Tighter WCET Estimates by Procedure Cloning

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Outline

1. Introduction
2. Procedure Cloning
3. Environment & Results
4. Future Work

1. Reducing Analysis Complexity

- loops are of main interest in ES software
- for precise static WCET analysis

  ⇒ represent each loop iteration by single context
- example MPEG: 1 context: 126 s ⟷ 4 contexts: 4,5 h
- compromise: restrict distinguished contexts
  - summarize loop iterations into single context

    ⇒ high WCET overestimation

1. Insufficient Loop Annotations

```
int f(int n) { ...
  for (i=0; i <= n; ++i ) {...} }
```

- loops annotated by [min,max]
- problem: **loop executions controlled by func. parameters**
- no explicit specification of loop iterations possible
  - exact loop bounds cannot be derived
- overestimation for last summarized context
  - static WCET analysis must assume worst case (safeness)
    - always assume upper loop bounds & longest path

  → loop analysis highly imprecise
- solution for tight WCET estimates: **Procedure Cloning**

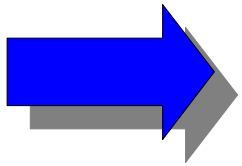
2. Procedure Cloning

- also known as **Function Specialization**
- compiler optimization aiming at reducing ACET
- generates specialized function copies
  - provides good basis for inter-procedural DFAs
  - opportunity for further standard optimizations
  - reduces calling overhead
  - simplifies control flow

2. Example for Procedure Cloning

```
int f(float *x, int n, int p) {
  for (i=0; i<=n; ++i) {
    x[i] = p * x[i];
    if(i==10) {...}
  }
  return x[n];
}

int main(void) {
  // multiple calls of f(x,5,2);
  return f(a,5,2);
}
```

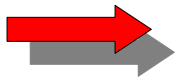


```
int f1(float *x) {
  for (i=0; i<=5; ++i) {
    x[i] = 2 * x[i];
    if( i==10) {...}
  }
  return x[5];
}

int main(void) {
  // multiple calls of f1(x);
  return f1(a);
}
```

2. Exploit for WCET estimation

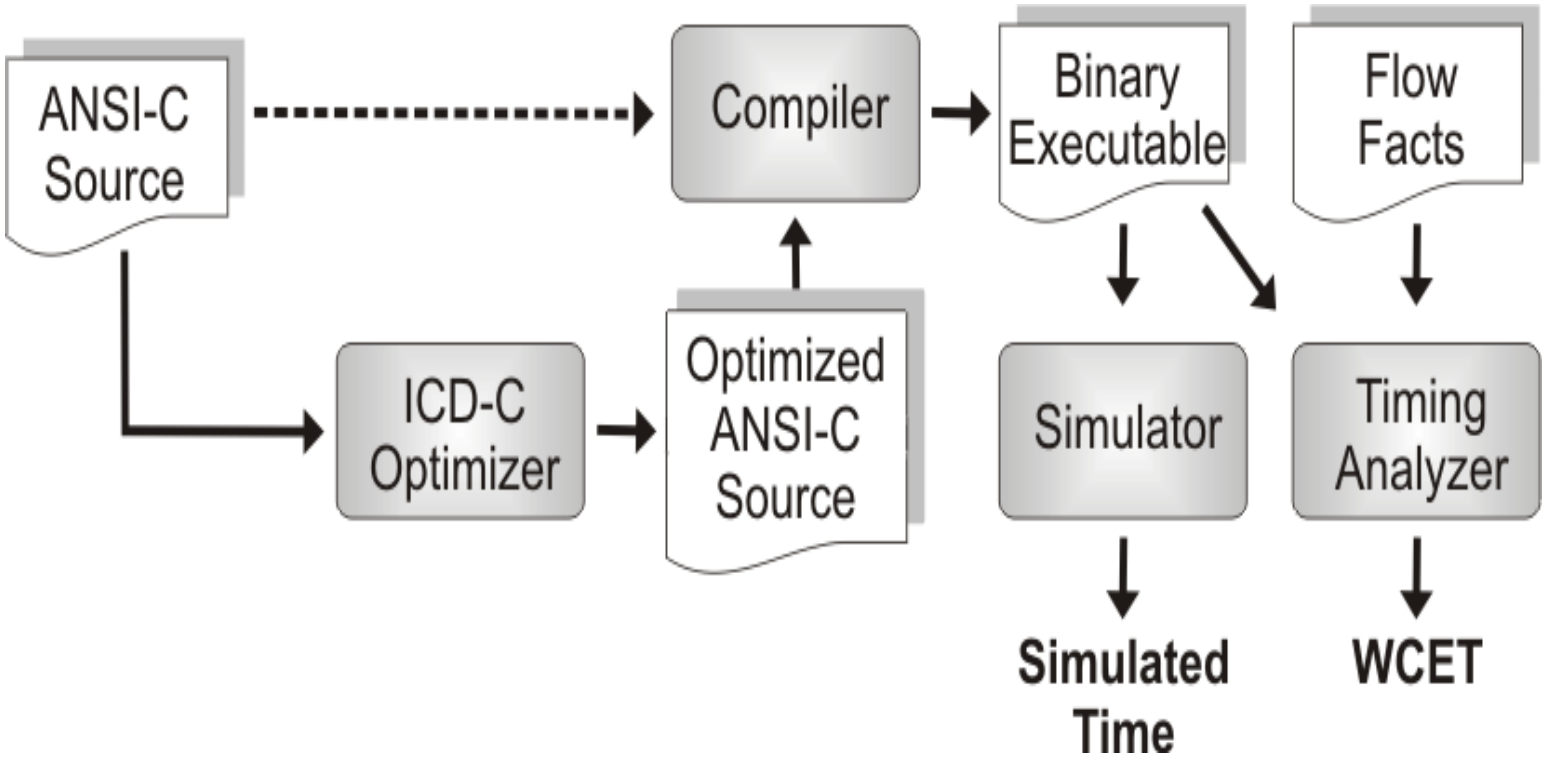
- Procedure Cloning makes code more predictable
  - function clones dedicated to individual loop executions
    - makes different function call contexts explicit
  - eliminates infeasible paths
- suitable for typical ES software
  - loop iterations controlled by function parameters
  - functions called multiple times with varying constants
- restriction of contexts (less) harmful



fast way to get tighter WCET estimates

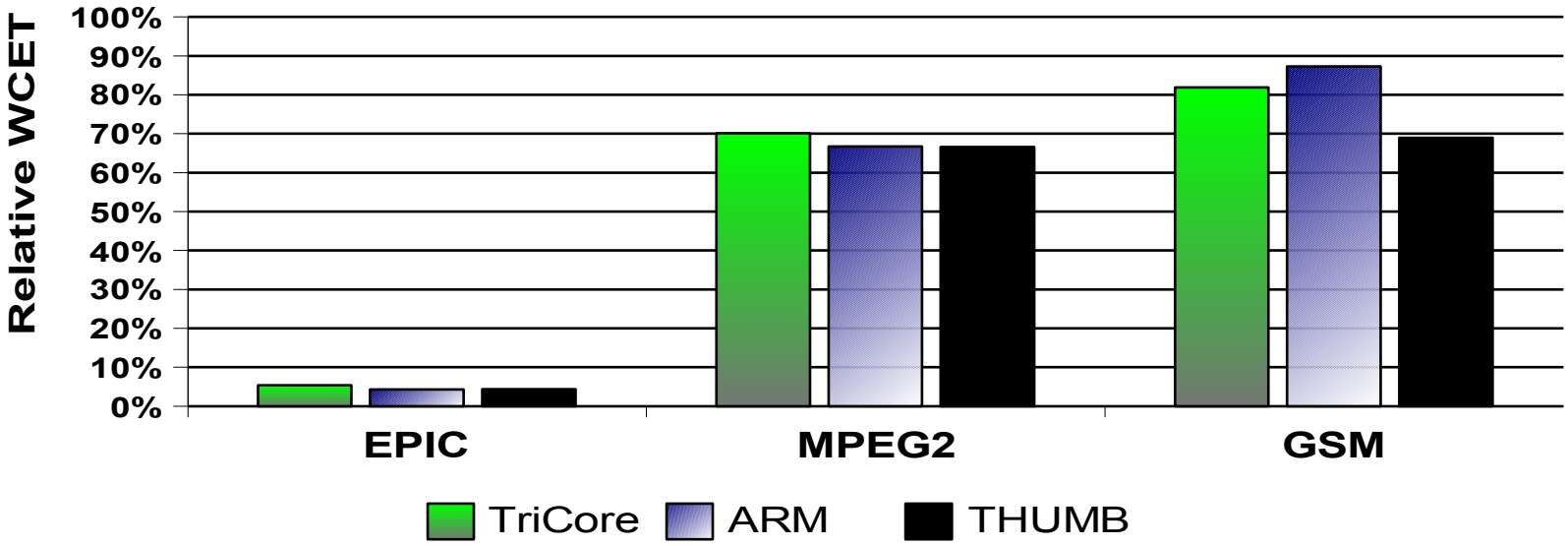
3. Experimental Environment

- benchmarks from MiBench suite
- analysis for TC1796 and ARM7TDMI (ARM+THUMB)
- AbsInt's aiT used as WCET analyzer



3. Results

- relative WCET for opt. code wrt. original code (100%)



- improvements for both processors of up to 95 %
  - results from nested loops controlled by constants
- code size increase: up to 300%
- increase of WCET analyzer runtime: on average 14%

4. Future Work

- incorporation into WCET-aware C compiler ***WCC***
- better exploitation of Procedure Cloning
  - optimize functions on WC path
- cope with increasing code size
  - perform a trade-off between WCET and code size
- automatic generation of flow facts
- virtual Procedure Cloning at analysis level