Steady-State Dynamic Temperature Analysis and Reliability Optimization for Embedded Multiprocessor Systems

Ivan Ukhov, Min Bao, Petru Eles, and Zebo Peng

Embedded Systems Laboratory
Linköping University, Sweden

June 2012
Temperature Analysis (TA)
Temperature Analysis (TA)

Steady-State [Static] TA (SSTA):

- Constant power $\rightarrow$ Constant temperature.

![Temperature vs. Time Graph](image)
Temperature Analysis (TA)

Steady-State [Static] TA (SSTA):
• Constant power $\rightarrow$ Constant temperature.

Transient TA (TTA):
• Transient power profile $\rightarrow$ Transient temperature profile.
Temperature Analysis (TA)

Steady-State [Static] TA (SSTA):
• Constant power $\rightarrow$ Constant temperature.

Transient TA (TTA):
• Transient power profile $\rightarrow$ Transient temperature profile.

Steady-State Dynamic TA (SSDTA):
• Periodic power profile $\rightarrow$ Periodic temperature profile.
Overview

We have:
- Multiprocessor platform with thermal package.
- Periodic dynamic power profile.

We perform:
- Steady-State Dynamic Temperature Analysis.

We obtain:
- Steady-State Dynamic Temperature Profile.

We demonstrate:
- Importance for reliability optimization.
Iterative simulation using TTA…

Gradually approaching SSDTP

Successive simulations with the same power profile

... takes a long time to perform.
The State of The Art (2)

Steady-State Approximation (SSA) using SSTA...

SSA assumes the system is always in the steady state.

... gives a rough estimation.
Thermal RC Circuit

Source of heat
Thermal capacitance
Thermal resistance

Heat sink
Heat spreader
Thermal interface material
Hot die
Proposed Method (1)

Heat equation:

\[ C \frac{dT(t)}{dt} + G(T(t) - T_{amb}) = P(t) \]

Leakage inside
Proposed Method (1)

Heat equation:

\[ C \frac{dT(t)}{dt} + G(T(t) - T_{amb}) = P(t) \]

Iterative solution:

\[ T_{i+1} = K_i T_i + B_i P_i \]
Proposed Method (1)

Heat equation:

\[ C \frac{dT(t)}{dt} + G(T(t) - T_{amb}) = P(t) \]

Iterative solution:

\[ T_{i+1} = K_i T_i + B_i P_i \]
Proposed Method (1)

Heat equation:
\[ C \frac{dT(t)}{dt} + G(T(t) - T_{amb}) = P(t) \]

Iterative solution:
\[ T_{i+1} = K_i T_i + B_i P_i \]

Leakage inside

TTA

SSDTA

\[ T_{start} = T_{end} \]
Proposed Method (2)

Huge system of linear equations:

\[ AX = B \]

\[ N_s N_n \times N_s N_n \]

Number of steps in the power profile

Number of nodes in the thermal circuit
We propose:
• Auxiliary transformation of the heat equation.
• Analytical solution via a condensed system.

We consider:
• Structure and sparseness of the system.

We deliver:
• Accurate and computationally cheap results.

Proposed Method (3)

\[ \propto N_s N_n^3 \]

\[ N_s \gg N_n \]
Proposed Method outperforms TTA with HotSpot.

Experimental Results (1)

- Application Period, s
  - 2000× faster

- Number of Cores
  - 5000× faster
Thermal Cycling Fatigue

Total damage depends on maximal temperature, amplitudes, and frequency of thermal cycles.
Reliability Optimization: Motivation
Reliability Optimization: Motivation

Map & Schedule

SSDTPs

3 cycles
Reliability Optimization: Motivation

Map & Schedule

SSDTPs

3 cycles

2 cycles

+45% lifetime
Reliability Optimization: Motivation

Map & Schedule

SSDTPs

3 cycles

2 cycles

+45% lifetime

1 cycle

+55% lifetime
Reliability Optimization: Summary

Goal:
- Decrease the thermal cycling (TC) fatigue in order to prolong the lifetime of the system.

Means:
- Employ a genetic algorithm to perform a temperature-aware mapping and scheduling.

Important:
- SSDTP is a must to address the TC fatigue.
- Do not compromise the energy efficiency.
Experimental Results (2)

Real-life example:
- MPEG2 decoder.
- 34 tasks.
- 2 cores.

Increase of the lifetime:
- $24 \times$ using Proposed Method.
- $5 \times$ using TTA with HotSpot.
- $11 \times$ using Steady-State Approximation.
Thank you!

Questions?