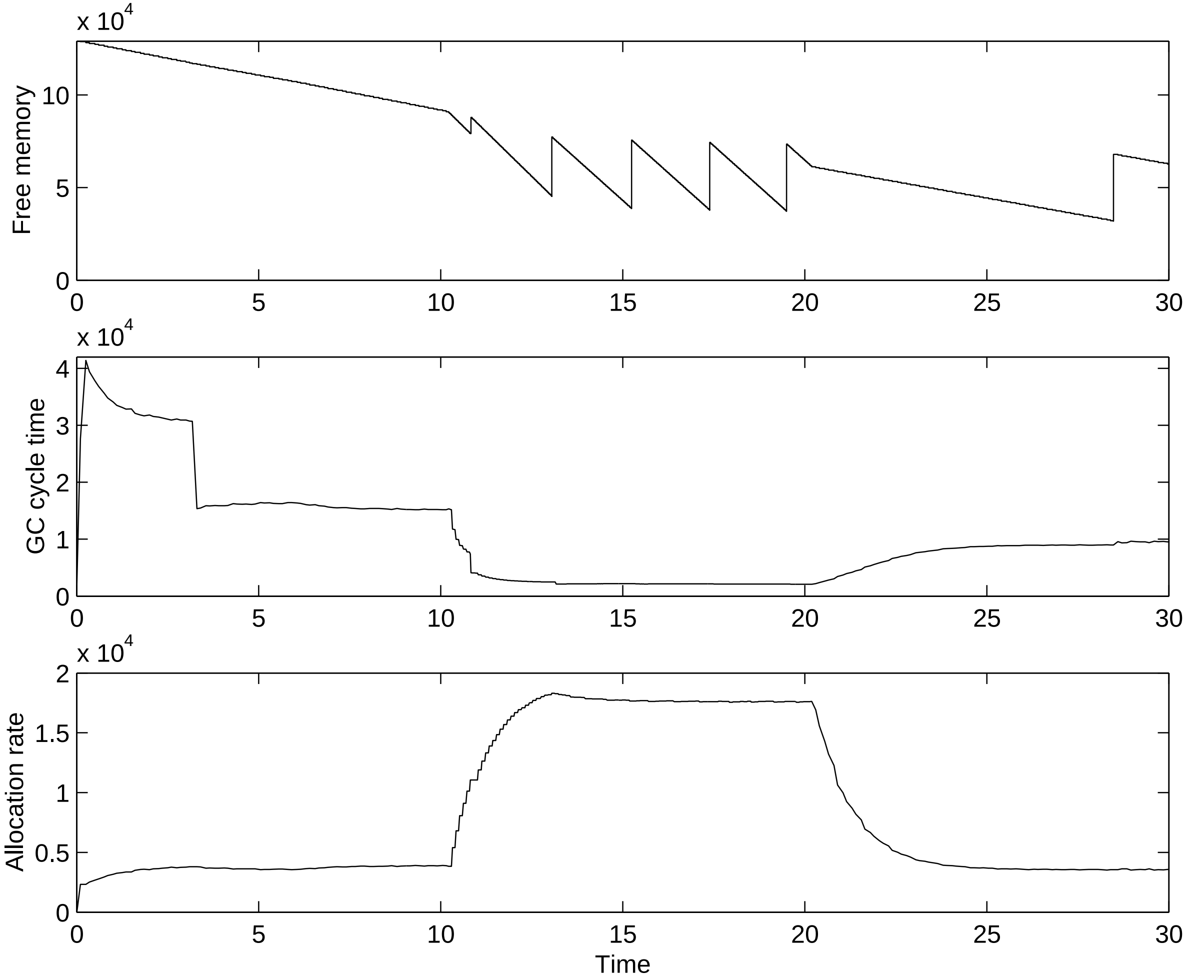
GC cycle time auto-tuning

A simple model:

$$T_{remaining\ this\ cycle} = \frac{F}{\dot{a}}$$

$$T_{GC} = \frac{F}{\dot{a}} + T_{elapsed}$$

Experiment


x 10^4
Free memory
0
5
10
0
5
10
15
20
25
30
x 10^4
GC cycle time
0
1
2
3
4
x 10^4
Allocation rate
0
0.5
1
1.5
2
Time

Priorities for memory allocations

Memory is a global resource

- Great responsibility on programmers
- Out-of-memory errors have serious consequences

Background

Not all of the code is critical

- Critical parts must always be executed
- Non-critical parts may be skipped if there is not enough memory to run them safely
- Critical and non-critical "aspects"

The basic idea

Prevent system from running out of memory by limiting the amount of non-critical allocations.

- Traditionally done manually
- Run-time system support

Priorities for memory allocations!

Non-critical limit

Keep the amount of live, non-critically allocated memory below a safe limit

or

Keep the amount of allocatable memory above the safe level

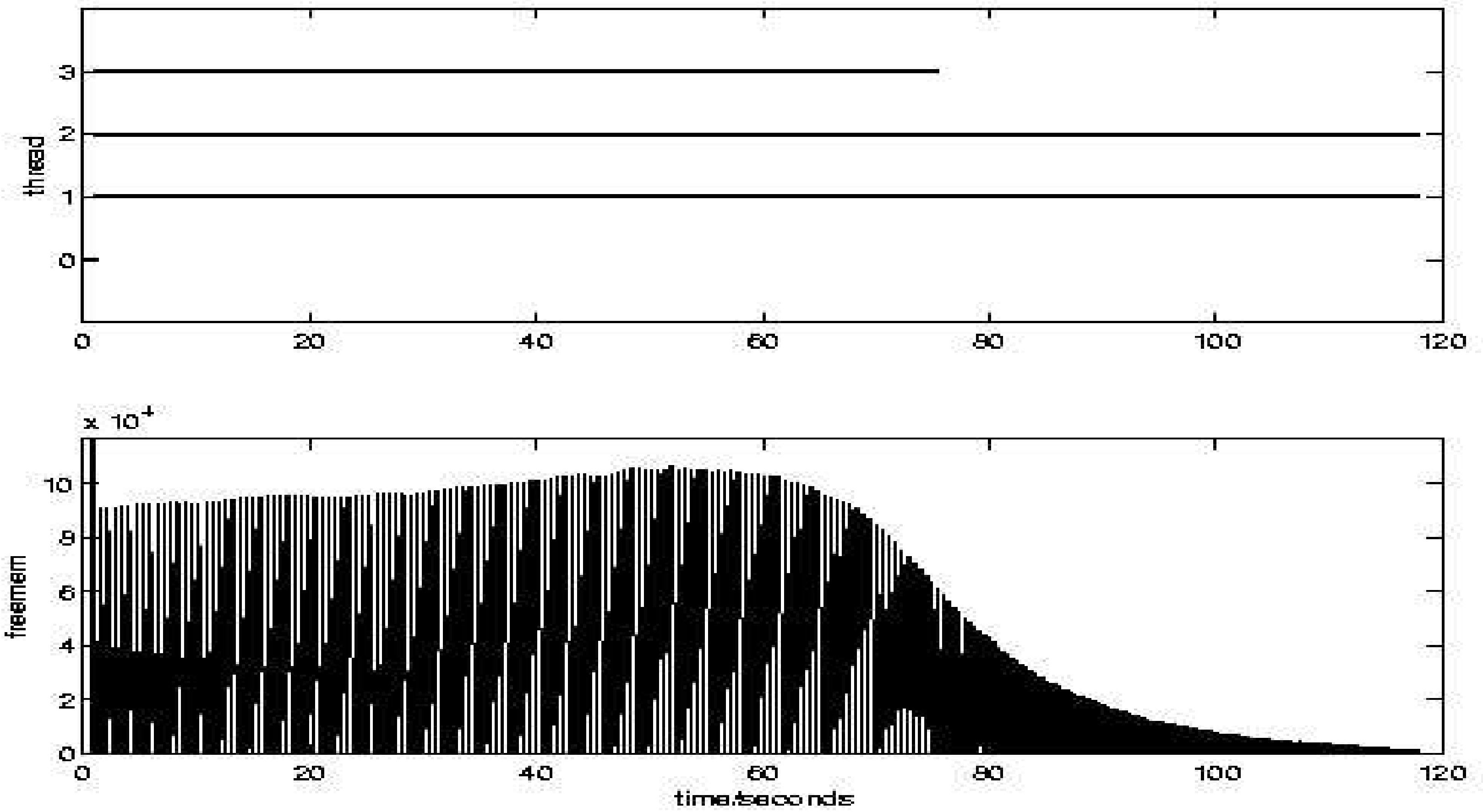
Example: logging

Simple control application

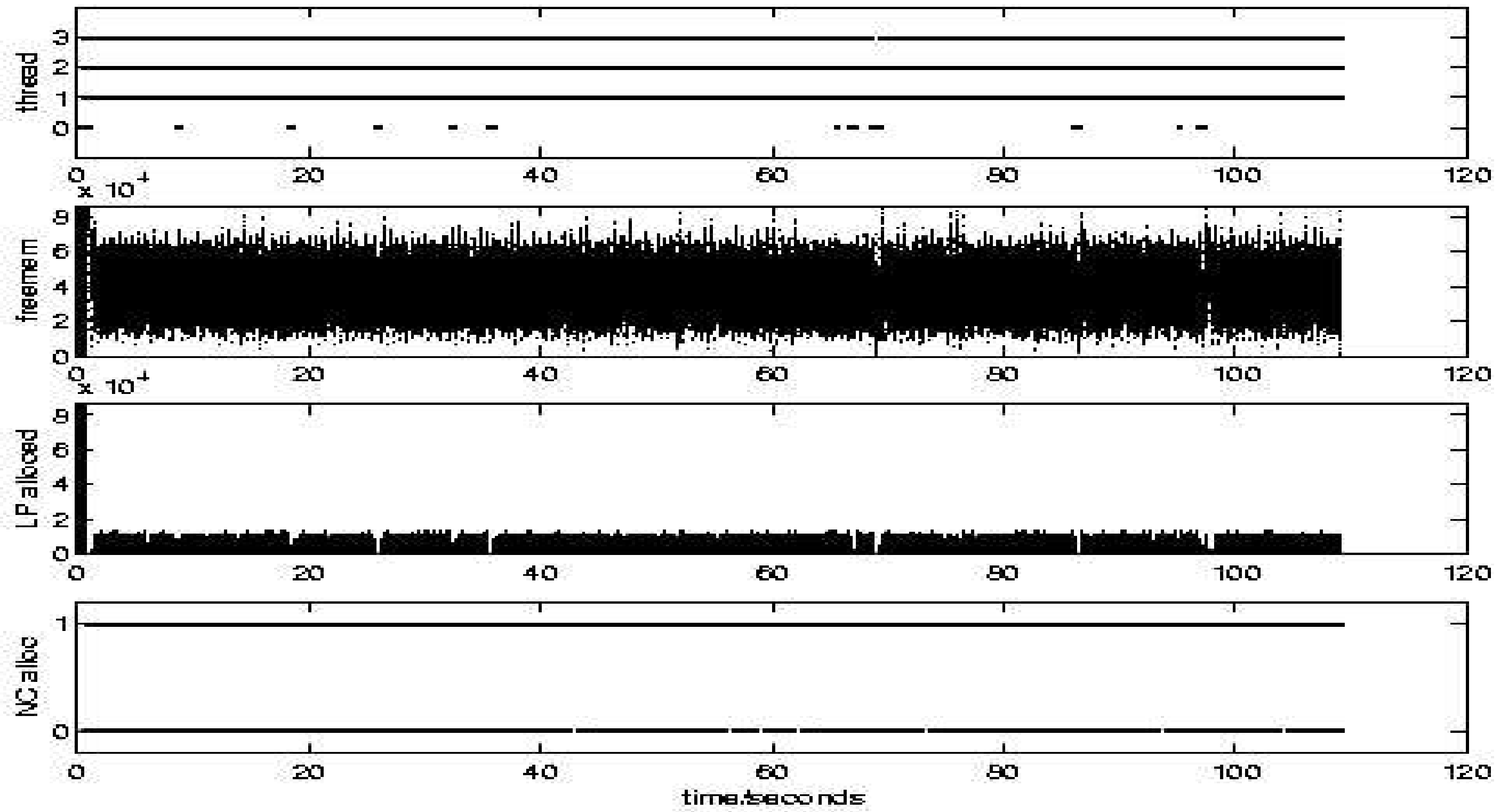
- Control – critical
- Logging – non-critical

```
void control(){
    calculateControlSignal();
    updateState();
    try{
        deliverLogData();
    } catch(NoNonCriticalMemoryException e) {
        // not enough memory to safely allocate log data
    }
}
```

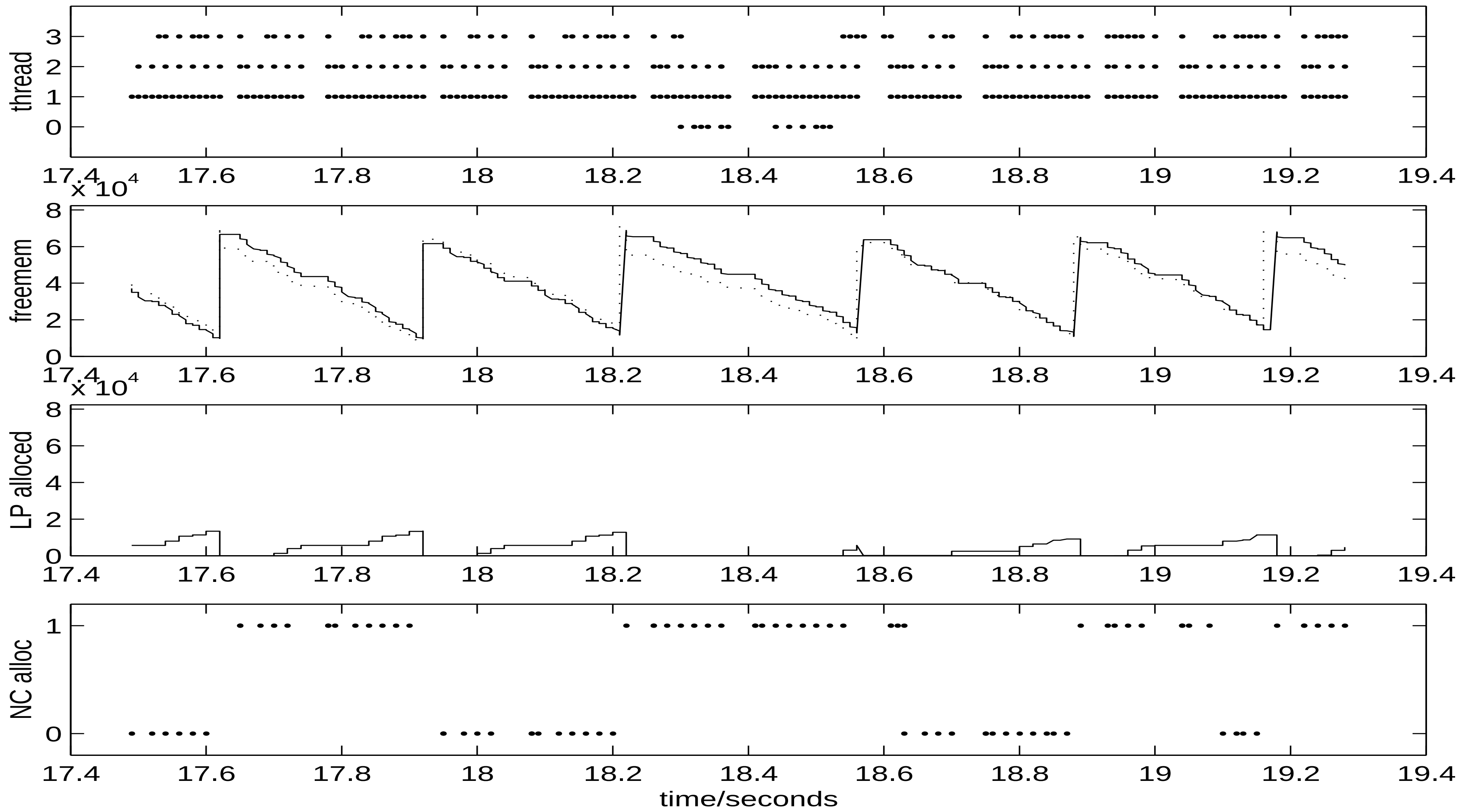
Example: all allocations critical



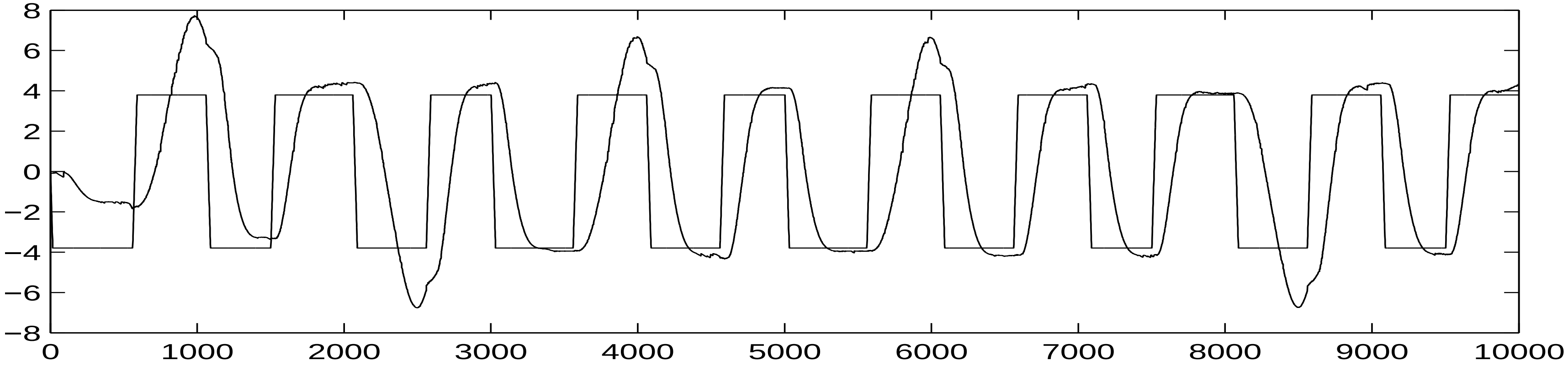
Example: log data is NC



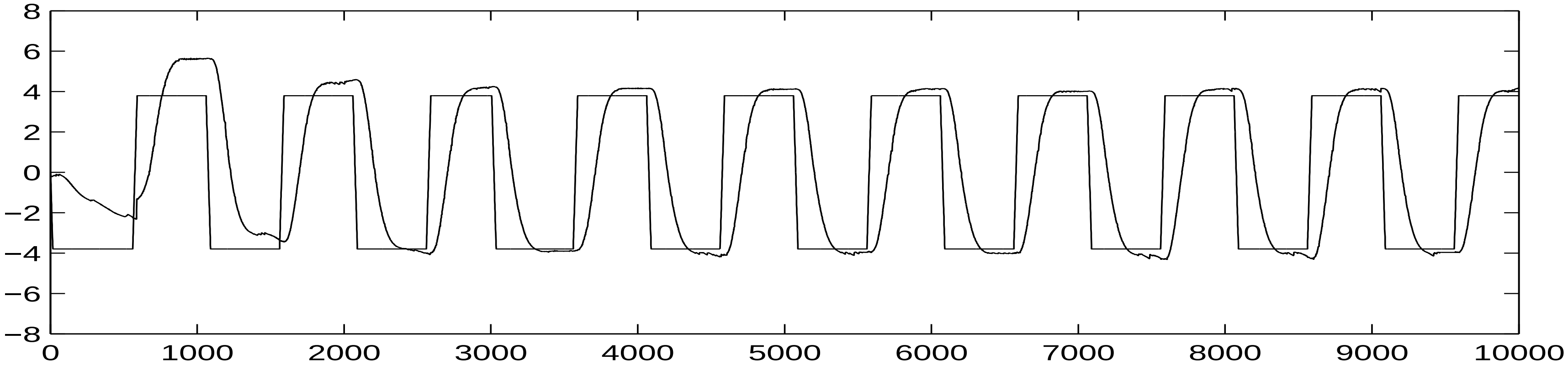
Example: closeup



Example: Performance



a) log data objects are always allocated



b) allocation of log data is non−critical

Priorities for memory allocations

- Memory requirements can be separated into “critical” and “non-critical”
- Separate memory and CPU time priorities

  Not all of the allocations in a HP process are critical
- Run-time system support
- Improves robustness and performance
- possibility to control the memory behaviour
- Worst case analysis only needed for critical parts

Summary

Time-triggered GC scheduling

- Cycle-level view on GC scheduling
- Non-intrusive GC with guaranteed progress under EDF
- Explicit scheduling parameters fi ts well into feedback scheduling and auto tuning systems

Priorities for memory allocation

- Increased robustness and performance
- Possible to control allocation rate

Future Work

- Integrated prototype
- Feedback scheduling
- Distributed systems, composability