An Approach to Embedded System Development Based on Dynamically-typed Language

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Outline

1)Introduction (Embedded devices)

2)The proposed development process

3)Details of the compilation process

4)Case study *[optional]*

Software in Embedded Systems

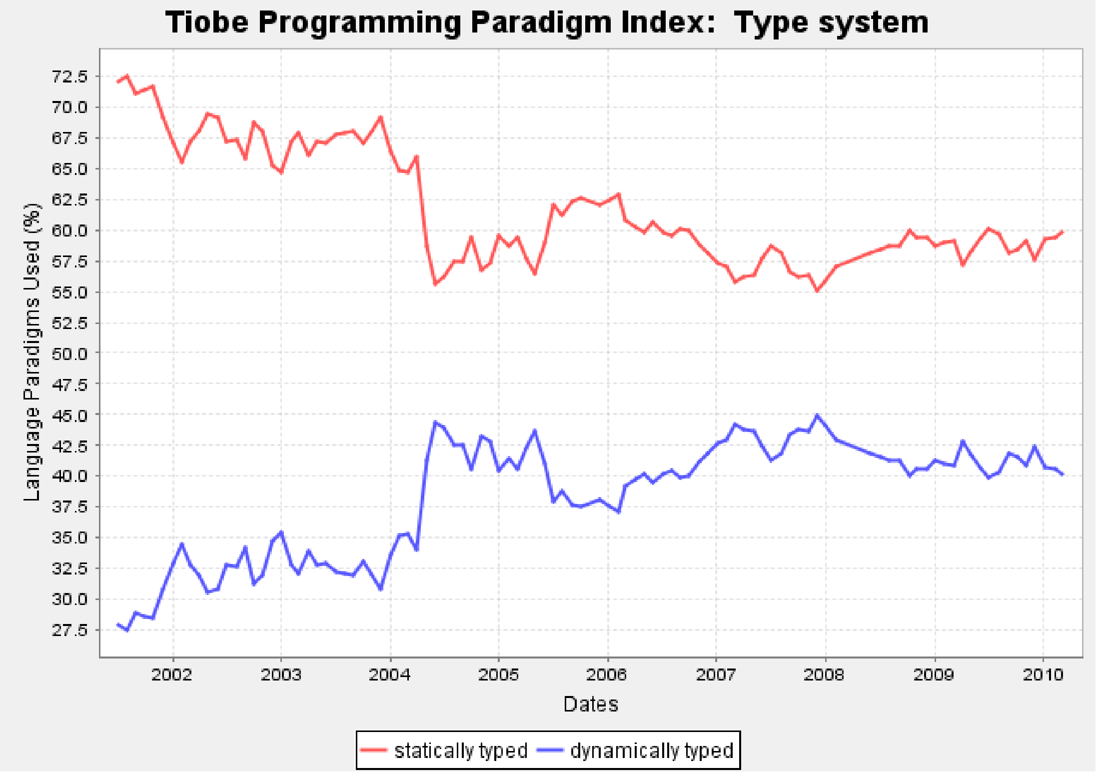
- Constrained hardware resources (cheap HW)
- Dependable
  - failure may have severe consequences
  - hard to fix the errors
- Usually works in reactive mode
  - hard/soft realtime
- Computational time is more expensive than programmer's time

State of the Art in Embedded SW

- *(Development tends to be conservative)*
- Higher level, general purpose languages
  - Java
- Formal methods
- Model-driven development, generative programming, ...

Ease development even further?

- Python – very high-level language
  - generate efficient native code?
  - formal verification?



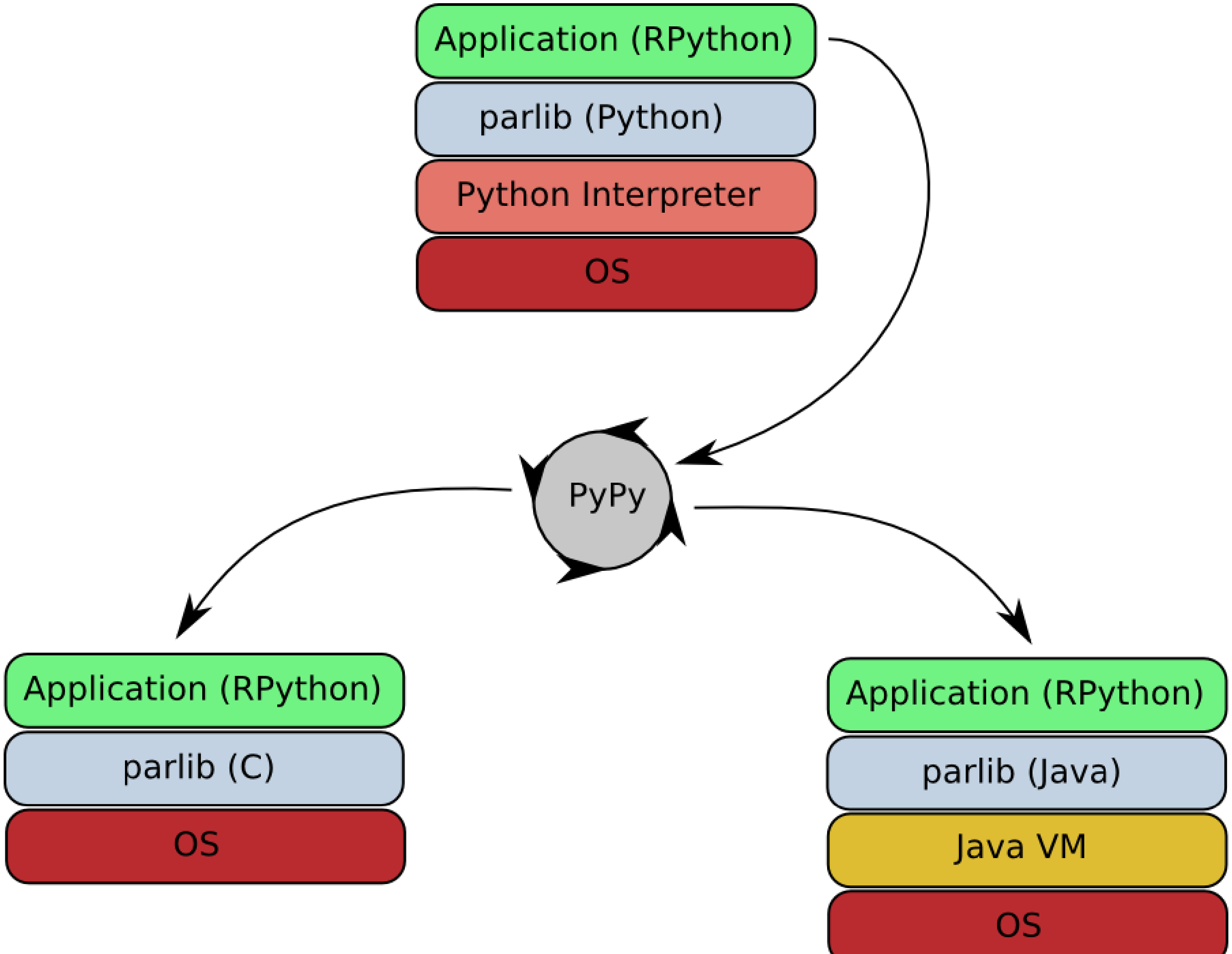
RPython

- Rich enough subset of Python
  - comfortable for programmer
- Part of the PyPy project (ETH Zürich)
  - experimental Python interpreter and compiler
- Good characteristics of dynamic languages
  - shorter code (less errors)
  - open for new paradigms (DbC, AOP)
- Translation to various codes (C, JVM)

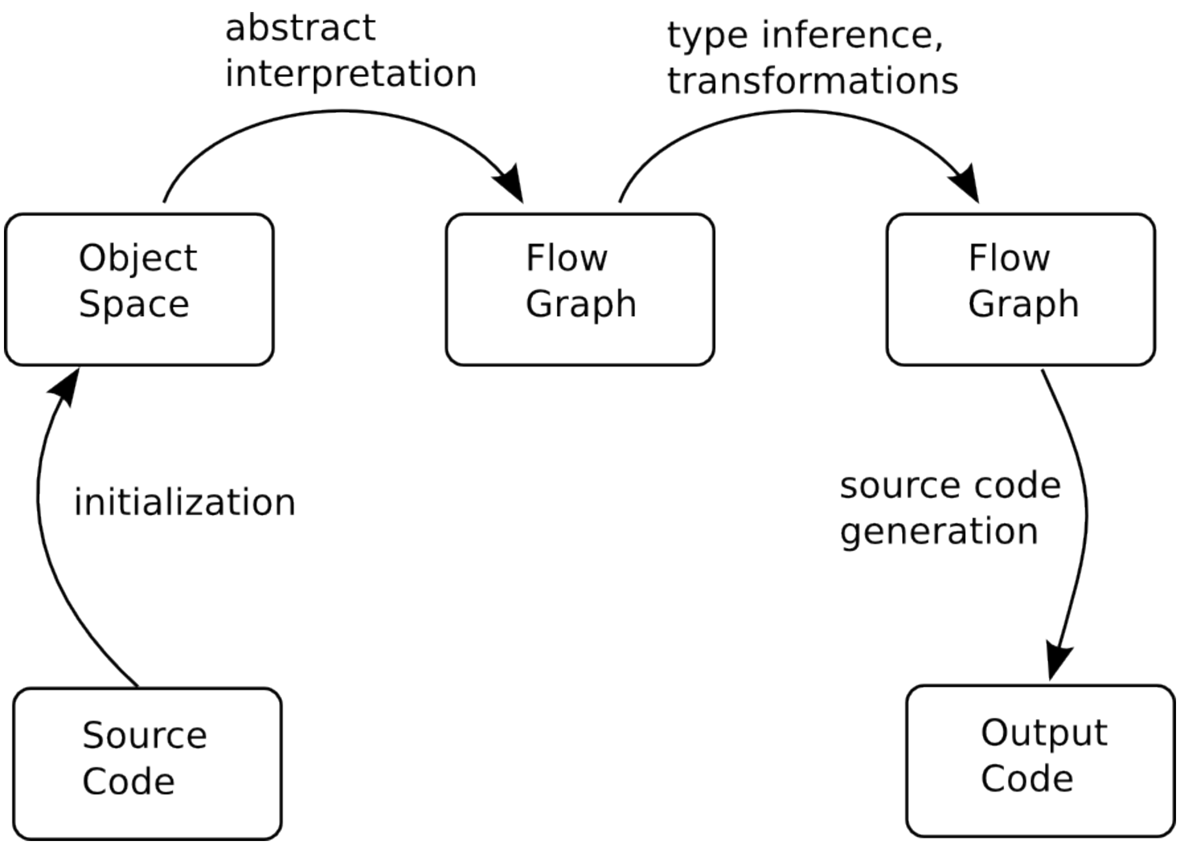
Development Process

- Software is primary written in RPython
  - can run on standard Python interpreter
- C code can be generated from the RPython source
  - results in high performance native code
- Java byte-code is also generated
  - to be verified by tools developed for Java

Code Generation Scheme



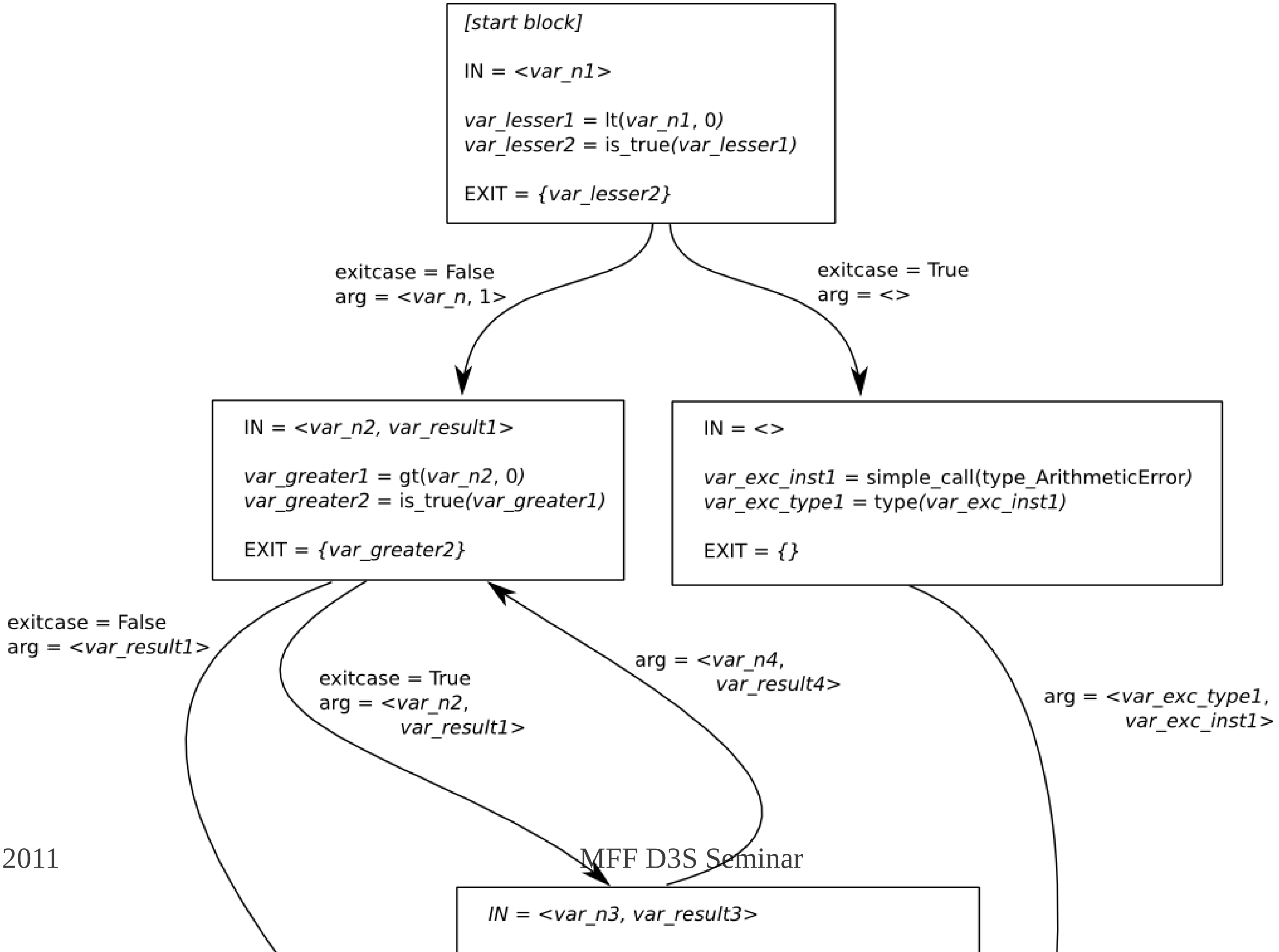
PyPy Compilation Chain



Abstract Interpretation

- **Input**: initialized graph of objects (“object space”) in the memory of Python interpreter
  - And the selected entry point
- **Output**: internal PyPy program representation called *flow graph*
- data types of the initial flow graph are *abstract*

Flow Graph Example



Flow Graph Transformations

- Can change the structure of the graph
- Can add new information
- Examples:
  - Add type annotations for a particular code generator
  - Add reference counting for GC

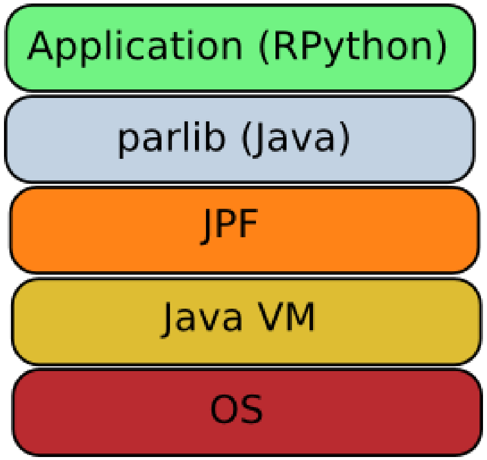
C vs. Java-btcd. Generation

- Java bytecode:
  - Assign JVM types to the abstract types
  - Generate bytecode

- C:
  - Assign C types to the abstract types
  - Exception transformation
  - GC transformation (empty for BoehmGC)
  - Generate C code

Java Pathfinder (JPF)

- Explicit model-checker for Java bytecode
- JVM with backtracking
  - deadlocks
  - uncaught exceptions
  - Linear Temporal Logic



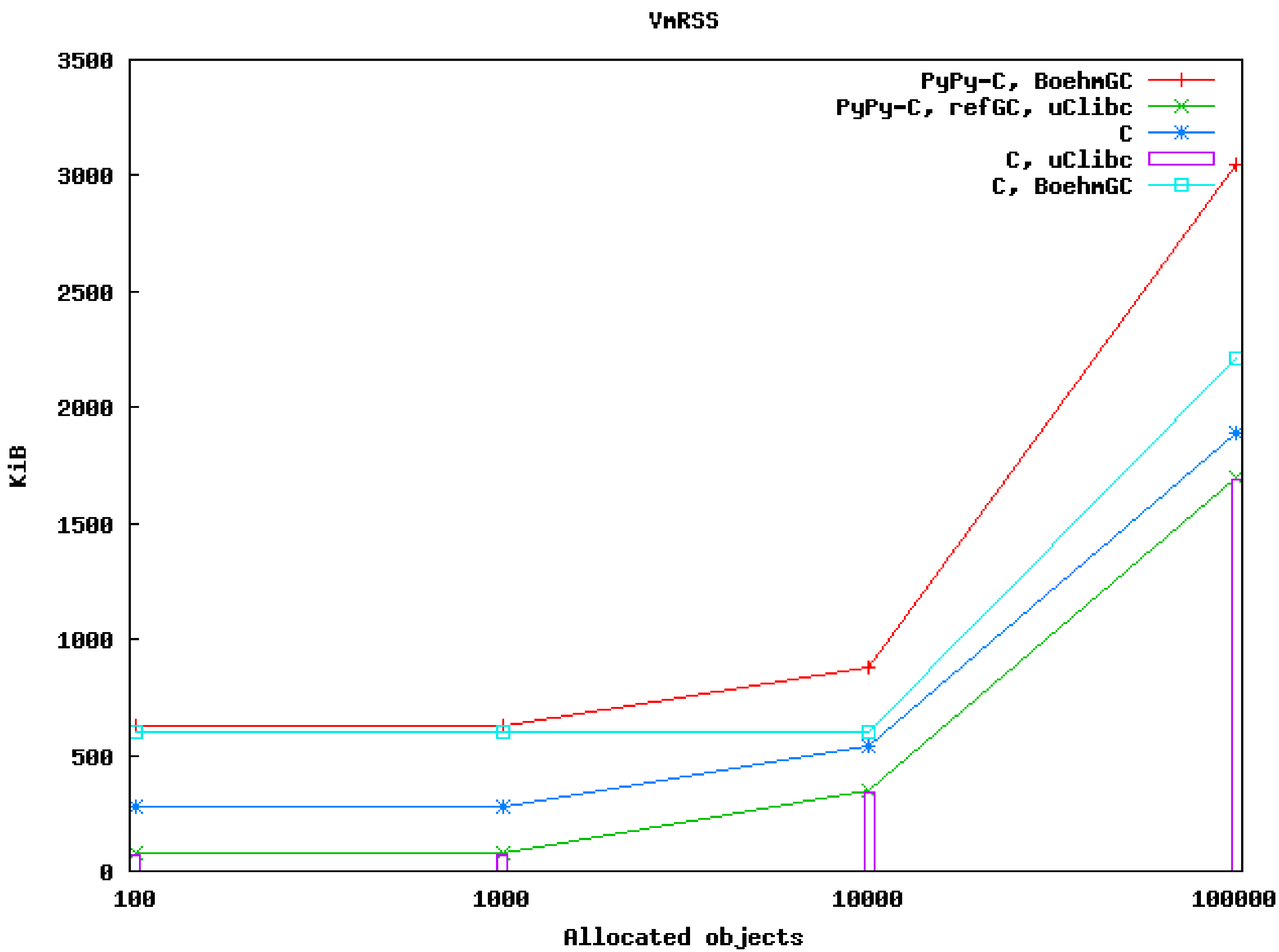
Process Dependability

- How can we know that the C and Java bytecode programs behave the same?
  - The most tricky parts (object space initialization, abstract interpretation) are shared
  - We have precise definition of the additional transformation for the C compilation, however no formal proof of correctness

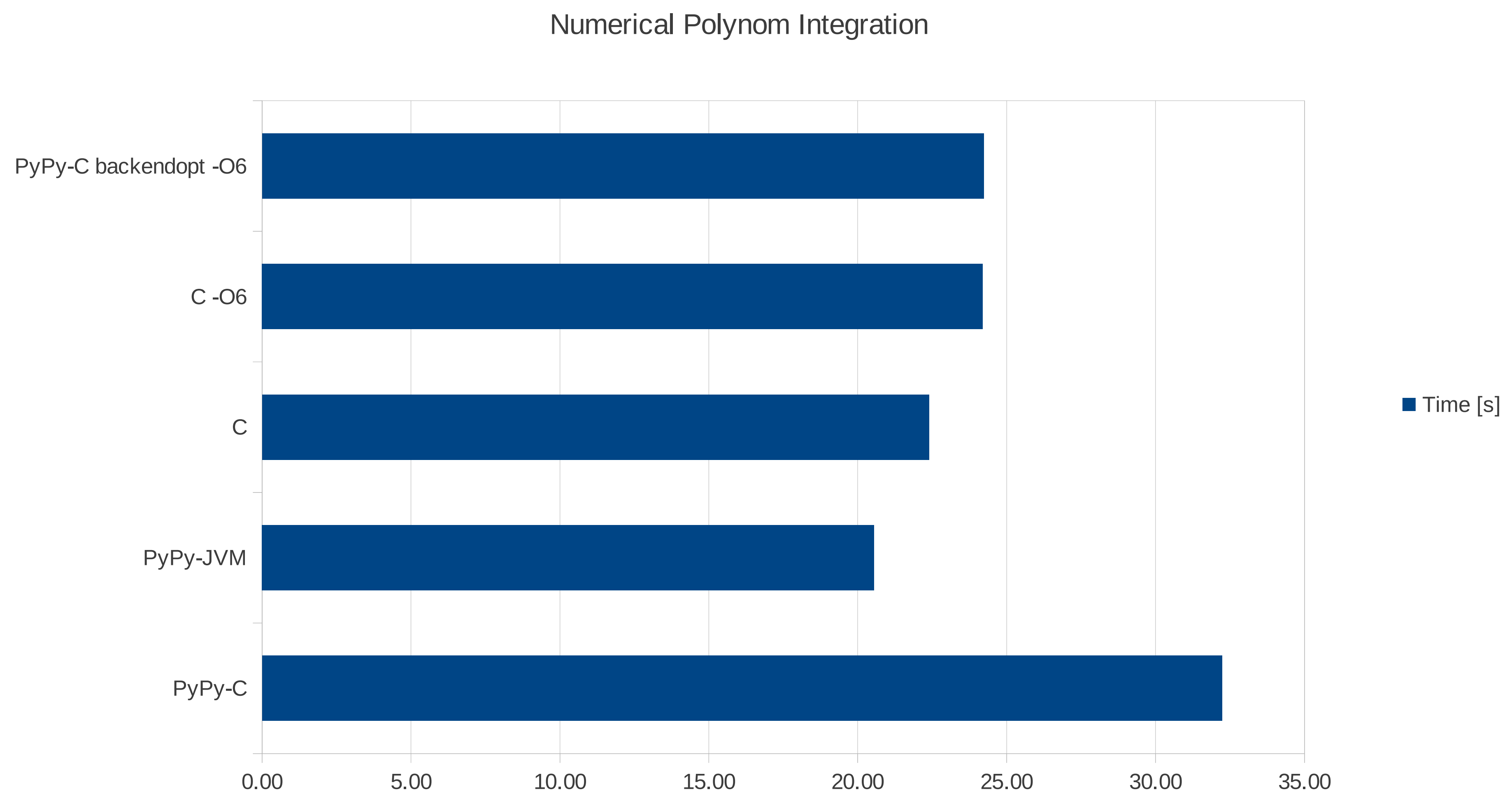
Shared Threading Model

- All variants of the program (interpreted RPython, C, Java bytecode) use *monitors* as we know them from the Java world
  - Allows JPF to perform optimizations
  - Monitors for C and RPython are implemented in the *parlib* library
  - *(They are structured and that's nice)*

Memory Requirements



Computational Performance



Linear Temporal Logic

- Defined over sequences of states
  - $s_0 s_1 s_2 s_3 \ldots$
- There are propositions that hold (not hold) for every particular state
  - $\varphi = x > 4$
  - $\varphi(s_2) = \mathit{true}$ or $\varphi(s_2) = \mathit{false}$
- Temporal operators
  - $X\varphi$, $G\varphi$, $F\varphi$, $\varphi_1 U \varphi_2$

LTL Examples

- F(all_records_processed)
  - some positive event guaranteed
- G(there_is_at_least_one_runnable_thread)
  - program is deadlock-free
- G(request => X(F(response)))
  - request is inevitable followed by response
- G(¬file_closed U result_written)
  - write and then close the file

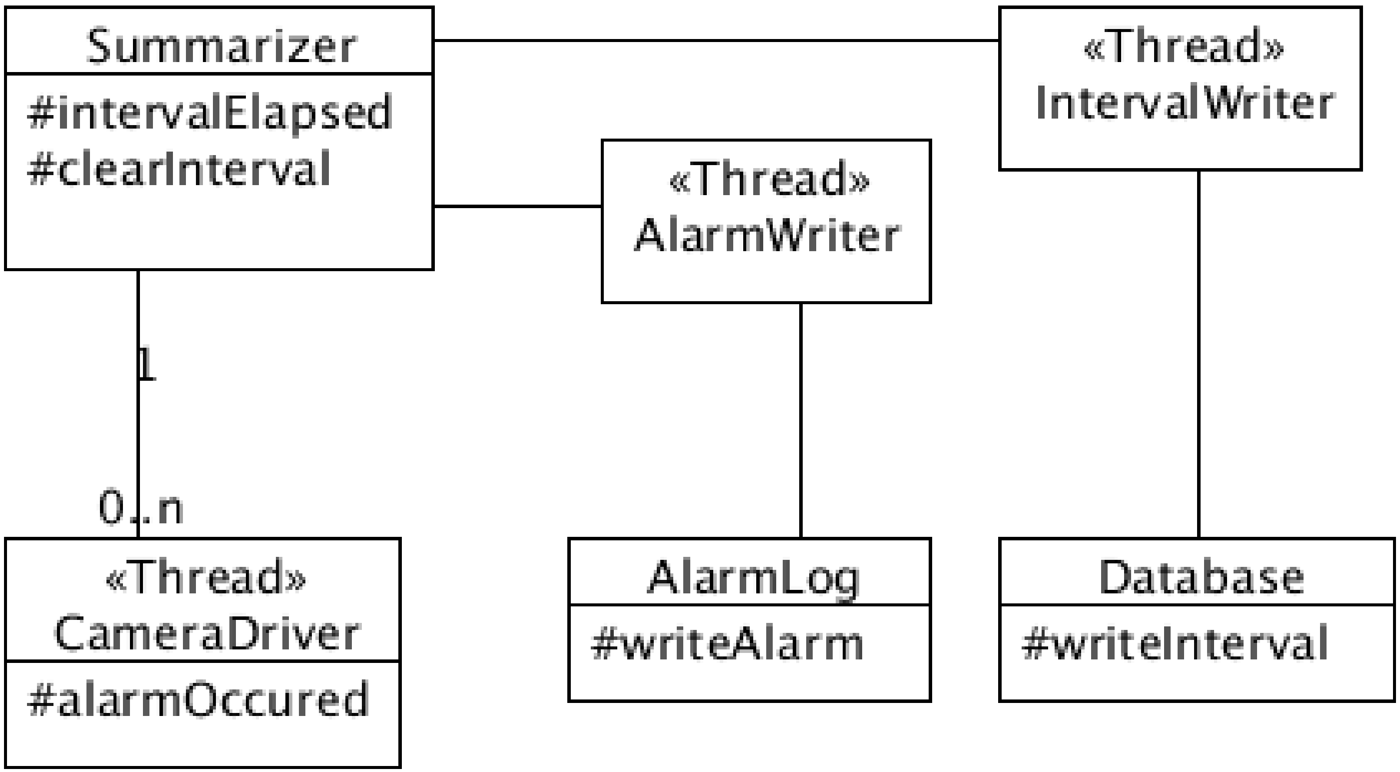
Case Study: NVR

- Network Video Recorder is a device that manages IP cameras over computer network.
  - records video produced by cameras
  - records events produced by cameras
    - motion detection
    - alarms

NVR Internals

- For every camera there is a dedicated camera driver that downloads the video and events.
- Events are summarized to time intervals and then written into a database.

NVR Scheme


Summarizer
#intervalElapsed
#clearInterval
«Thread»
IntervalWriter
«Thread»
AlarmWriter
1
0..n
«Thread»
CameraDriver
#alarmOccured
AlarmLog
#writeAlarm
Database
#writeInterval

Real LTL Formula

- Whenever camera driver detects an alarm it is inevitably written into the alarm log.

```
G((method:Driver.alarmOccurred)
   ->(X(F(method:AlarmLog.writeAlarm))))
```

Real LTL Formula (2)

- Whenever a time interval elapses, the summarized value is not cleared until it is written into the database

```
G((method:Summarizer.intervalElapsed)
  =>(X(
          (~(method:Summarizer.clearInterval))
          U(method:Database.writeInterval)
      )
    )
 )
```

Conclusion

- A novel approach to embedded systems development
  - very high level description (RPython)
  - flexible code generation
  - LTL-properties verified by Java Pathfinder holds also for the production C code

The End

- Thank you for your attention.
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