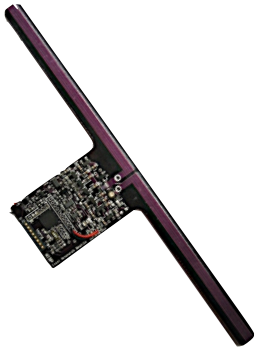
CMOS Workshop 2009

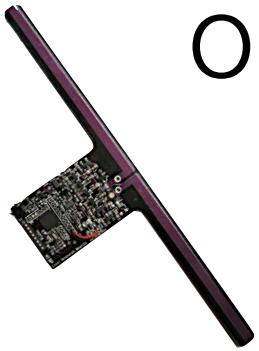


Energy-aware Circuits for RFID

Kevin Fu, Wayne Burleson
Benjamin Ransford, Shane Clark, Mastooreh Salajegheh
kevinfu@cs.umass.edu
Department of Computer Science
University of Massachusetts Amherst

CMOS Workshop 2009

Getting Things Done ☑ on Computational RFIDs with Energy-Aware Checkpointing and Voltage-Aware Scheduling



Kevin Fu, Wayne Burleson
Benjamin Ransford, Shane Clark, Mastooreh Salajegheh
kevinfu@cs.umass.edu
Department of Computer Science
University of Massachusetts Amherst

Scenario: RFID Sensor Network

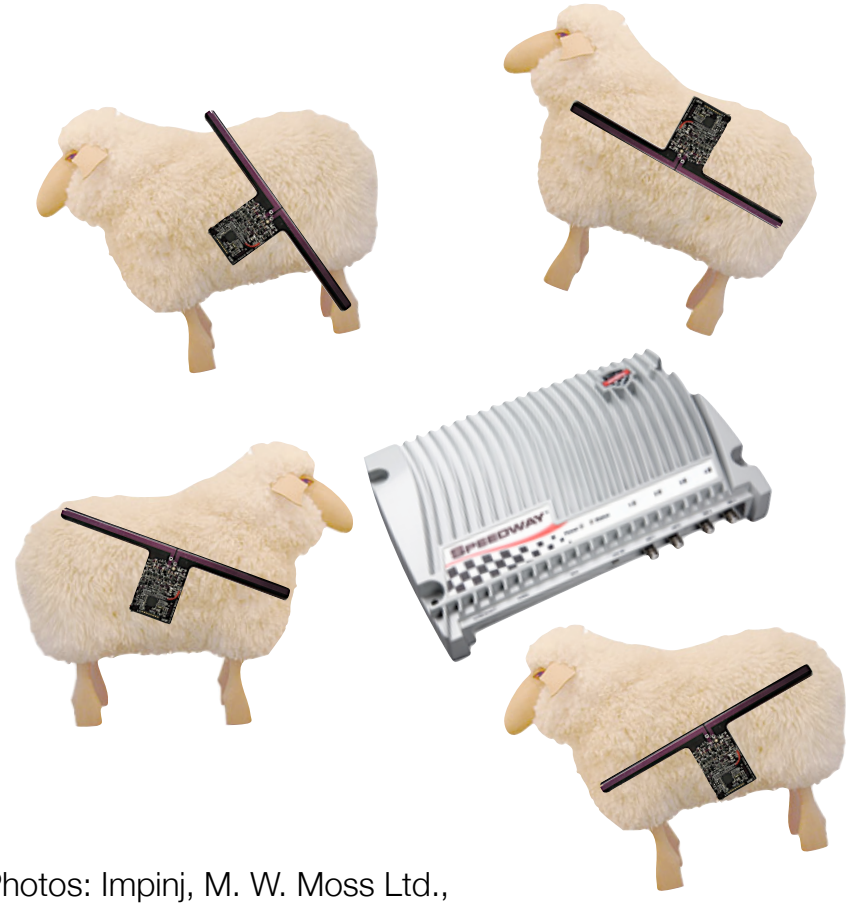
[HotNets '08]

- Maintenance-free
- Batteryless nodes
- RF power harvesting
- Public-key crypto?

Photos: Impinj, M. W. Moss Ltd., reinforcedearth.com

Scenario: RFID Sensor Network

[HotNets '08]



- Maintenance-free
- Batteryless nodes
- RF power harvesting
- Public-key crypto?

Photos: Impinj, M. W. Moss Ltd., reinforcedearth.com

Scenario: RFID Sensor Network

[HotNets '08]

- Maintenance-free
- Batteryless nodes
- RF power harvesting
- Public-key crypto?

Photos: Impinj, M. W. Moss Ltd., reinforcedearth.com

The next 15 minutes

1. Batteryless computing with computational RFID (CRFID)
2. Obstacles to computing on harvested energy
   - Fluctuating supply, power loss
3. Mementos: s/w for *getting things done*
   - Checkpointing, program reordering

Batteries constrain design.

Big & heavy relative to circuits.

Must be replaced or recharged.

Energy density *slooooowly* increasing.
(1991: 204 Wh/l ... 2005: 514 Wh/l)

photos: Duracell, Micro-Tools.com, Crossbow

How can we do useful computation without a battery?

How can we do useful computation without a battery?

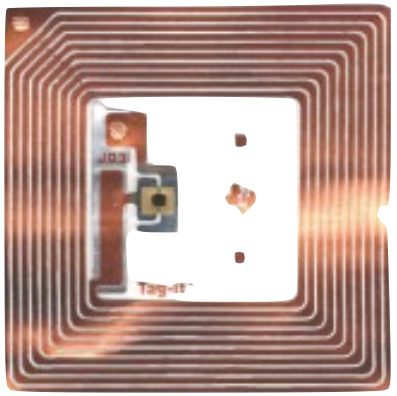
Focus on energy harvesting.

Perils of RF harvesting

- Devices become dependent on energy supply
- Unpredictable supply
- Fluctuating voltage
- Frequent loss of power/state

Today's batteryless computers

must finish in one energy lifecycle



non-programmable circuitry

Photos: thisismoney.co.uk, TI

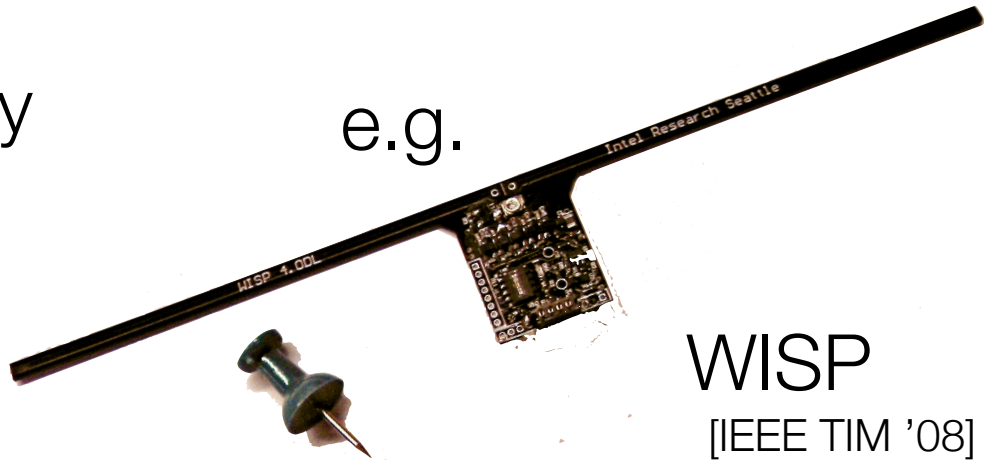
Computational RFID

(new term)

- Made possible by ultra-low-power (1.5μA sleep, 600μA active) programmable microcontroller
- von Neumann architecture
- RAM, flash memory

No battery...
RF harvesting.

e.g.



WISP
[IEEE TIM '08]

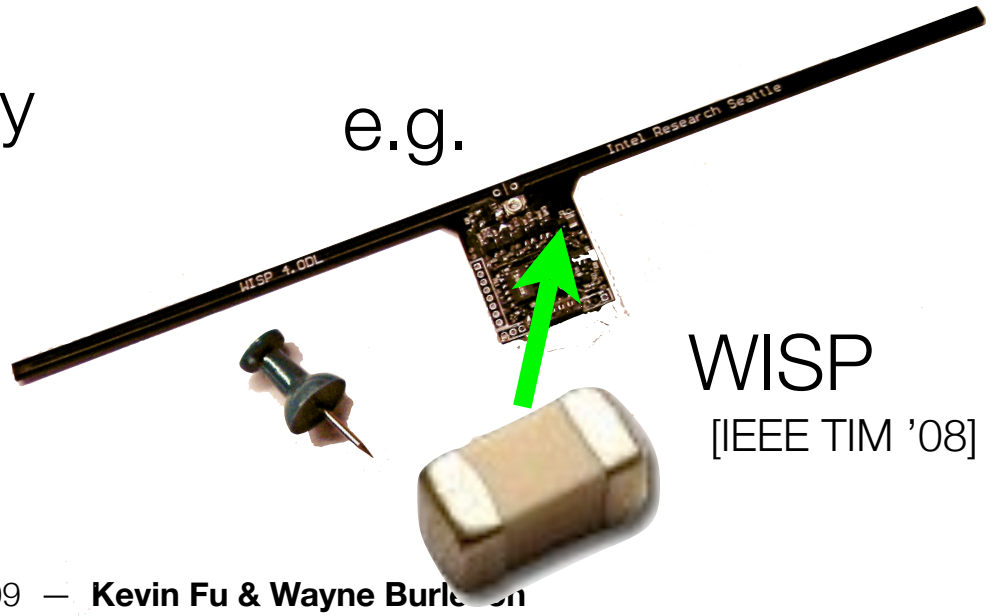
Computational RFID

(new term)

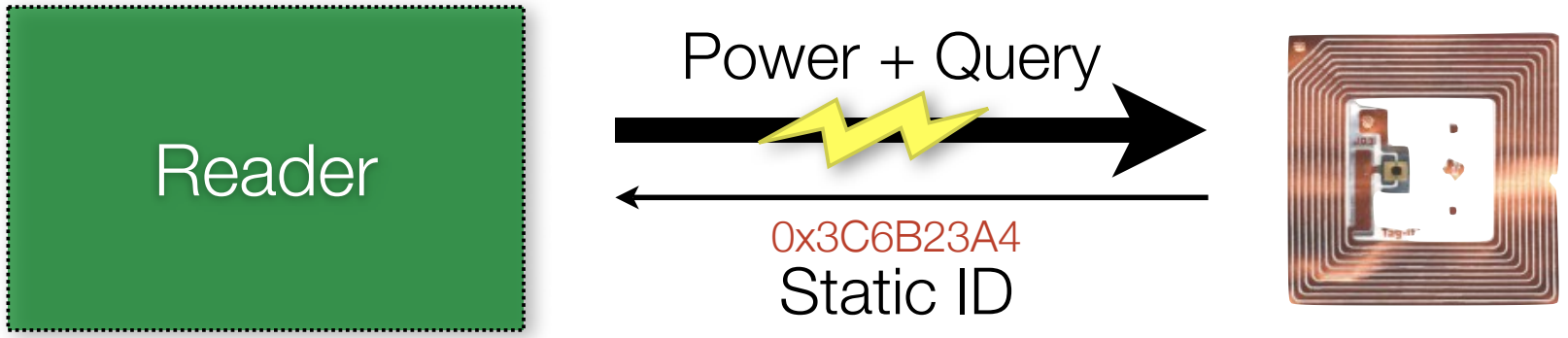
- Made possible by ultra-low-power (1.5μA sleep, 600μA active) programmable microcontroller
- von Neumann architecture
- RAM, flash memory

No battery...
RF harvesting.

e.g.



WISP
[IEEE TIM '08]

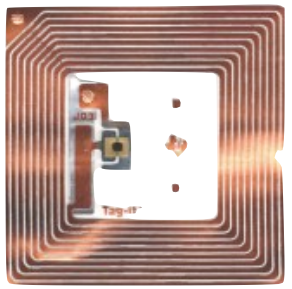

Reader
Power + Query
0x3C6B23A4
Static ID

Reader

Power + Query

0x3C6B23A4

Static ID

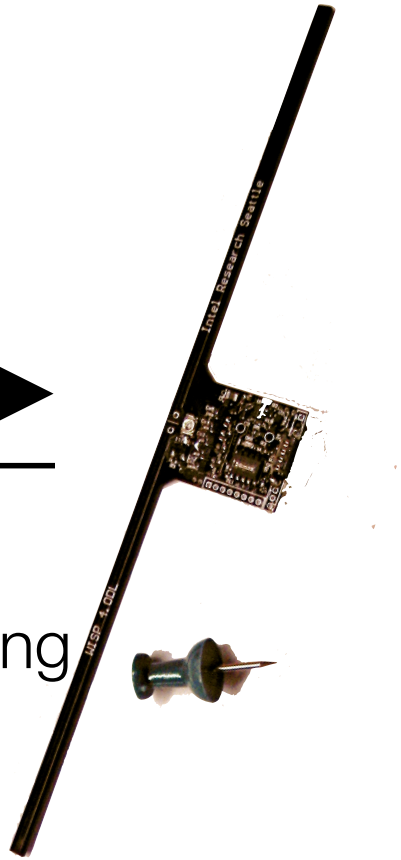


Reader

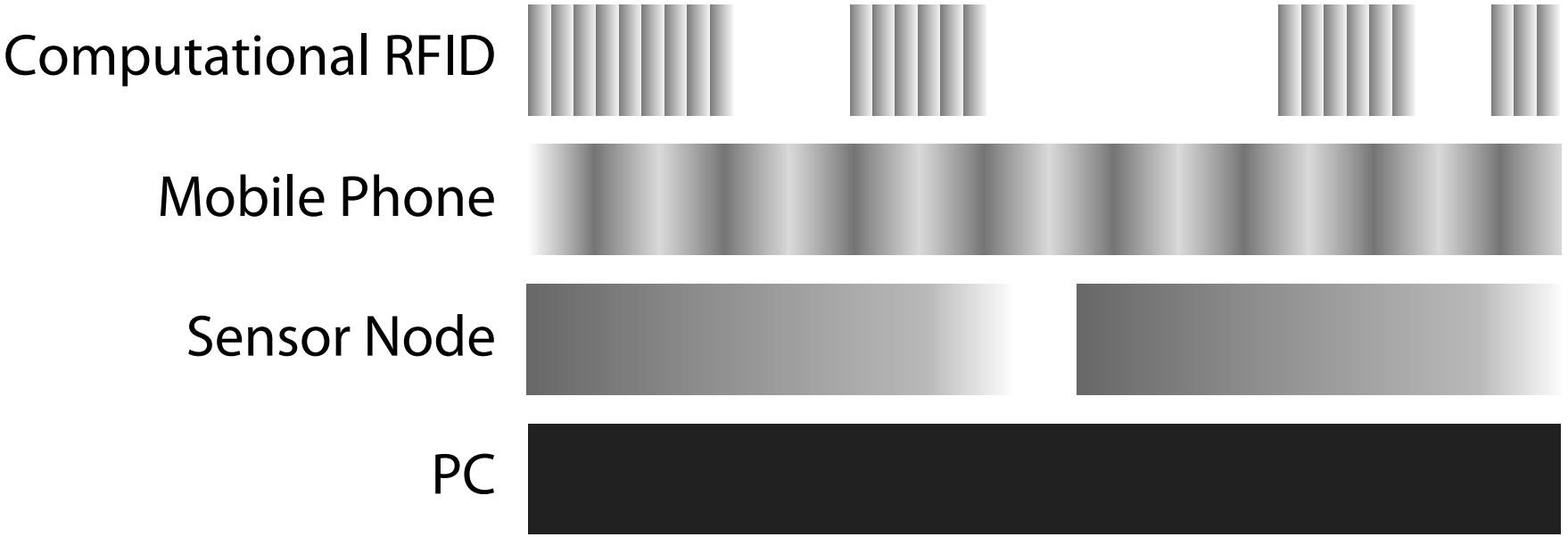
Power + Query

0x1234CAFE

Results of computation or sensing



Common case: Frequent power loss



Perils of RF harvesting

- Devices become dependent on energy supply
- Unpredictable supply
- Fluctuating voltage
- Frequent loss of power/state

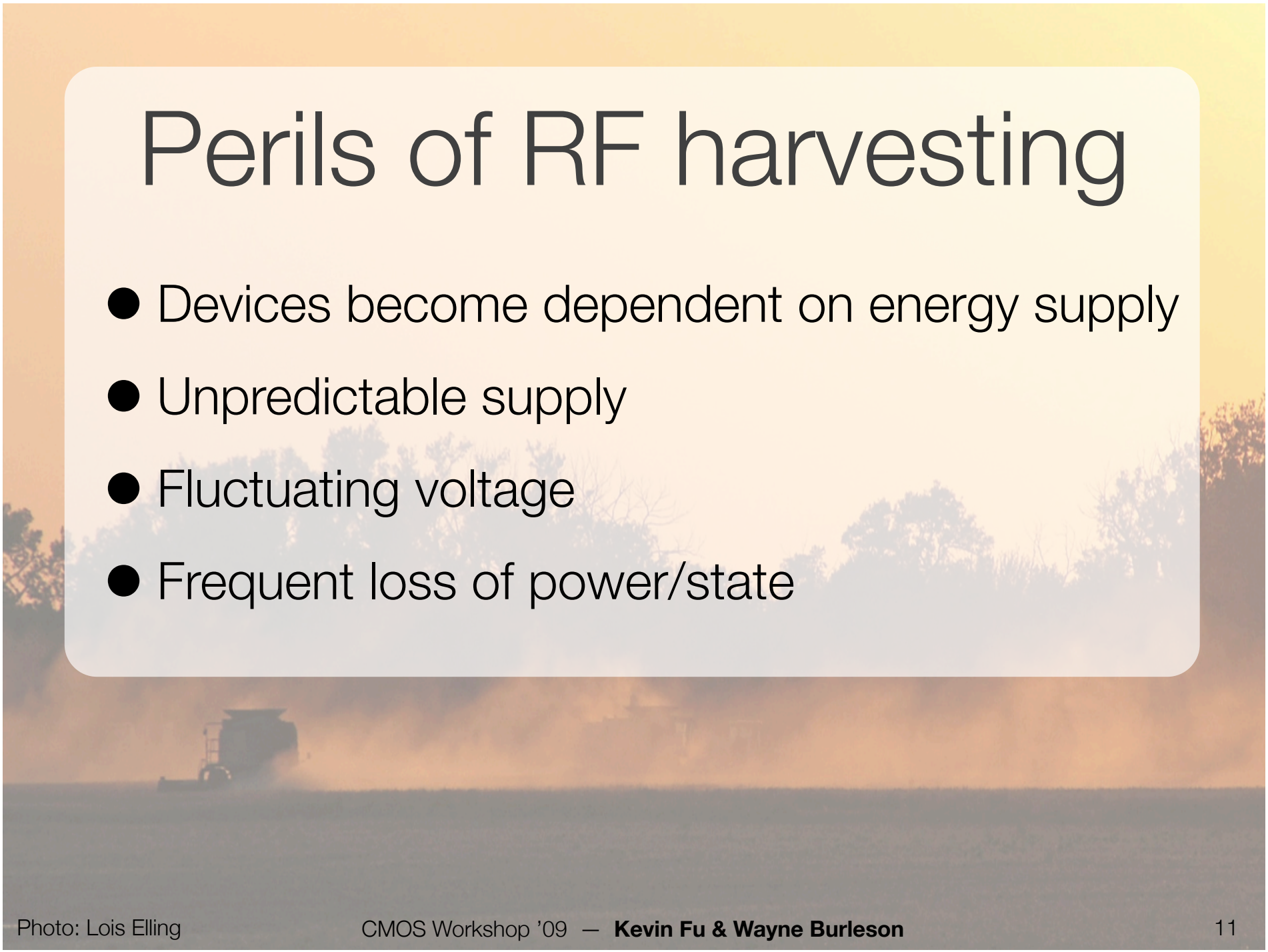


Photo: Lois Elling

Perils of RF harvesting

- Devices become dependent on energy supply
- Unpredictable supply
- Fluctuating voltage
- Frequent loss of power/state

Getting things done

Major goal: help programs on CRFIDs
make **forward progress** despite
fluctuating voltage and constant interruption.

Our system: *Mementos*

- Designed to aid forward progress.

- Execution checkpointing (suspend, resume)
- Program reordering

Our system: *Mementos*

- Designed to aid forward progress.
- Frequent loss of power/state
- Execution checkpointing (suspend, resume)
- Program reordering

Our system: *Mementos*

- Designed to aid forward progress.
- Execution checkpointing (suspend, resume)
- Program reordering

- Frequent loss of power/state
- Fluctuating voltage

Newmarket Capital Group

Newmarket Capital Group

Checkpointing

- Frequent loss of power/state

- Idea: save state to flash before dying
- Challenging! Not cheap:
  - Flash:register 400:1
  - Flash:memory 40:1

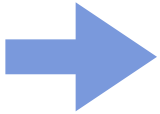
Checkpointing

- **Compile time** static analysis:
  - Compute per-block energy estimates
- **Run time:**
  - CRFID checks own voltage
  - Dynamic checkpointing decision

Energy estimation

at compile time

Instr.	Dest.	Src.	Energy/Instr. (nJ)
NOP	—	—	2.0
MOV	reg	reg	1.1
		flash	5.2
		mem	6.3
MOV	mem	reg	8.1
		flash	11.8
		mem	11.7
MOV	flash	reg	461.0
		flash	350.3
		mem	1126.2

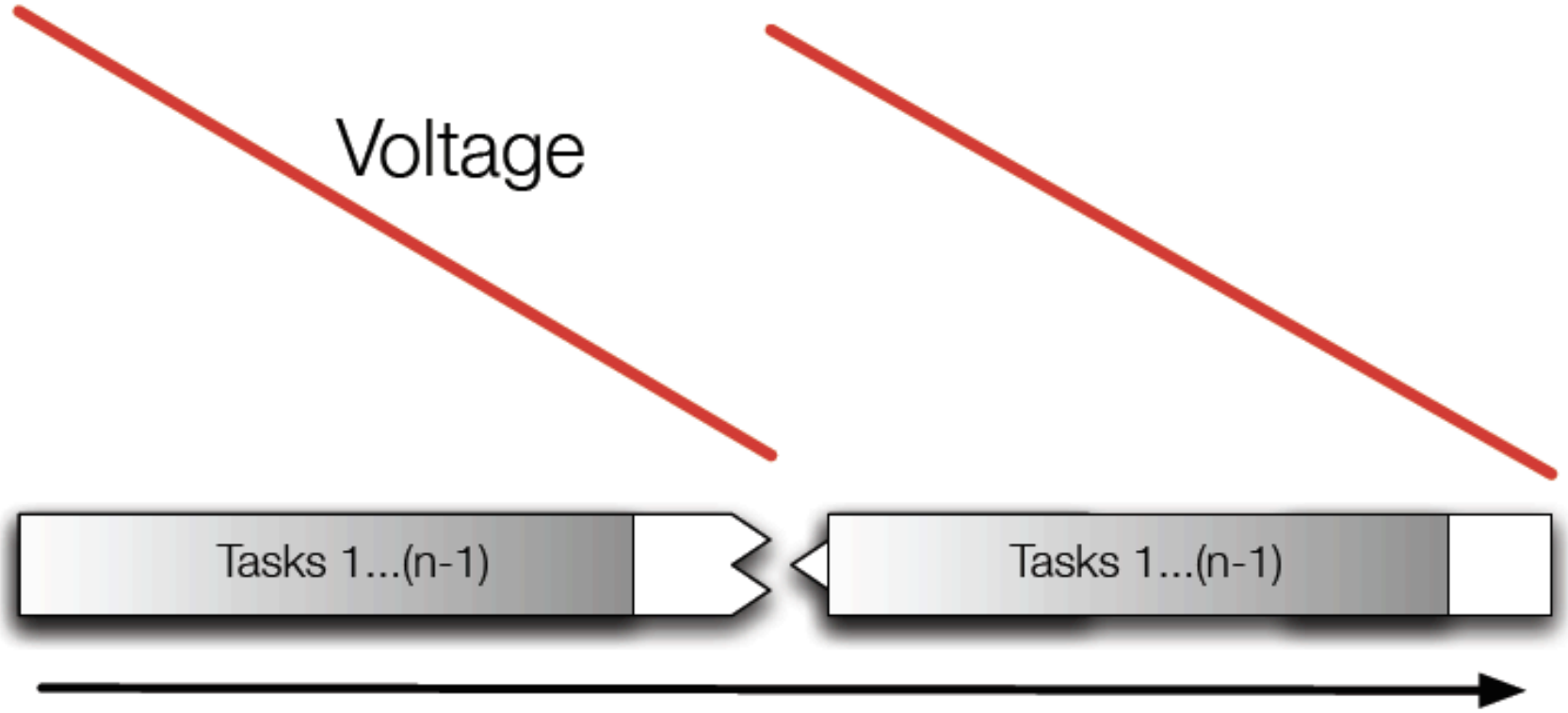


```
label1:
MOV R11, R12      1 nJ
ADD R12, R8       1 nJ
(Flash write)     461 nJ
JMP label2        --
...               ...
```

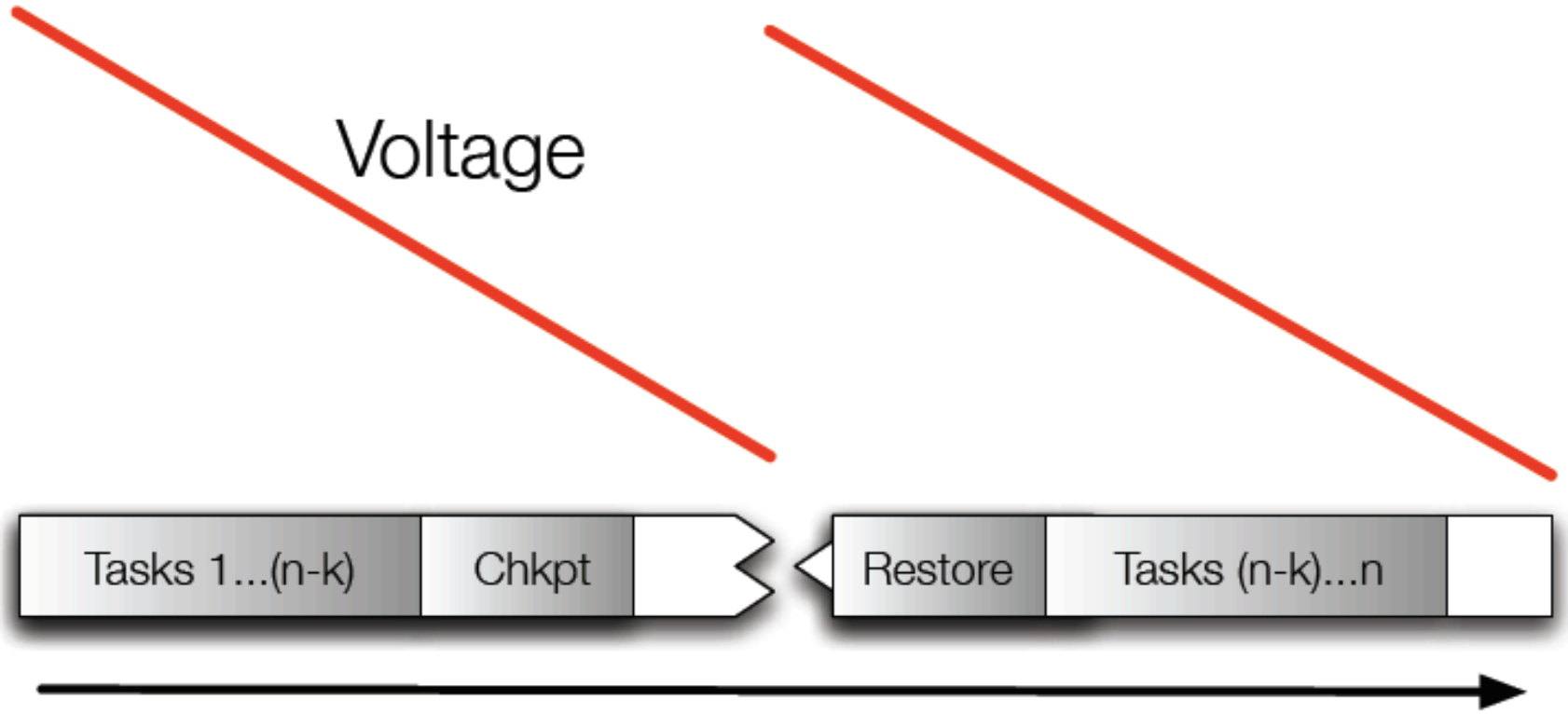
Platform-specific energy profile

Annotated instruction stream

Checkpointing to accomplish *n* tasks



Checkpointing to accomplish *n* tasks



e.g.: modexp

- Halve 32-bit exponent, square 32-bit base
  - No checkpointing: dies before finishing

e.g.: modexp

- Halve 32-bit exponent, square 32-bit base
  - No checkpointing: dies before finishing

e.g.: modexp

- Halve 32-bit exponent, square 32-bit base
  - No checkpointing: dies before finishing
  - Checkpoint halfway through:
    - Save base, exp., accumulated result after 15 iterations; die before finishing
    - Restore from checkpoint; 17 more iterations; complete.

Program reordering

- Fluctuating voltage

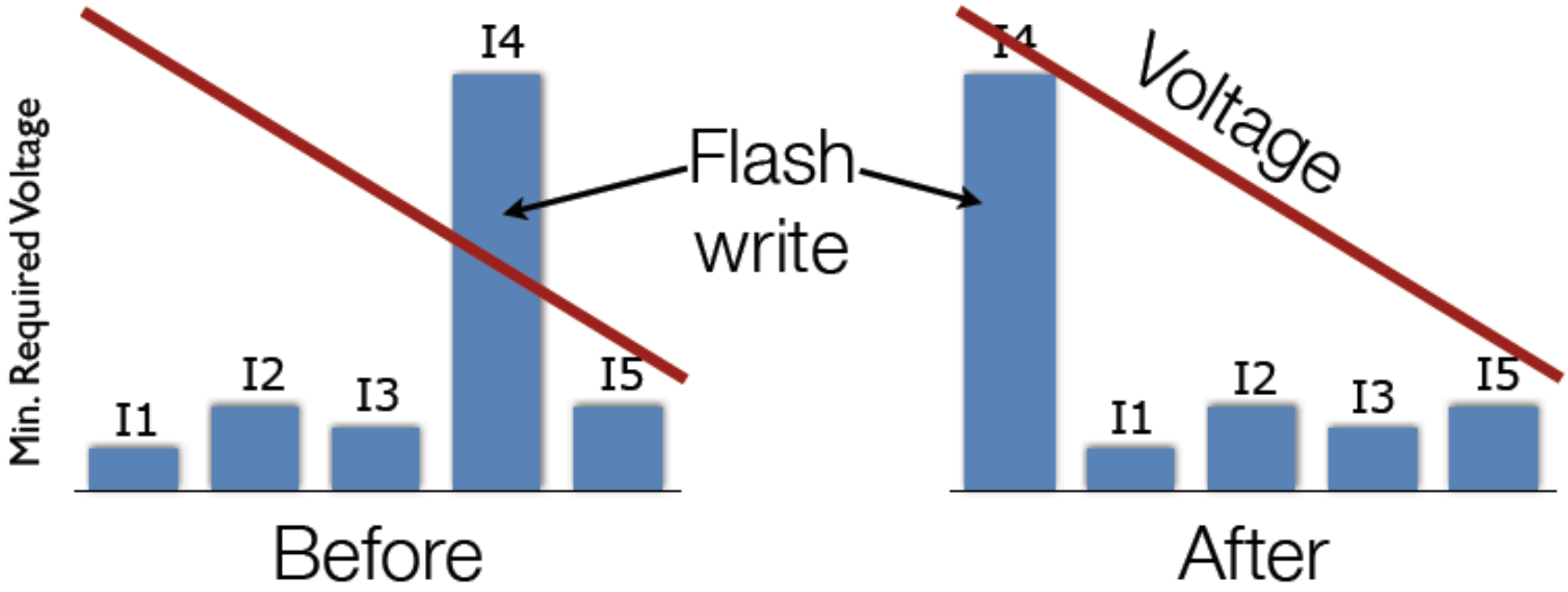
- Observations:
  - Some operations require higher voltage
  - Voltage tends to decline
  - Microcontrollers don't perform well on continuously varying voltage (PLL logic limitations)

Program reordering

- Static analysis at compile time
  - Estimate energy requirements
  - Derive dependency graph
- Must not violate program semantics!

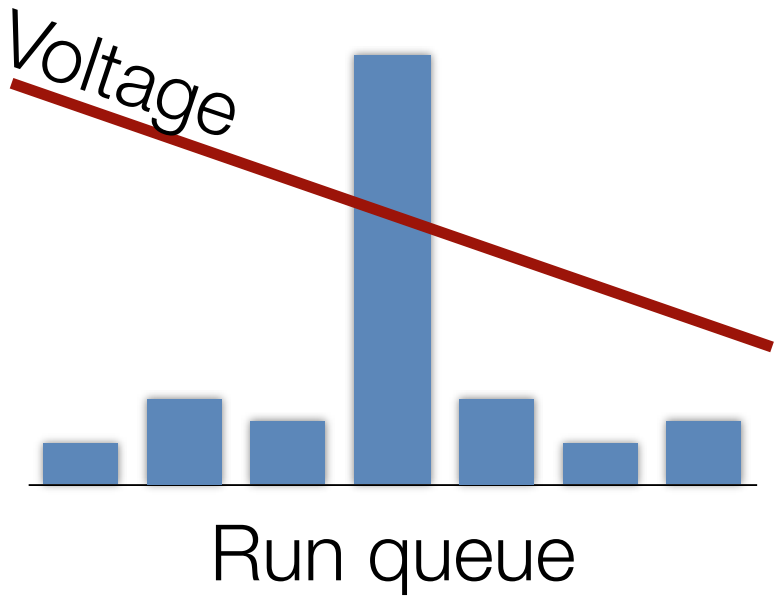
Program reordering

- Voltage declines: reorder independent blocks at **compile time** to excute high-V ops when supply voltage is high



Program reordering

- Smaller timescale: adaptively reschedule blocks at **run time** to avoid logjams



Challenges

- Predicting program behavior is hard.
- Balance checkpointing behavior:
  - How much state to save
  - How often to checkpoint
- Program reordering:
  - Finding dependencies

Oh, and physics

- Can’t harvest RF energy at arbitrary distances (current prototypes: ≤ 10 m)
- Diode drop limits energy harvesting

CRFID applications

- Medical implants [Oakland '08]
- RFID Sensor Networks [HotNets '08]

- Computation in inaccessible locations.
  fragile
  hazardous

Future developments

- Our work:
  - Fully implement checkpointing, reordering
  - Device profiling
- CRFIDs:

Intel Looks To Blanket The World With Self-Powered Sensors

By Antone Gonsalves
InformationWeek
December 5, 2008 05:37 PM

- Intel Research competition (Google *intel wisp challenge*)

Summary

- Computational RFIDs: general-purpose batteryless computers
- Mementos for forward progress
  - Checkpointing to cope with constant power interruptions
  - Program reordering to cope with fluctuating voltage