Motivation

- Modern mobile platforms integrate multiple CPUs, GPUs and accelerators
- Power consumption and resulting heat dissipation is a major problem for mobile platforms [1]
  - High temperature affects user experience and reliability
  - Power and temperature form a positive feedback system
- Uncontrolled temperature can also cause safety risks

Solution approach

A complete heat-up/cool-down cycle on Exynos 5422 SoC

This work:

1. Derives the necessary and sufficient conditions for the existence of the fixed point
2. Proves the stability of the fixed point(s) and region of convergence
3. Finds the maximum dynamic power consumption to guarantee a thermally safe temperature
4. Is validated empirically on 8-core big.LITTLE platform

Thermal and Power models

- Temperature at a future time step can be written as:
  \[ T_{n+1} = T_n + \Delta T_n \]
  \[ \Delta T_n = \frac{P_{dyn}(t)}{C_R} + P_{Th} + P_{Leak} \]
  - \( C_R \) models the effect of temperature in time step \( n \) in time step \( n+1 \)
  - \( P_{dyn}(t) \) models the effect of each power source on the temperature

- Power consumption can be expressed as the sum of dynamic and temperature dependent leakage
  \[ P = P_{dyn}(t) + P_{Th} + P_{Leak} \]
  \[ P_{dyn}(t) = I_d(V_d + \alpha T) + \beta \]
  \[ P_{Leak} = Z \]
  where \( I_d \) is the switching current, \( V_d \) is the voltage, \( \alpha \) is the temperature coefficient, \( \beta \) is the threshold voltage, and \( Z \) is the leakage power dissipation.

Fixed Point Function

- Nonlinear MIMO system due to exponential terms in \( P(t) \)
  - No closed-form solutions for this nonlinear system
- Solution approach
  - Reduce to SISO model to find an initial estimate of fixed points
  - Then, use Newton’s method to solve the MIMO system
  - At steady state (\( \dot{T} = 0 \)) we have
    \[ T = \alpha T + \beta \]
    where \( 0 < \alpha < 1 \) and \( \beta > 0 \) are parameters of reduced order SISO system
- Using change of variables we can write,
  \[ P(T) = \ln \left( 1 + \frac{1}{\alpha} T \right) \]
  Taking logarithm on both sides,
  \[ P(T) = \ln \left( 1 + \frac{1}{\alpha} T \right) + \ln(1 - \alpha T) + \gamma = 0 \]

Fixed Point Analysis

- Lemma 1: \( F(T) \) satisfies the following properties
  - \( F(T) \) is concave in the interval \( \Delta T \)
  - \( F(T) \) has a unique maxima at \( T_m \) given by
    \[ T_m = 1 + \frac{1}{\alpha} T \]
  - \( F(T) \) is increasing in \( (0, T_m) \) and decreasing in \( (T_m, \infty) \)

- Lemma 2: Value of \( T \) in the temperature iteration increases when \( \dot{T}(t) < 0 \), and decreases when \( \dot{T}(t) > 0 \)

- Theorem 2: Stability of fixed points is as follows
  - When \( \dot{T}(t) \) has no solution, the temperature iteration diverges, i.e.
    \[ T \to 0 \] (\( T \to \infty \))
  - Where there are two fixed points, \( T_1, T_2 \) is unstable and \( T \) is \( T \) is stable.

Our Contributions

Our technique takes 75.2 μs when integrated into Android OS
- We validated our approach empirically on the Odroid-XU3 board

Conclusions

- Theoretical stability analysis for power-temperature dynamics
  - Existence: Derived sufficient and necessary conditions
  - Stability: Found region of stability
  - Safety: Derived maximum allowed dynamic power

References