Exploiting Dynamic Timing Slack for Energy Efficiency in Ultra-low-power Embedded Systems

Hari Cherupalli - Minnesota
Rakesh Kumar - Illinois
John Sartori - Minnesota
Why Ultra-low-power Embedded Systems?

• Low-power μPs and μCs are the most abundant type of processors

• Saving power for these processors can have a huge impact
Opportunity

Low-power embedded systems run the same application over and over.

Many applications do not exercise all functionalities of a low-power general purpose processor.
Dynamic Timing Slack (DTS)

Reduce power (voltage) without reducing performance (frequency)
Dynamic Timing Slack: Fact or Fallacy?

Measurements provide evidence of DTS in real embedded systems.
How to determine DTS?

Why not use input-based profiling?

Problem:

- Activity depends on input
- Critical path can depend on input
- Variations depend on input and operating conditions

WE NEED A DIFFERENT APPROACH
Identifying Dynamic Timing Slack

- Application Binary
- Application Analysis
- Unexercisable Nets
- Voltage Safety Analysis

Symbolic simulation with X as inputs for input independent analysis

Timing analysis at worst case for variation-independent analysis
Application Analysis

(Binary)

1. mov #0, r4;
2. mov #0, r5;
3. mov &0x0020, r15;
4. cmp r15, #10000;
5. jl else

then:
6. mov #1000, r4
7. jmp end

else:
8. mov #1000, r5
end:
9. sub r4, r5, r6;

1. mov #0, r4;
2. mov #0, r5;
3. mov &0x0020, r15;
4. cmp r15, #10000;
5. jl else

then:
6. mov #1000, r4
7. jmp end

else:
8. mov #1000, r5
end:
9. sub r4, r5, r6;

Unexercisable Nets
Voltage Safety Analysis

Unexercisable Nets

<table>
<thead>
<tr>
<th>c -&gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>e -&gt; 1</td>
</tr>
</tbody>
</table>

Critical Paths

- B a c g F
- C b f i H
- B-a-d-h-G

\[ V_{\text{min}} \]
Example code block for tHold:

```assembly
mov #0, r4 ; Initialize counter
loop:
    mov &0x0020, r15 ; Read from mem/port
    cmp r15, #10000 ; Threshold Detection
    jl else
    then:
        inc r4
    mov r4, 0x0028 ; Write to mem/port
else:
    jmp loop
```
Power savings from exploiting DTS

25% free power savings, on average
Conclusion

• Emerging applications are severely power constrained
• Only exercised parts of the processor need to meet timing
• Exploiting Dynamic Timing Slack can reduce power without reducing performance
• Average of 25% free power/energy savings