The `final` Frontier

Coping with Immutable Data in a JVM for Embedded Real-Time Systems

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`https://www4.cs.fau.de/Research/KESO/`

Introduction

Embedded devices

- Weak CPU
- Limited memory
  - SRAM expensive, scarce
  - Flash cheaper, more ample

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- Productivity
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- ! Performance
  - AOT compilation
  - Dependent on effective optimisations

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! Memory footprint
  - RAM usage in particular

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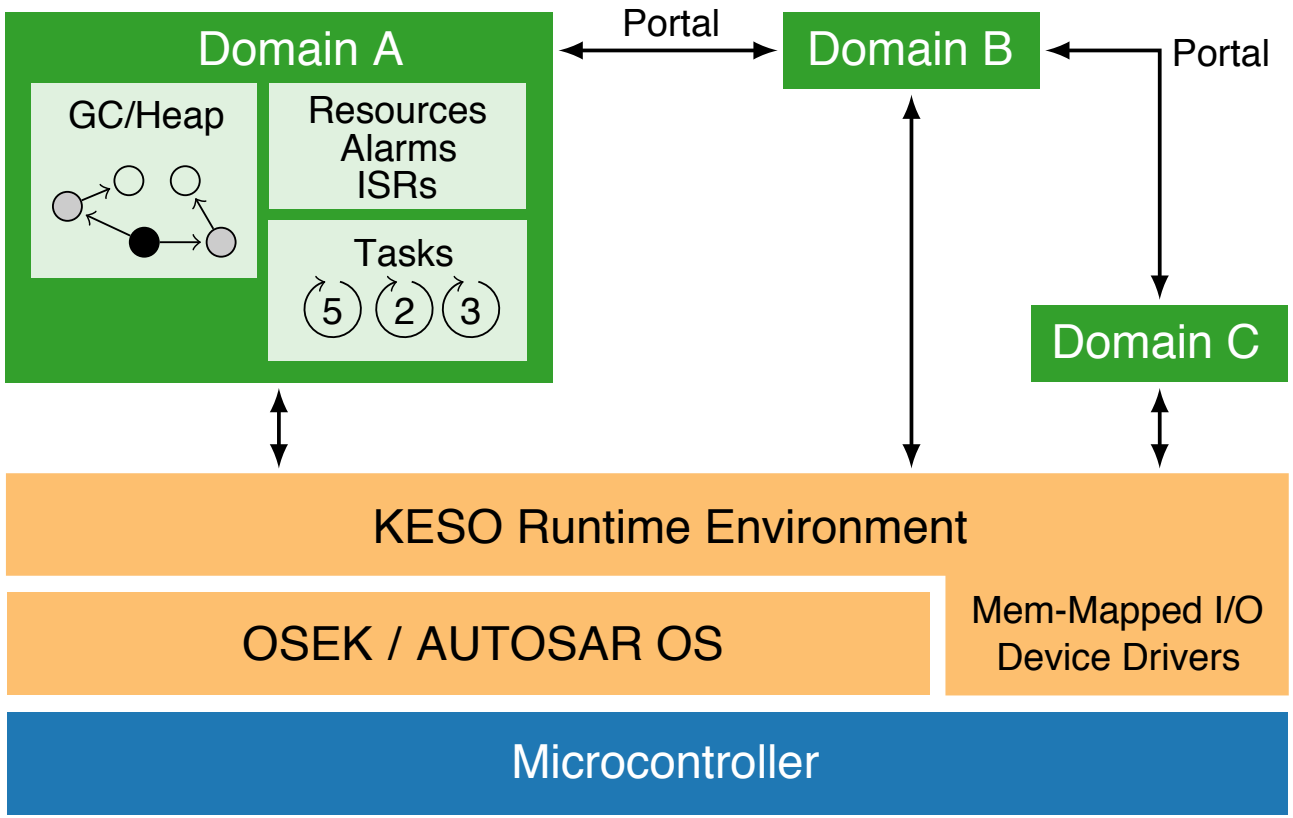
→ No statically allocated + initialised arrays
→ No programmatic flash allocation

Remedy: Compiler Analyses

Platform: KESO JVM



- Portable, scalable to low-end devices
- Static configuration
- Ahead-of-time compilation to C code

Effectively `final` Fields

```
public final class Constants {
    public static int MAX_FRAMES = 1000;
}

public class Main {
    private static void parseCmdLine(final String[] v) {
        // ...
        if (v[i].equals("MAX_FRAMES"))
            Constants.MAX_FRAMES = Integer.parseInt(v[i + 1]);
        // ...
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Let's focus on static fields for now.

Finding Effectively `final` Fields

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Criteria

1. Field is written exactly once, in the class constructor

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    static {
        if (...) {
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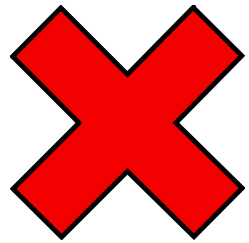

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Finding Effectively `final` Fields

```
public final class Constants {
    public static int MAX_FRAMES;
    static {
        System.out.println("MAX_FRAMES = " + MAX_FRAMES);
        MAX_FRAMES = 1000;
    }
}
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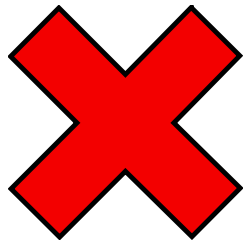

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Effect on optimisations

- Constant folding, check elision
- Potentially many indirect effects!

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        int[] a = new int[2];
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Multi-dimensional arrays: bottom-up approach

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};

void ConstArray__clinit_(void) {
    ConstArray_ARRAY = &ca;
}
```

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Constant arrays

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Other candidates for flash allocation

- Strings from constant pools
- Runtime-system data structures
  - Type-information store
  - Dispatch table

Flash-Memory Pitfalls

Mark-and-sweep GC

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AVR

! Separate access instructions for RAM and flash (`ld` vs. `lpm`)

→ For each use: determine correct instruction through alias analysis

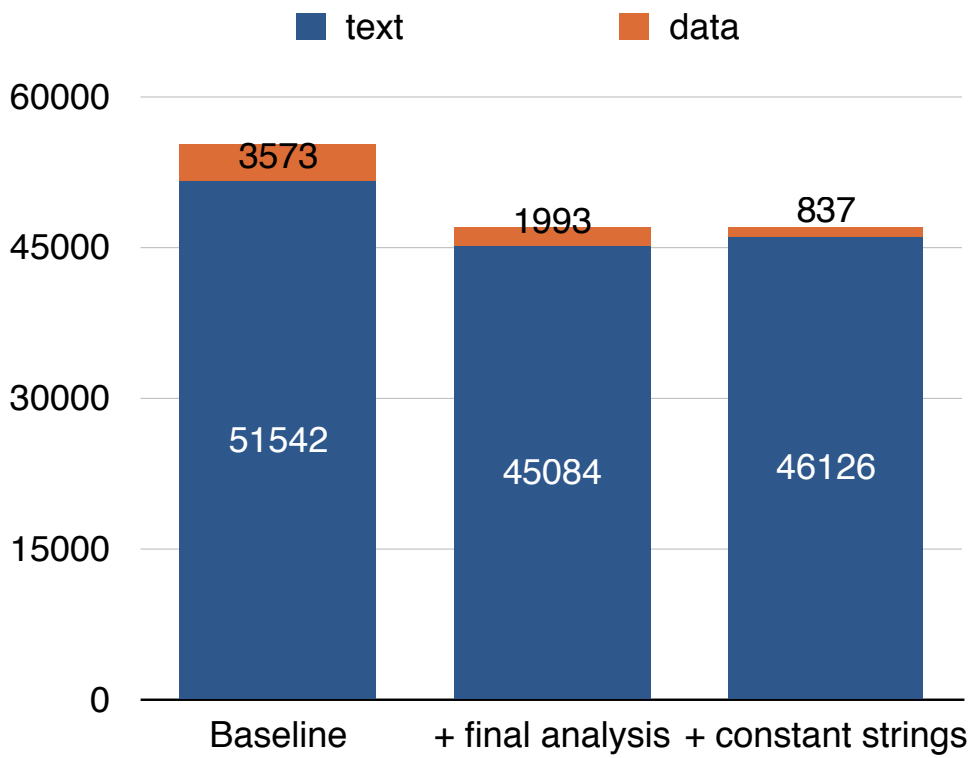
→ Prevent aliasing between RAM and flash objects

Evaluation

Collision Detector

CD$_j$ 1.2

- Real-time air-traffic simulator and collision detector
- CiAO OS
- TriCore TC1796 @ 150 MHz, 2 MiB flash, 1 MiB SRAM



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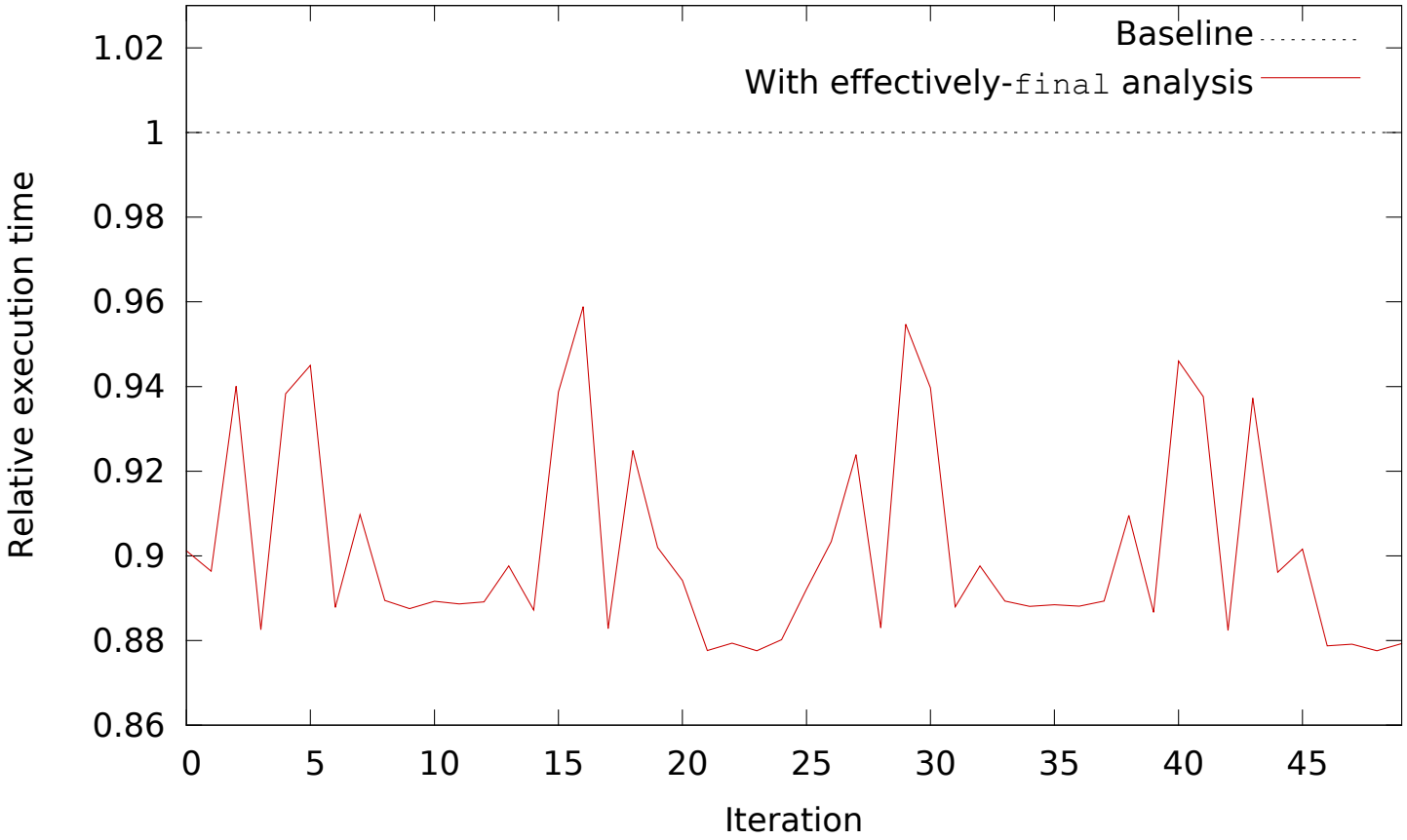
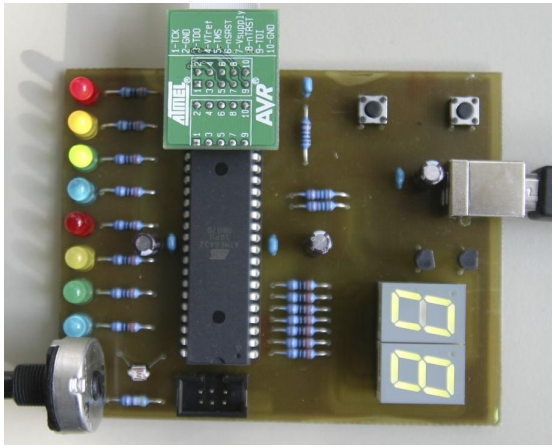


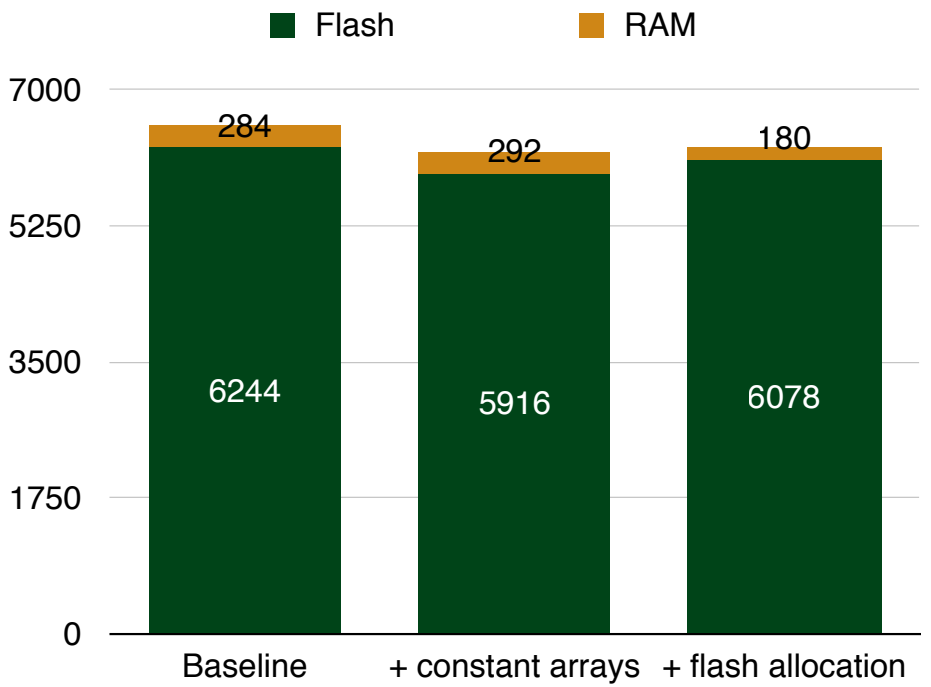
- Folded primitive constants
- Singleton objects → 30 % fewer `null`-checks

SPiCboardTest

Test application

- Evaluation board for teaching
- JOSEK OS
- AVR ATmega32 @ 1 MHz, 32 KiB flash, 2 KiB SRAM





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Outlook

- Permit programmer intervention through annotations
  - Cross-check against code to detect contradictions
- Exploit knowledge about target platform (e.g. memory map)