Energy-Driven Systems and Compute
Towards Self-powered Embedded Computing Systems

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An *energy harvester* is one part of a *system*.
ENERGY HARVESTING

Power / Energy

varies
temporally

varies
spatially

Highly variable supply + variable consumption!
ENERGY-NEUTRAL COMPUTING

Schematic

Block Diagram

\[
\int_{(n-1)\cdot T}^{n\cdot T} P_{\text{in}}(t)\,dt = \int_{(n-1)\cdot T}^{n\cdot T} P_{\text{c}}(t)\,dt
\]
ENERGY-DRIVEN COMPUTING

• What’s wrong with energy storage and complexity?

• Emerging applications demanding small dimensions, volumes, weight, cost, etc

• Properties of energy storage devices (sustainability, maintenance, etc)
ENERGY-DRIVEN COMPUTING

• Rethinking the design of EH systems

Energy-Driven Systems

Traditional Systems

Energy Storage

long deployment lifetime

maintenance-free

high QoS

eborn-friendly

compact

energy-driven: intermittent and/or power-neutral battery-powered

Optimization’
ENERGY-DRIVEN COMPUTING
INTERMITTENT COMPUTING

Simplify the system; design for intermittency

Compute across power outages

INTERMITTENT COMPUTING

Compute/Memory
• Self calibration for runtime threshold optimisation (*hibernus*++)
• Adaptive restore based on EH properties (*hibernus*++)
• Efficient state retention (Selective Policies, *ManagedState*)
• Fine-grained power adaption (*PowerNeutrality*)

Peripherals/Sensors/Communication
• Hibernation and restore of external peripheral state (*RESTOP*)
• Support for communication and mesh networking

Applications/Users/Interfaces/Design Tools
• Application case studies, e.g. cycle computer, fitness monitor, wall clock, etc
• Design tools, e.g. *ENSPECT*, *FUSED*, Device Sizing, Support for *Arm Mbed*

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POWER NEUTRAL COMPUTING

• In Power-Neutral computing, \( P_c(t) \approx P_h(t) \)

• We can approximate power-neutral behaviour if \( V_c(t) \approx k, \forall t \)

- Power consumption is modulated, eg through:
  - Core frequency and/or voltage
  - Power gating processor elements
POWER NEUTRAL COMPUTING

- What happens if $V_C$ remains constant ($V_C(t) \approx k$, $\forall t$)?
- MPPT approaches are needed as $V_C(t) \neq V_{H\_MPP}(t)$, $\forall t$
- ‘Software-only’ MPPT modulates $k$: $V_C(t) = V_{H\_MPP}(t)$

Estimating $V_{cc}$ and $P_C$, we can identify MPP
DISCUSSION

• We need to rethink the way that we design self-powered systems

• Progress is being made across all aspects of the system, but a wide range of challenges still exist
YOUR QUESTIONS

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