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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  - AOT compilation
  - Dependent on effective optimisations

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! Memory footprint
  - RAM usage in particular

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immutable → ARRAY

heap-allocated → 10, 2

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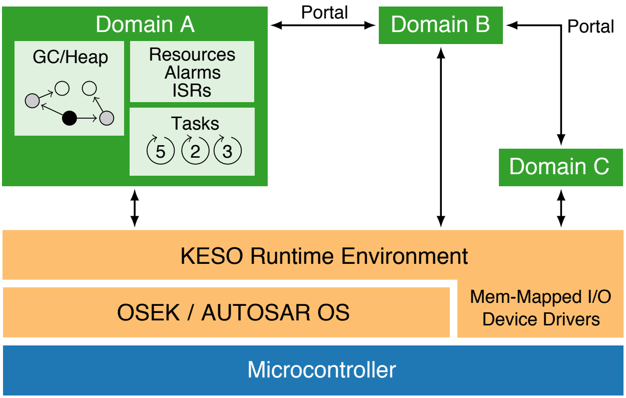
immutable (ARRAY) — heap-allocated ({10, 2})

→ 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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public final class Constants {
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Criteria

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

Finding Effectively `final` Fields

```java
public final class Constants {
    public static int MAX_FRAMES;
    static {
        if (...) {
            MAX_FRAMES = 1000;
        }
    }
}
```

Criteria

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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;
    }
}
```

Criteria

1. Field is written exactly once, in the class constructor
2. No read prior to initialisation
   - Within class constructor
   - Within method called from class constructor

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Effect on optimisations

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

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public class ConstArray {
    public static final int[] ARRAY;
    static {
        int[] a = new int[2];
        a[0] = 10;
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1. Array created with constant size, in class constructor

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Multi-dimensional arrays: bottom-up approach

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    uint16_t      classID;
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    const int32_t data[2];
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const int_array2_t ca = {
    /* .classID = */ INT_ARRAY_ID,
    /* .length  = */ 2,
    /* .data    = */ {10, 2},
};
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    const int32_t data[2];
} int_array2_t;

const int_array2_t ca = {
    /* .classID = */ INT_ARRAY_ID,
    /* .length  = */ 2,
    /* .data    = */ {10, 2},
};

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

Making Use of Flash Memory

Constant arrays

- Declare as `const` in emitted C code
- Emit `section` attribute
- Adapt linker script

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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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→ Don't scan flash-allocated objects

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AVR

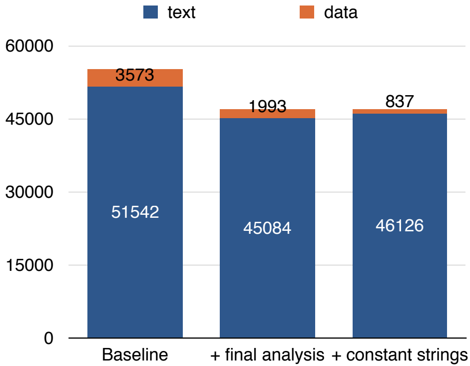
! Separate access instructions for RAM and flash (`ld` vs. `lpm`)
→ For each use: determine correct instruction through alias analysis
→ Prevent aliasing between RAM and flash objects

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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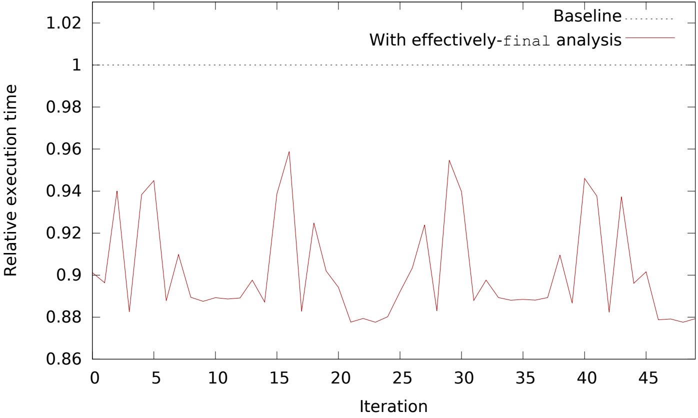
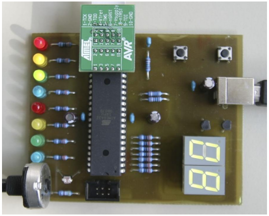


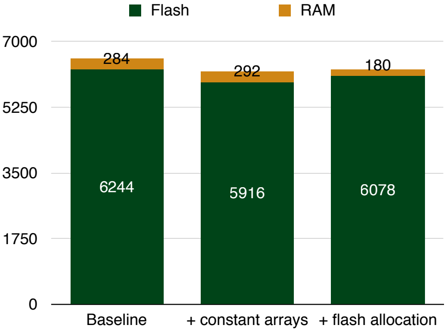
- Folded primitive constants
- Singleton objects → 30 % fewer `null`-checks

SPiCboardTest

Test application

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





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- Effectively-`final` analysis
  - Can greatly support optimisations
- Static initialisation + flash allocation of arrays
  - Improves startup times
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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)