PYDIAS
Ultra-Low-Power Holistic Design for Smart Bio-signals Computing Platforms

imec

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

europeanresearchservices gmbh

THE BENEFITS AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

Tobias Gemmeke

imec-nl / Holst-Centre

NiPS Summer School 2014

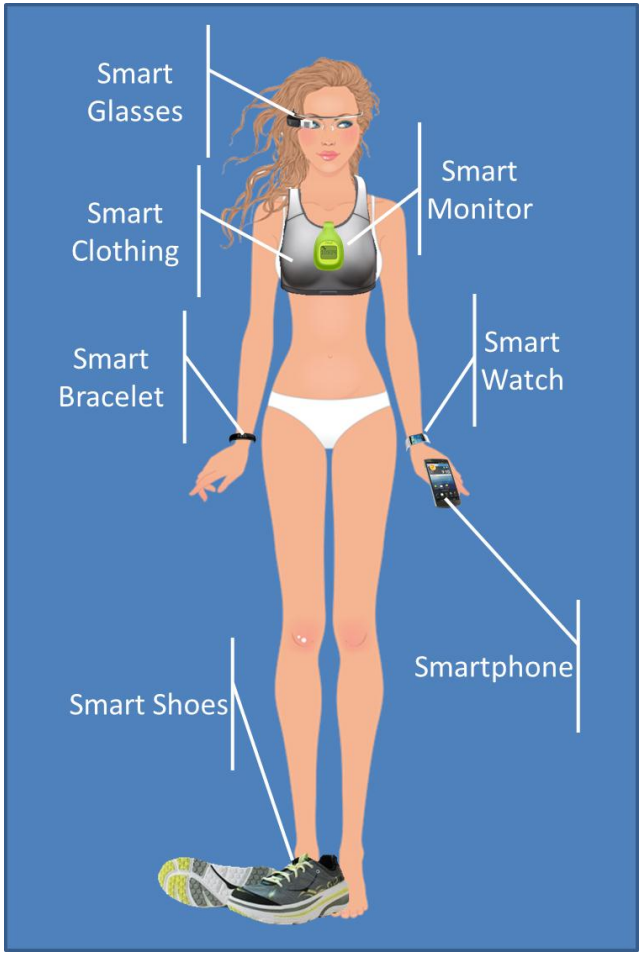
Perugia, Italy, July 14-18, 2014

THE BENEFITS AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR **WEARABLE DEVICES**

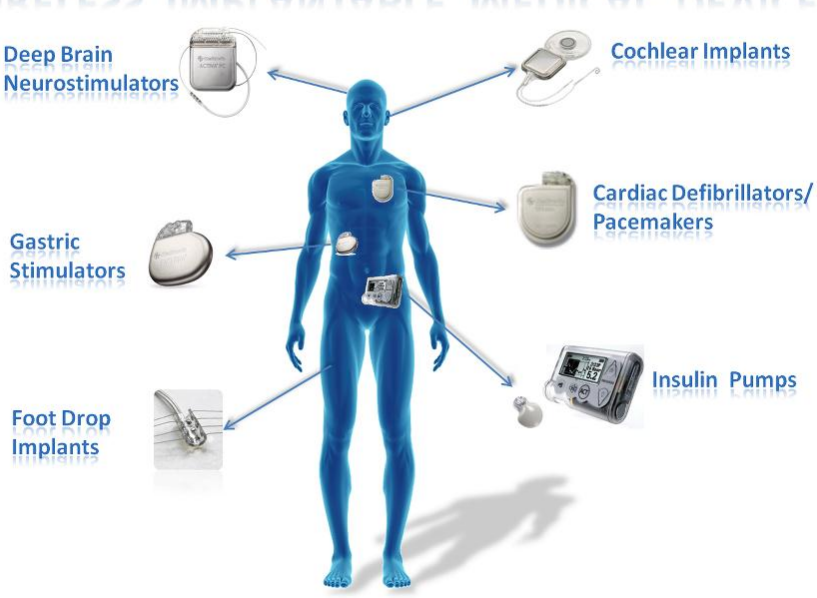
THE BENEFITS AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

- Pro-active
- Enhance
- Protect

WEARABLE DEVICES



[http://enterrasolutions.com/media/Wearable-devices.png]



[http://heightech.blogspot.be/2013/04/cutting-edge-wearable-medical-devices.html]

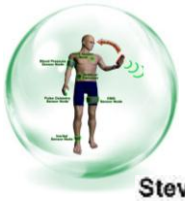
INDEPENDENT LIFESTYLE … ENHANCE

Ear2ear communication
- Directional hearing
- Noise suppression

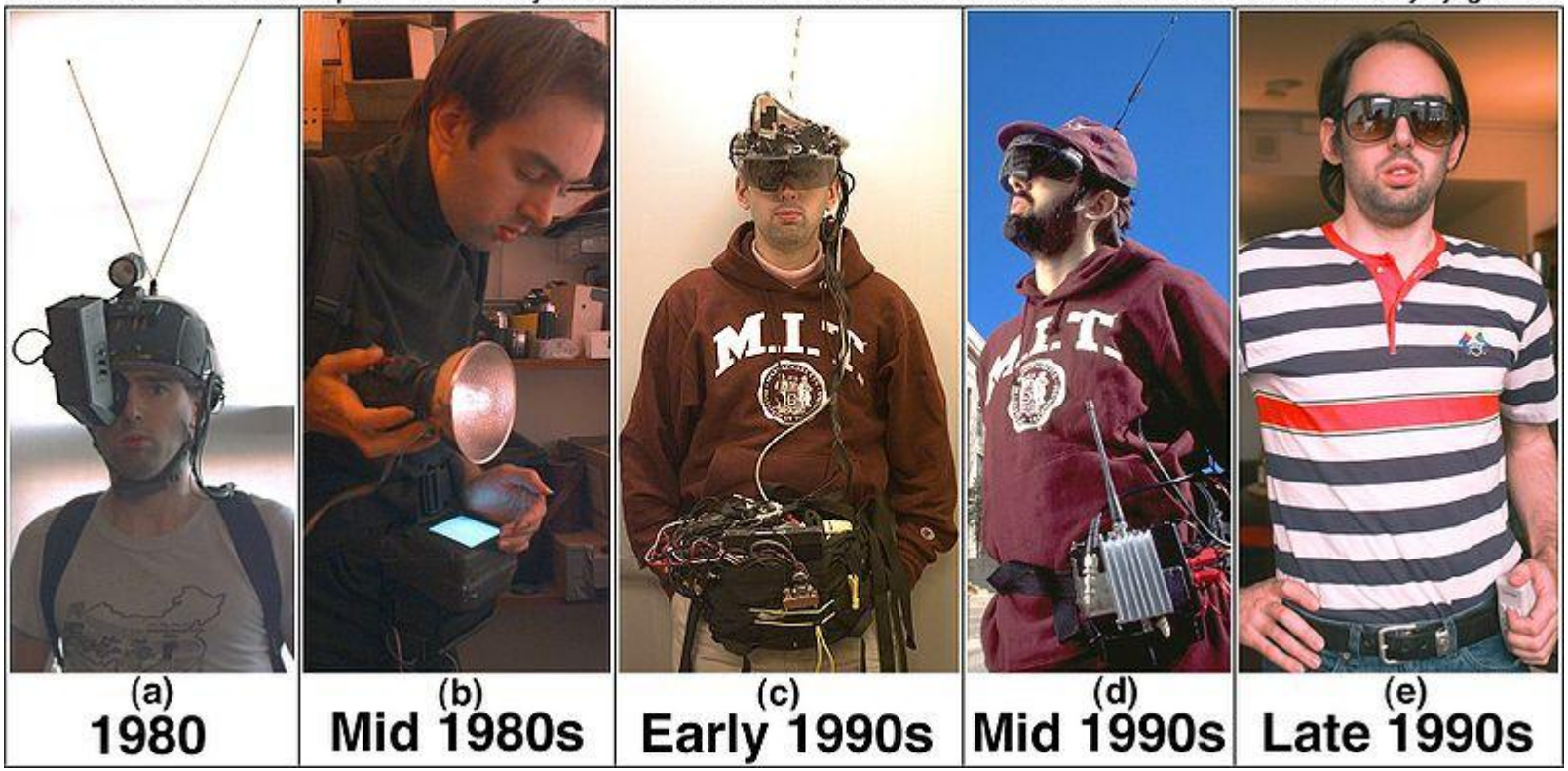
Control: (self-adaptive)
- Adjust to environment (noise level)
- Volume, pitch, tone

Streaming: (invisible speakers)
- Music
- Communication

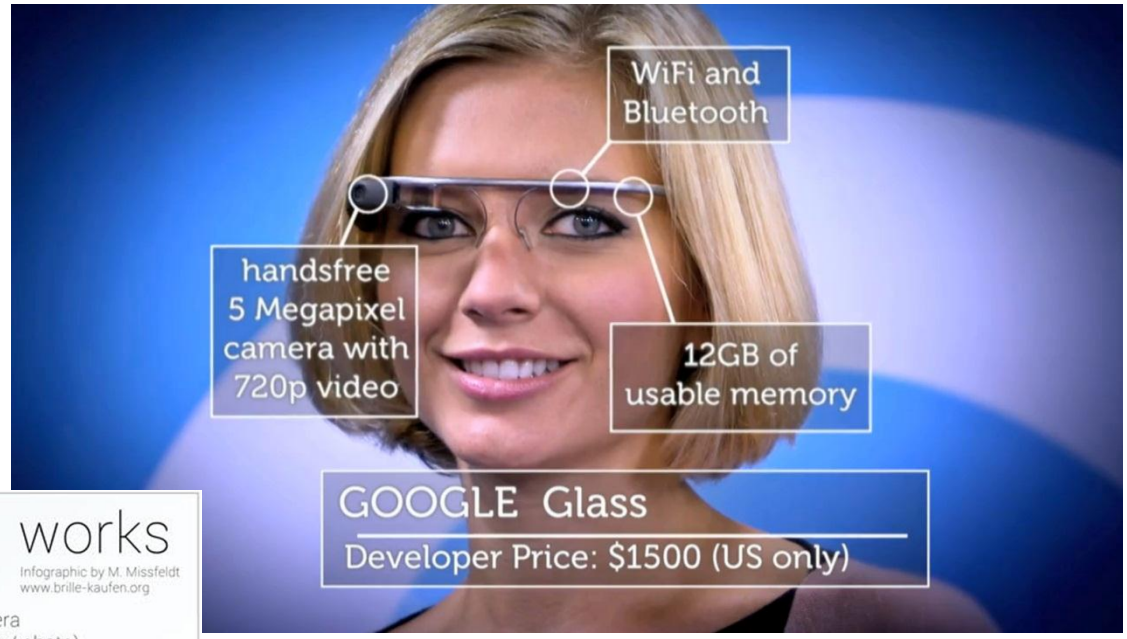
ENHANCE

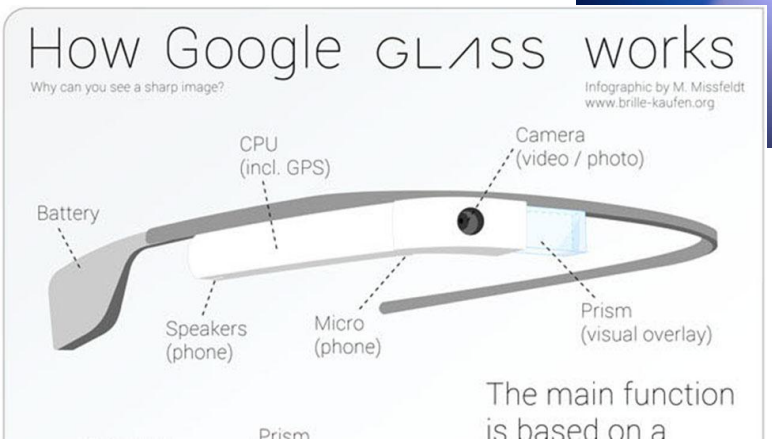


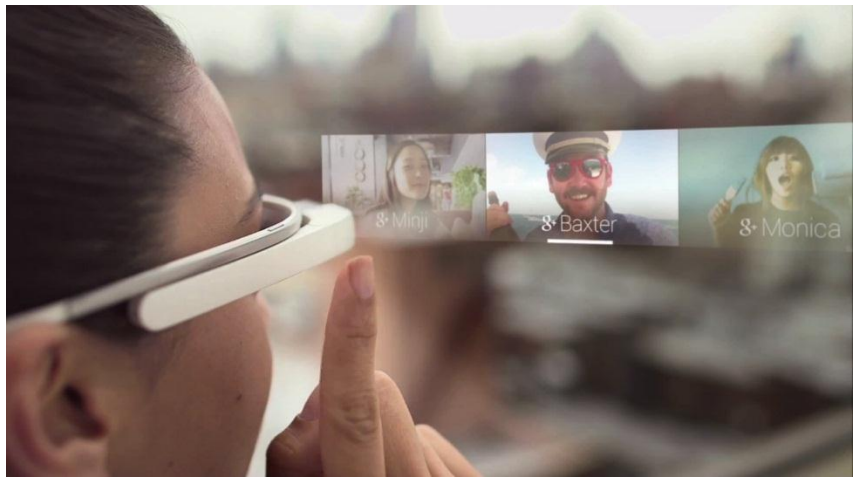
Steve Mann's "wearable computer" and "reality mediator" inventions of the 1970s have evolved into what looks like ordinary eyeglasses.



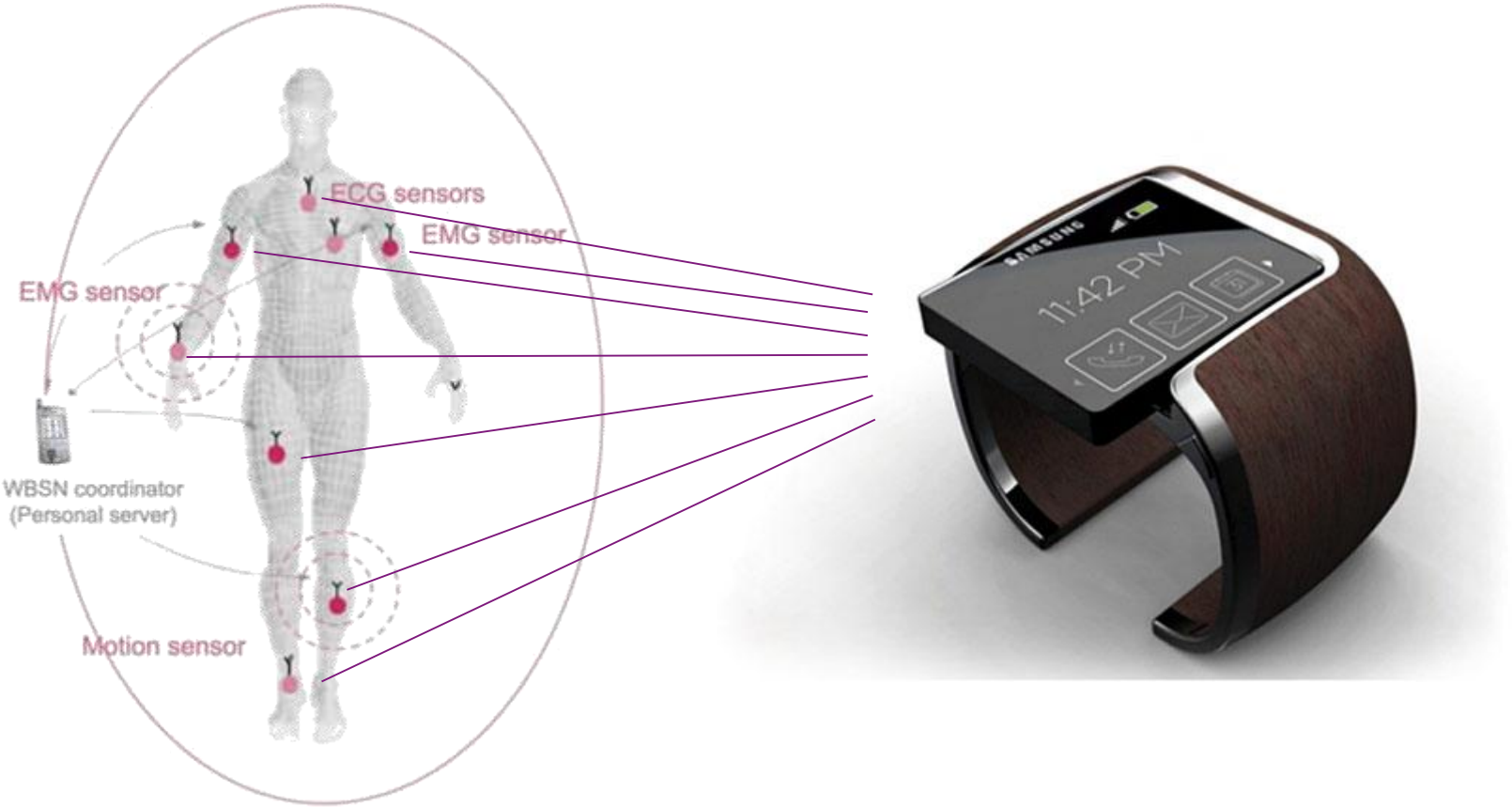
ENHANCE … INDEPENDENT LIFESTYLE







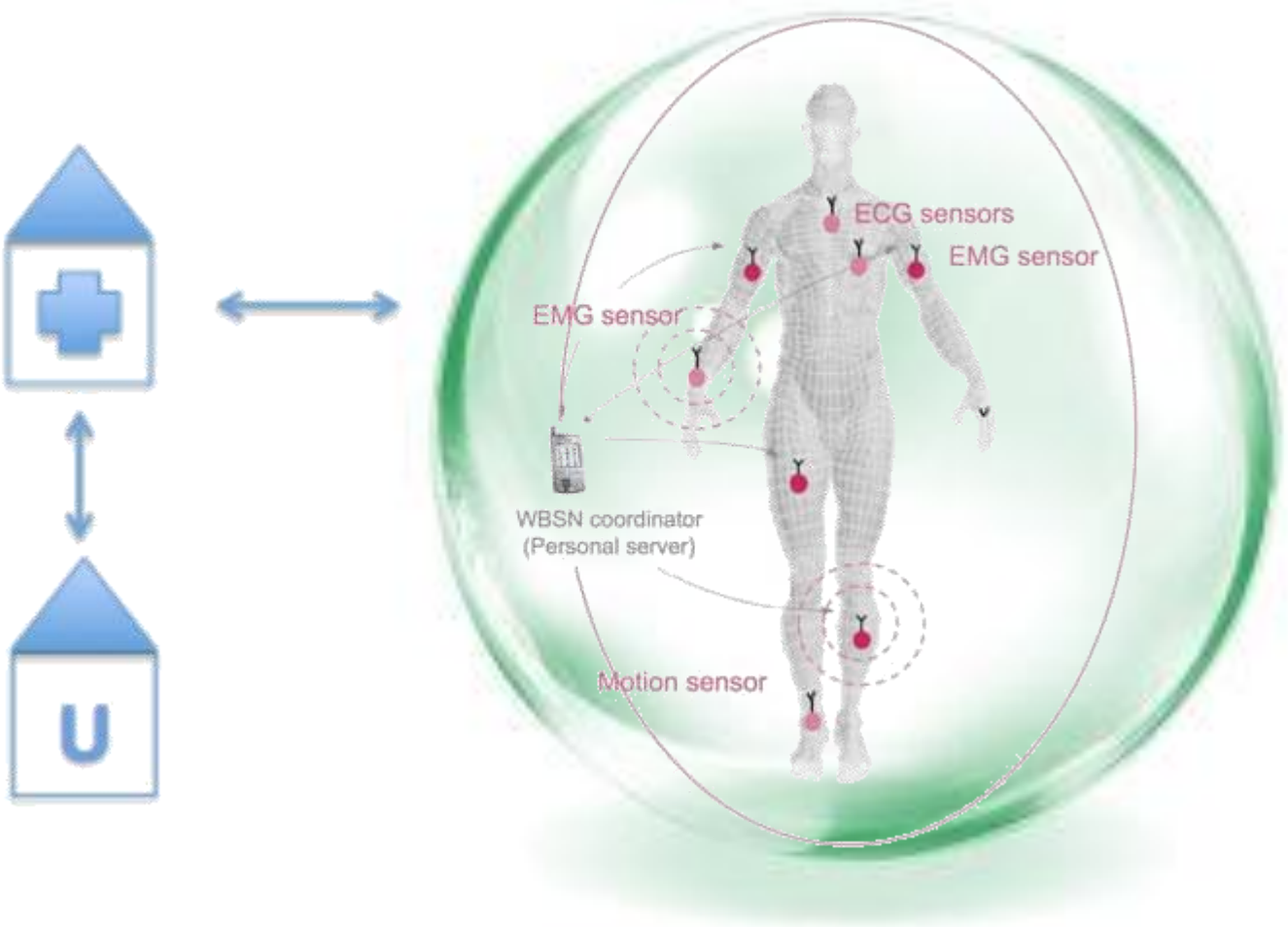
SENSOR FUSION



FROM QUANTIFIED SELF TO QUALIFIED SELF

- Pro-active
- Prevention
- Monitoring

ULTRA-LOW-POWER HOLISTIC DESIGN FOR SMART BIO-SIGNALS COMPUTING PLATFORMS



THE **BENEFITS** AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

WHAT IS THE DIFFERENCE?

NEAR-THRESHOLD COMPUTING

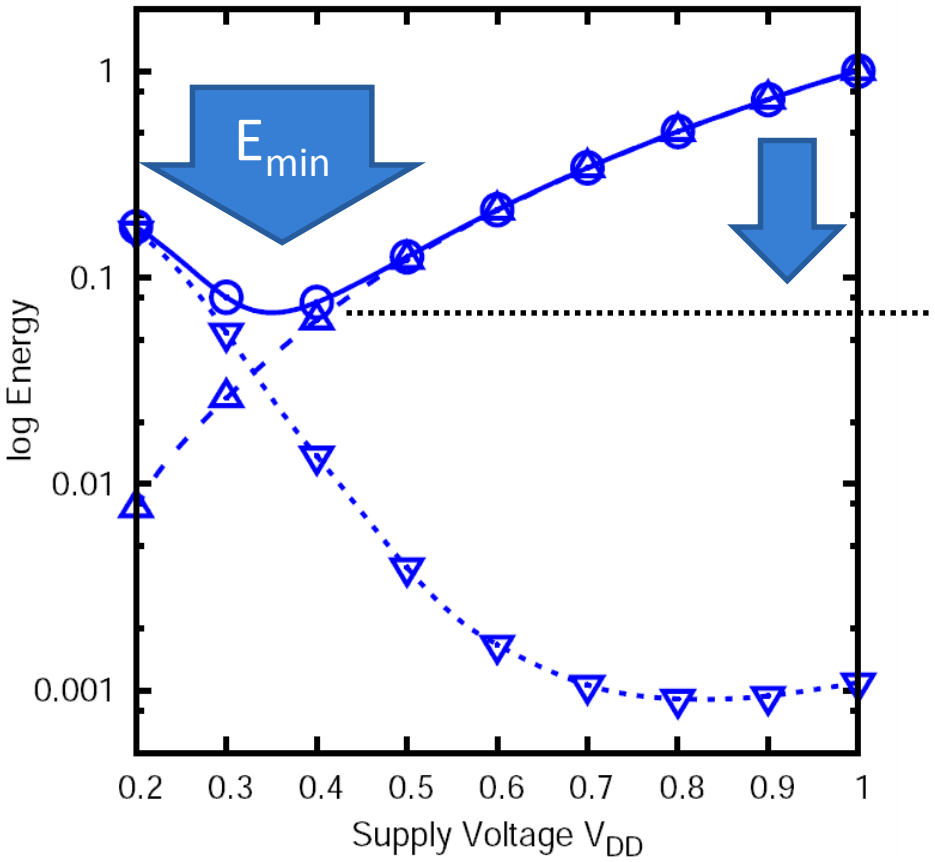
$$P_{dyn} = sf \cdot C \cdot V_{DD}^2 \cdot f$$

$$E_{dyn} = sf \cdot C \cdot V_{DD}^2$$

NEAR-THRESHOLD COMPUTING

$$E_{dyn} = sf \cdot C \cdot V_{DD}^2$$

$$E_{dyn} \sim V_{DD}^2$$



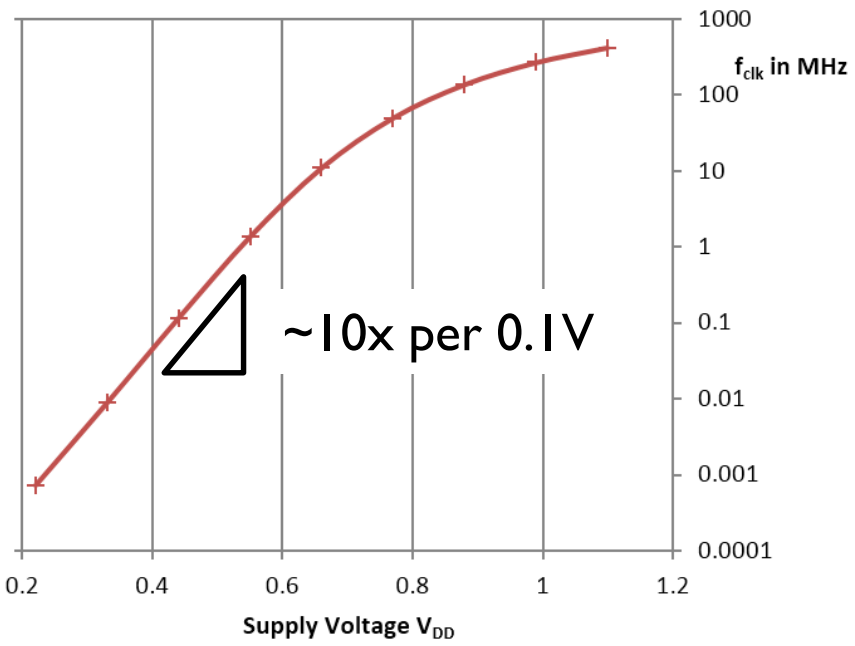
10x better energy efficiency

THE BENEFITS AND **CHALLENGES** OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

- *PERFORMANCE*
- *LEAKAGE*

NEAR-THRESHOLD COMPUTING
THE CHALLENGES

Performance



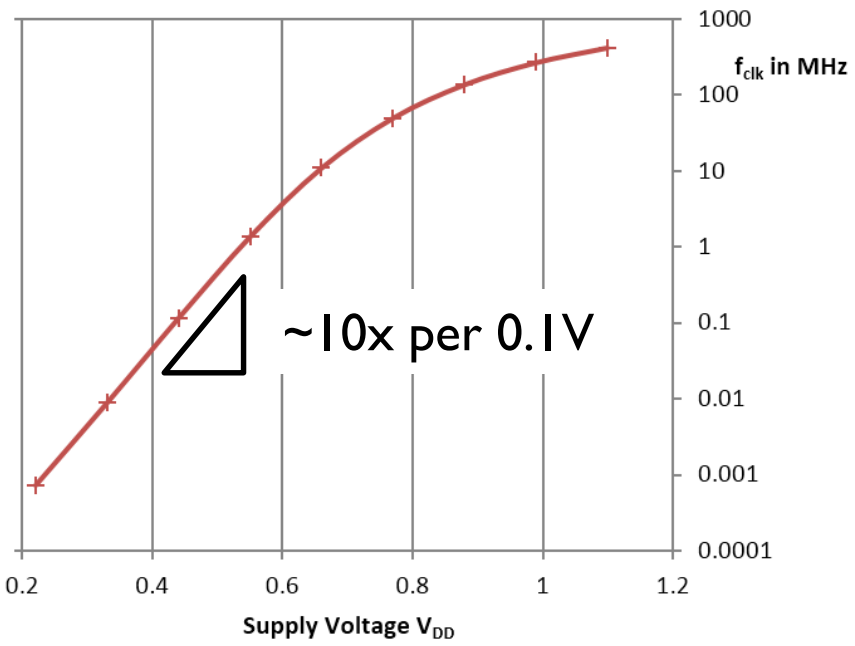
NEAR-THRESHOLD COMPUTING
THE CHALLENGES

$$E_{tot} = E_{dyn} + E_{stat}$$

$$E_{dyn} = sf \cdot C \cdot V_{DD}^2$$

$$E_{stat} = P_{stat} \cdot t_{cyc}$$

Performance

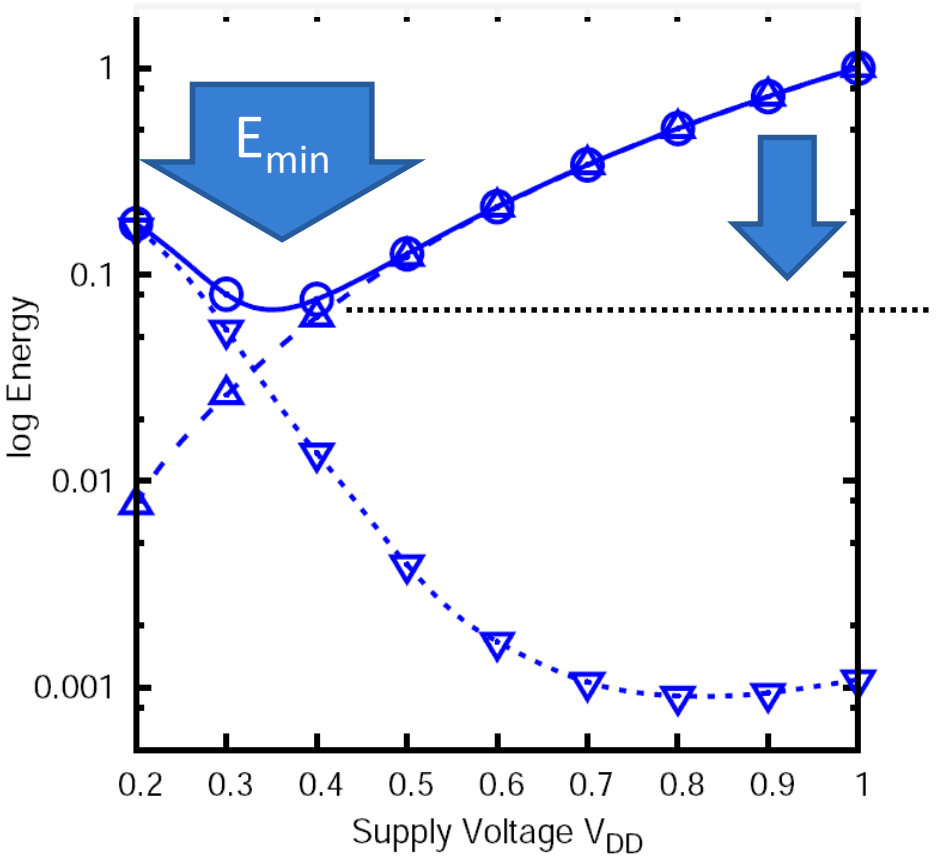


$$E_{tot} = E_{dyn} + \int_{0}^{t_{cyc}} P_{leak}$$

→ **Leakage**

NEAR-THRESHOLD COMPUTING

Point of minimal energy per operation



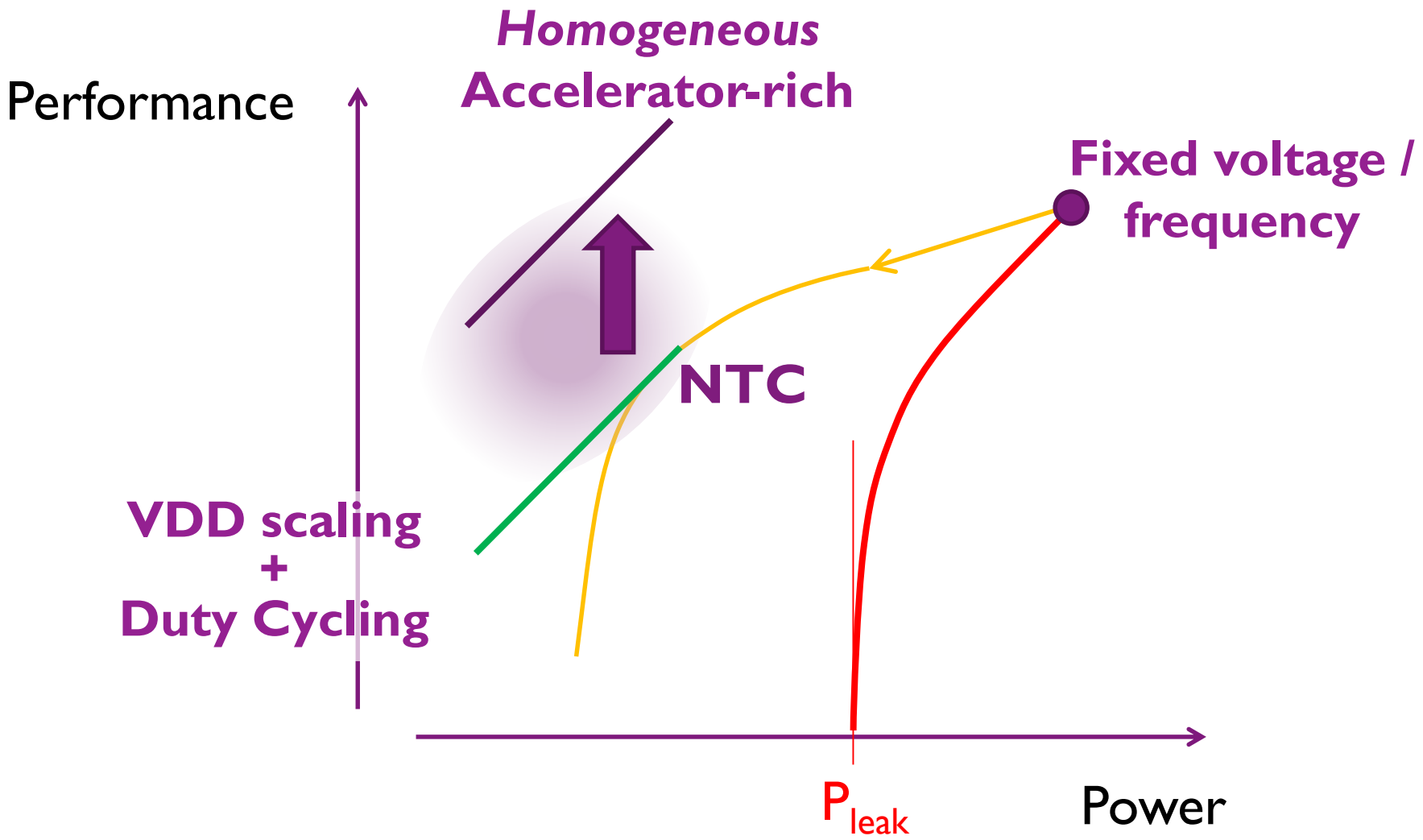
10x better energy efficiency

$$E_{tot} = E_{dyn} + E_{stat}$$

$$E_{dyn} = sf \cdot C \cdot V_{DD}^2$$

$$E_{stat} = P_{stat} \cdot t_{cyc}$$

ENABLING A WIDE OPERATING RANGE



ENABLING A WIDE OPERATING RANGE

Heterogeneous
Accelerator-rich

Performance

Fixed voltage / frequency

NTC

VDD scaling + Duty Cycling

P_{leak}

Power

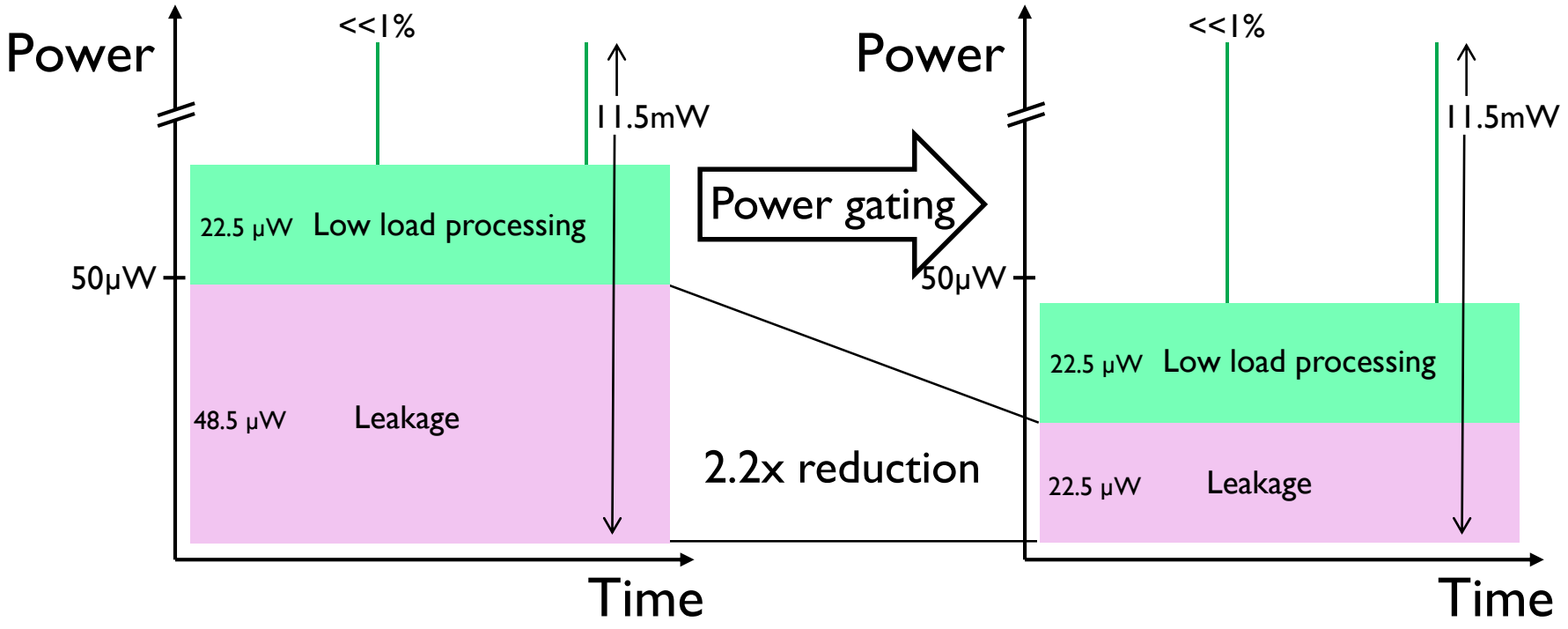
Performance & runtime boost @ scaled power!

THE **BENEFITS** AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

- *A CASE STUDY*

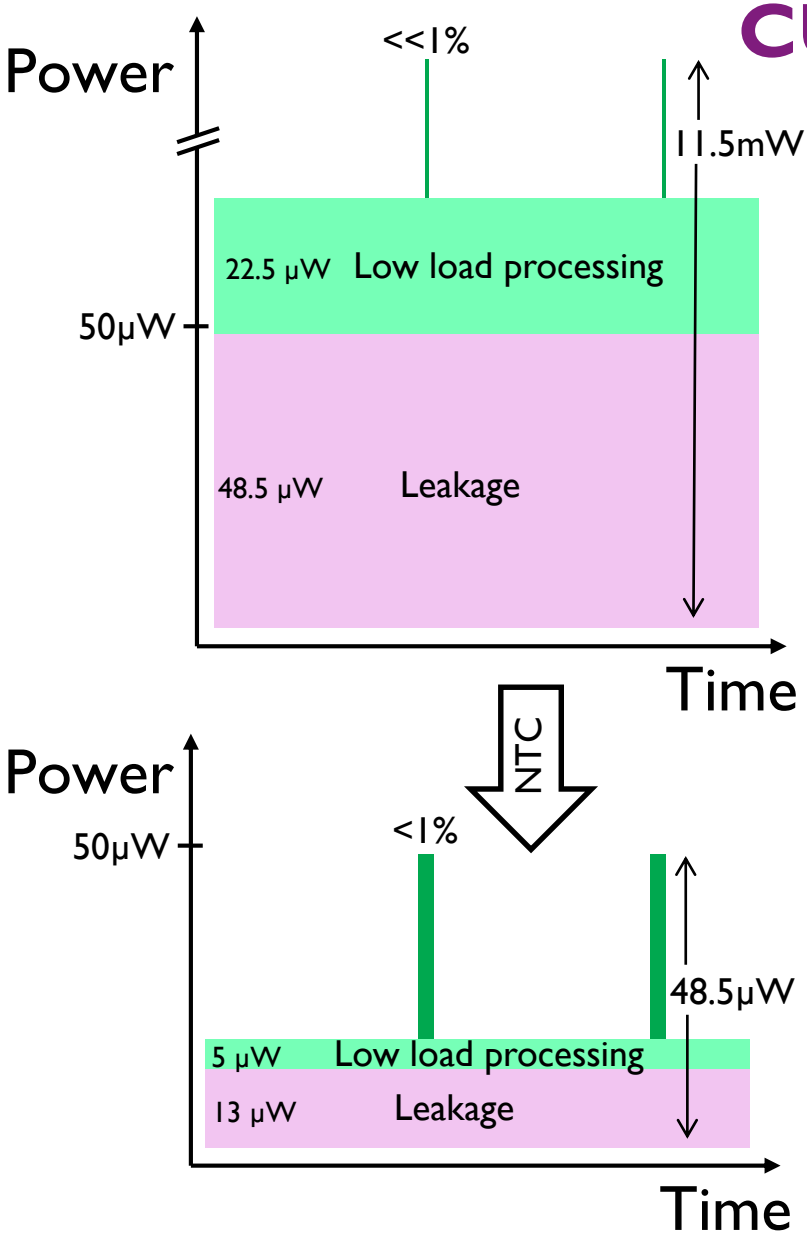
CASE STUDY: ECG PATCH

COMBATING LEAKAGE CURRENT



1.6x more energy efficient ECG

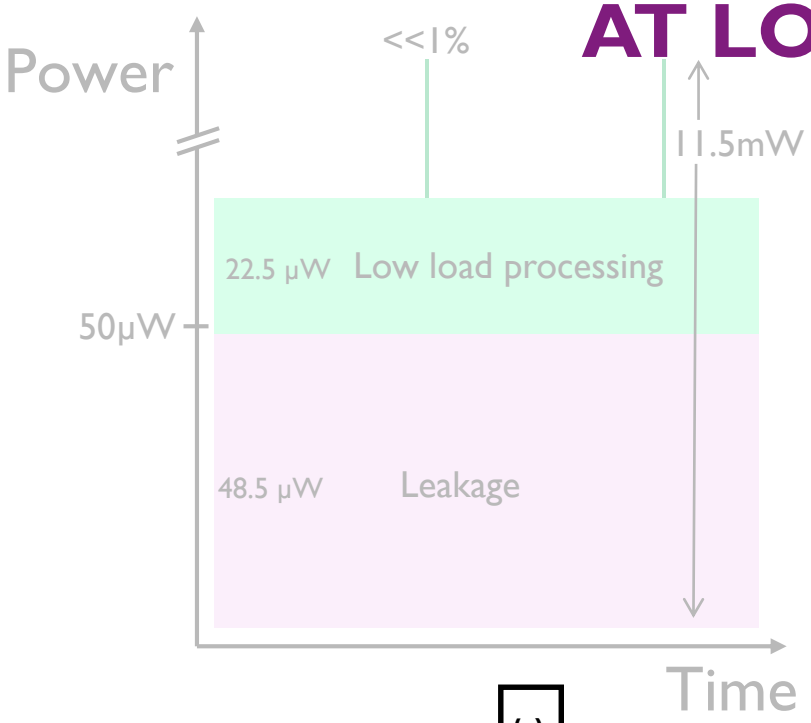
COMBATING LEAKAGE AND DYNAMIC CURRENT



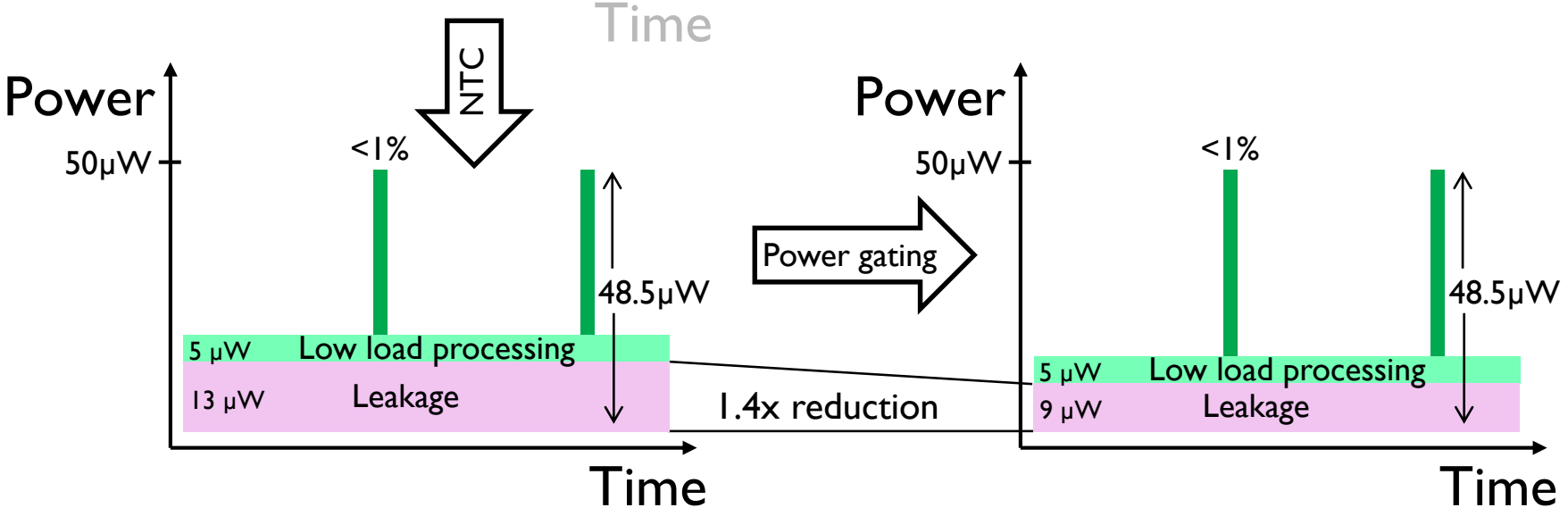
4.5x efficient processing
3.7x leakage reduction

4x more energy efficient ECG

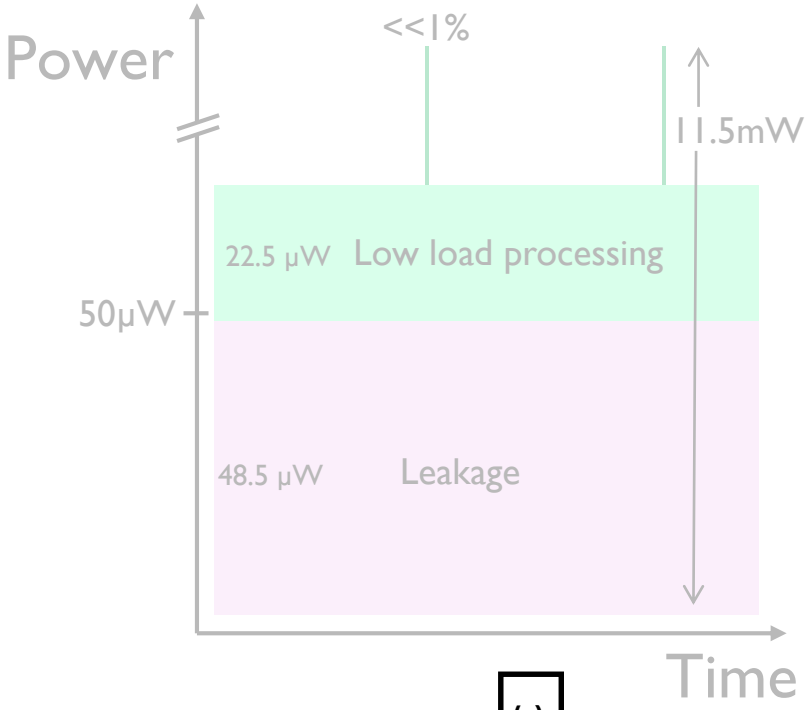
LIMITED BENEFIT OF POWER GATING AT LOW VOLTAGE



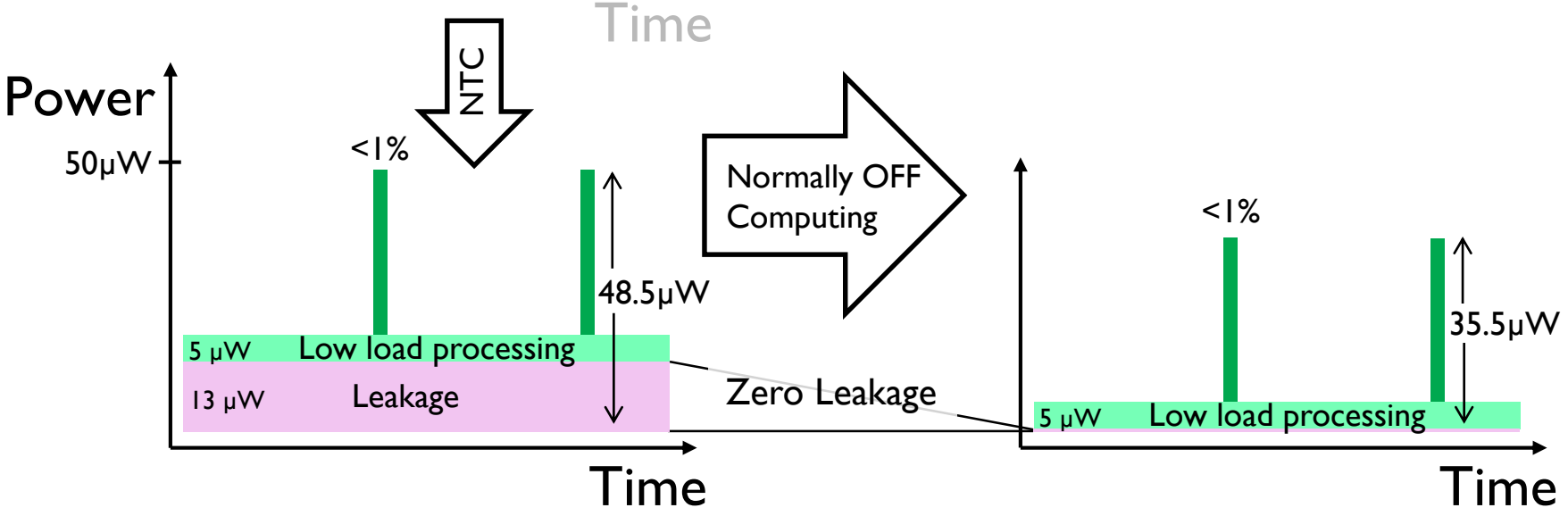
5x more energy efficient ECG



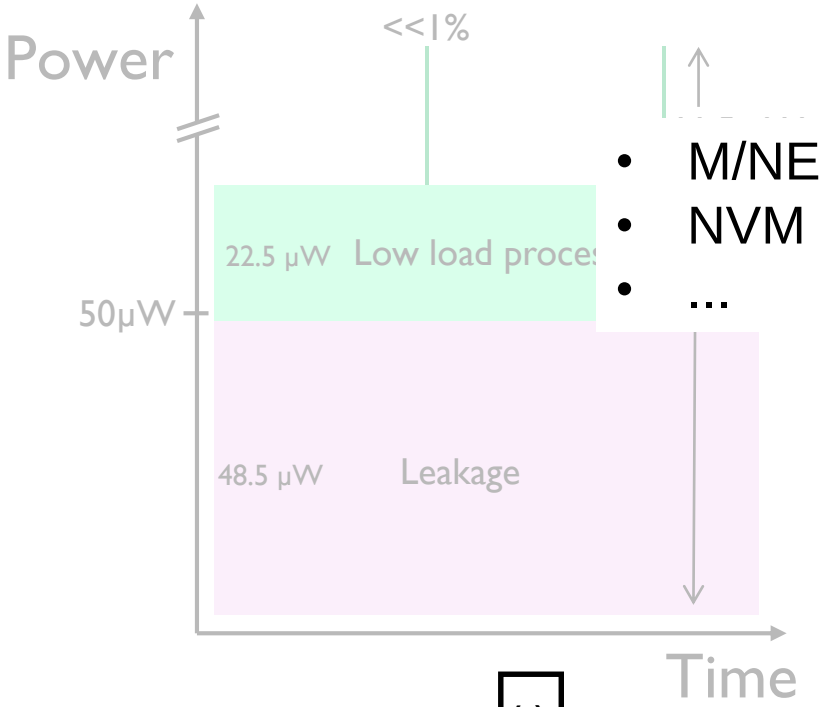
IDEAL SOLUTION ZERO LEAKAGE RETENTION



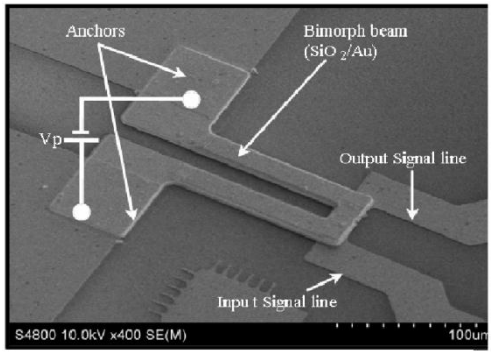
14x more energy efficient ECG



IDEAL SOLUTION ZERO LEAKAGE RETENTION

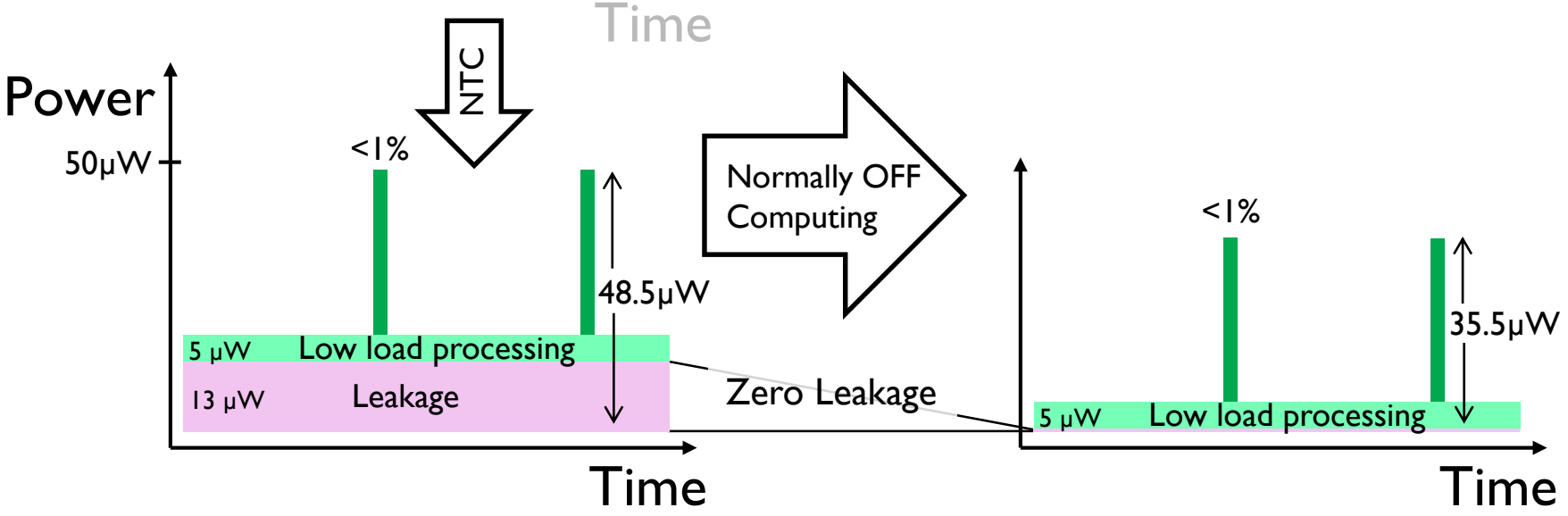


- M/NEMs power switch
- NVM
- ...



[Raychowdhury, CICC 06]

14x more energy efficient ECG



IDEAL SLEEP AND WAKE UP IMPACT ON THE WBSN (here: ECG PATCH)

	Streaming	Efficient processing	Normally-off computing
Power consumption	385 µw	173 µw	80 µw
Battery life time	24h	2 days	5 days

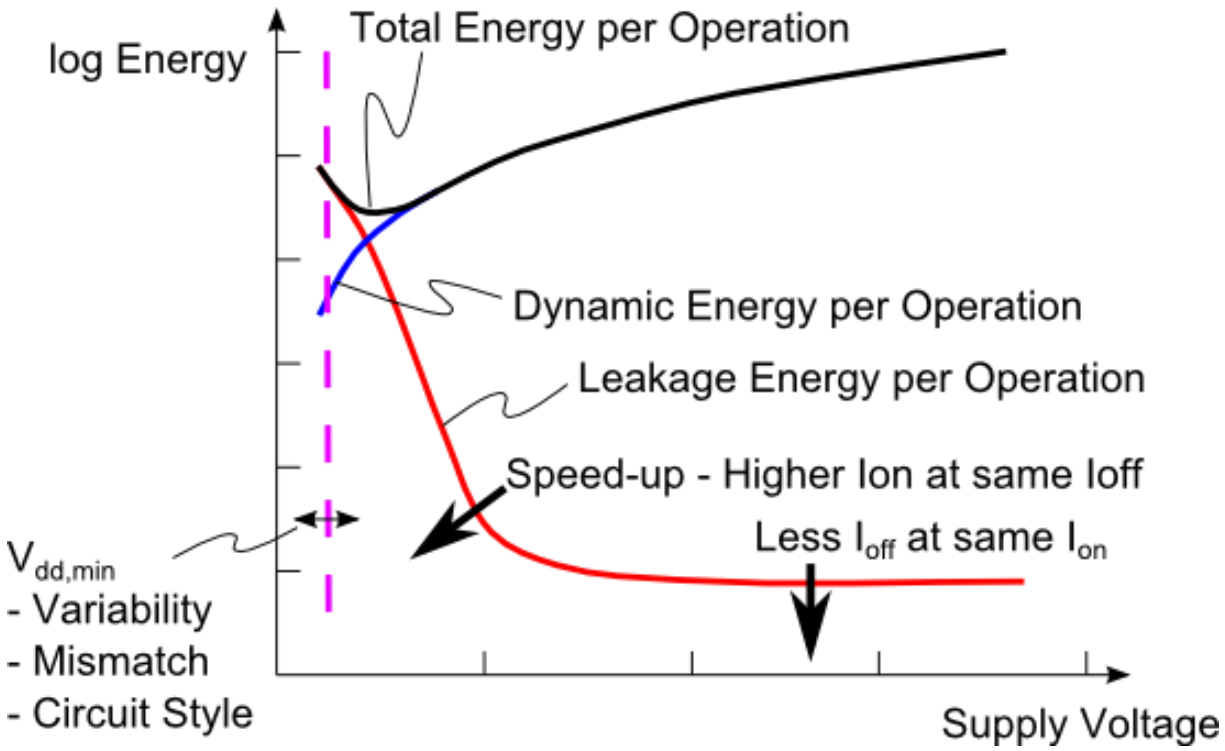
Powering by harvesters possible!

Thinfilm battery

THE **BENEFITS** AND CHALLENGES OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

- *TECHNOLOGY SELECTION*

WHAT IMPACTS THE POINT OF E_{MIN}

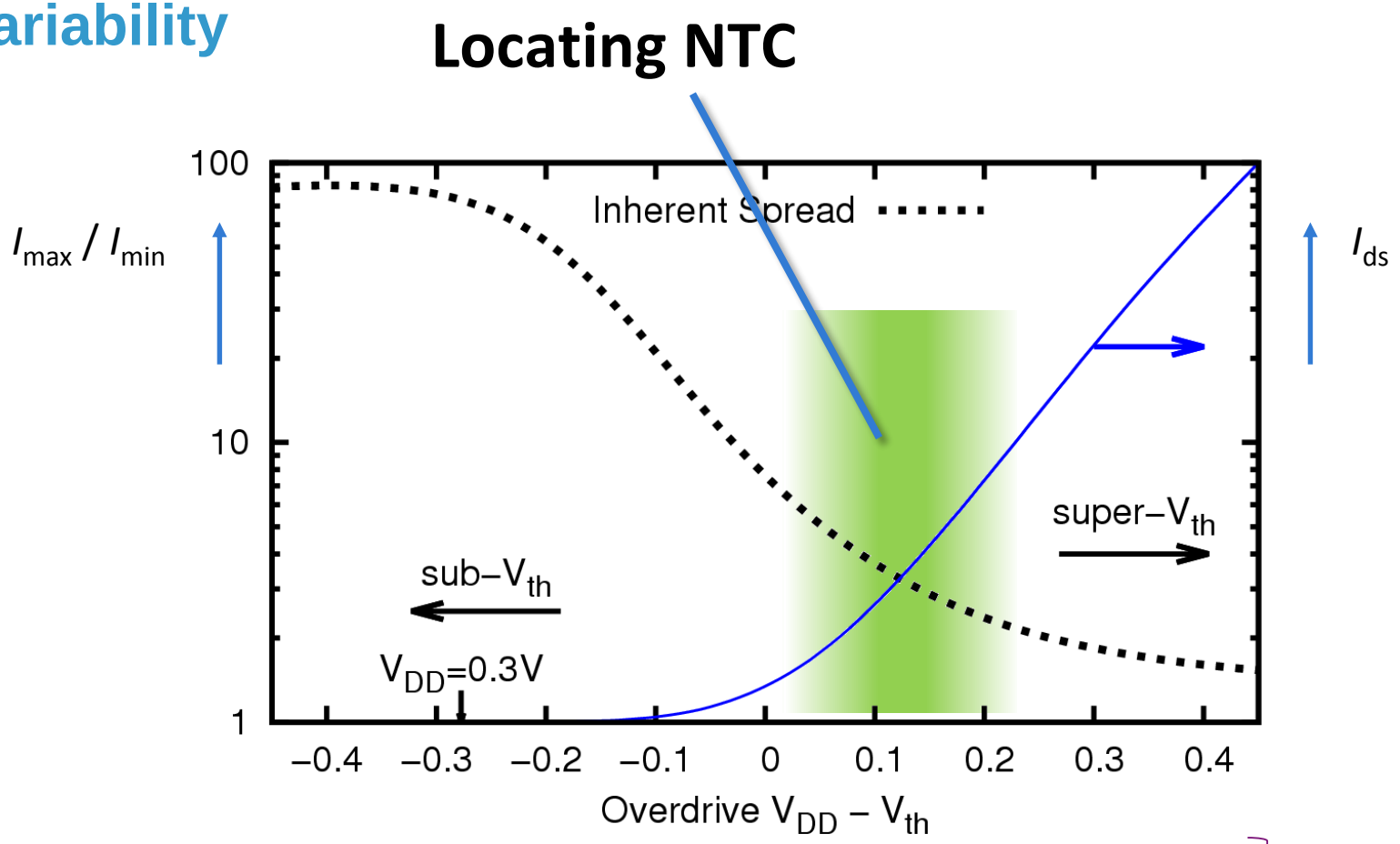


THE BENEFITS AND **CHALLENGES** OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

- *VARIABILITY*

NEAR-THRESHOLD COMPUTING
THE CHALLENGES

Variability

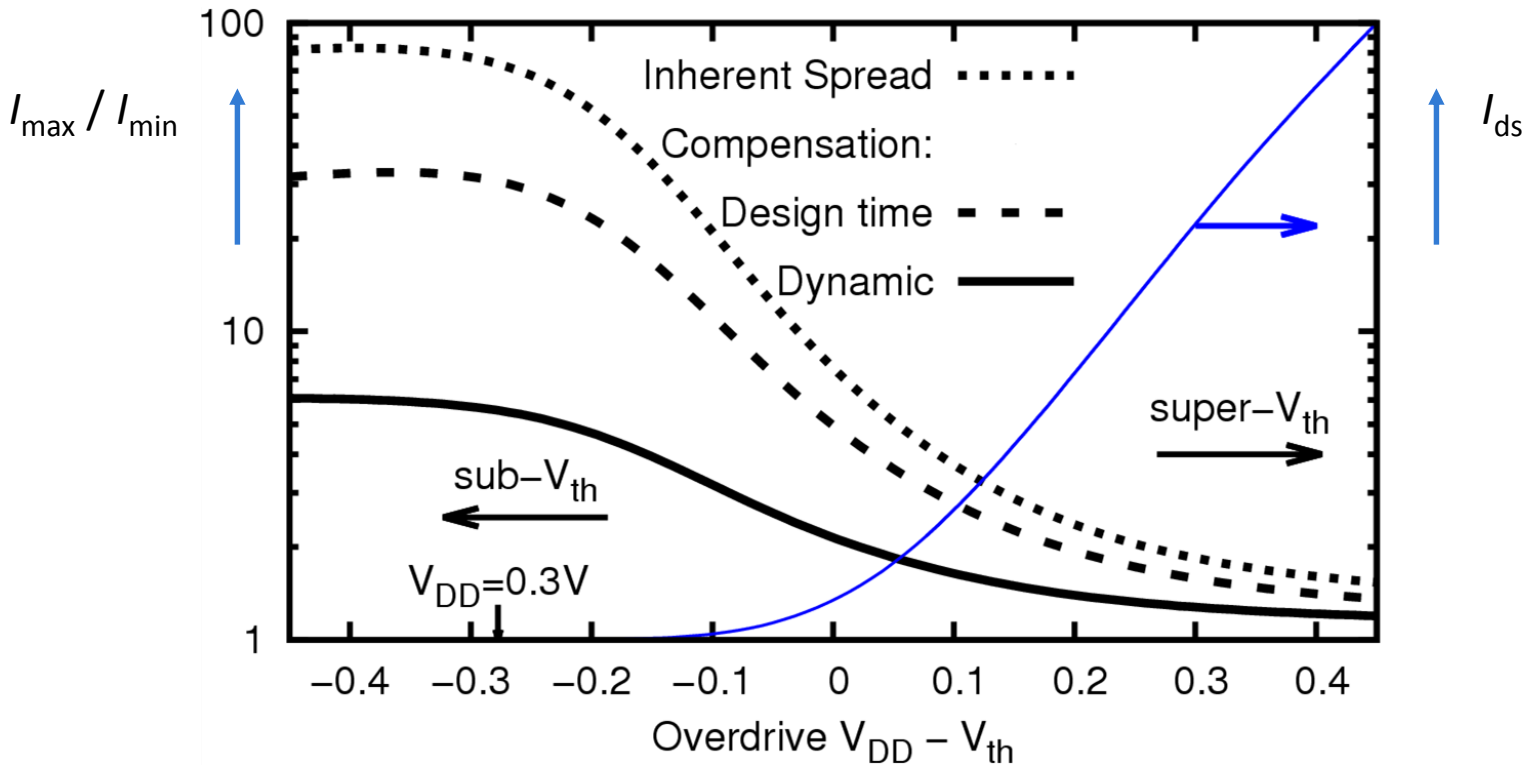


→ **Digital: Uncertainty in timing**

→ **Memory: V_{DDmin}, DRV**

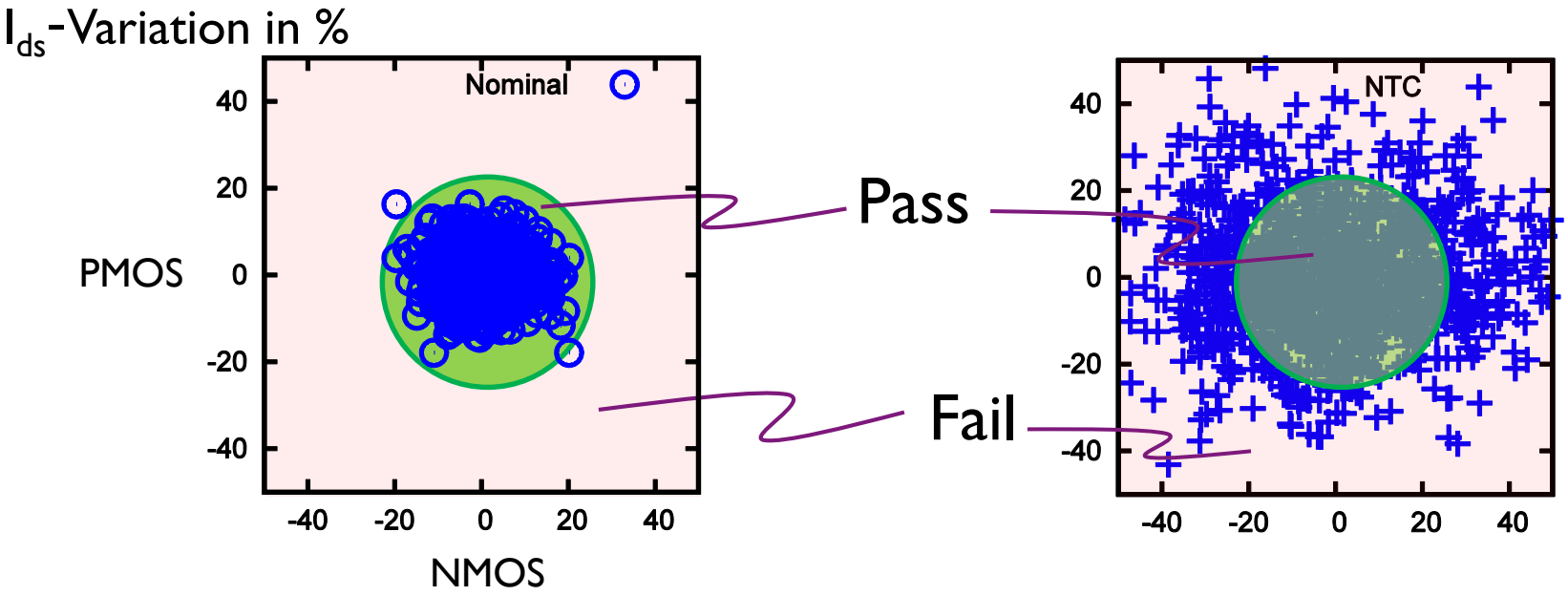
Yield?

VARIABILITY SPOILS THE BENEFITS?



NEAR-THRESHOLD COMPUTING
THE CHALLENGES

Variability

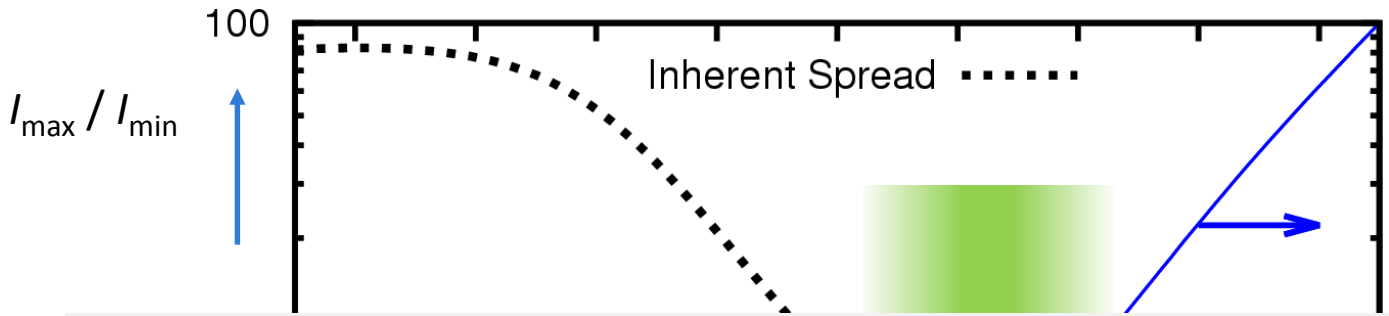


→ Increased variability kills yield.

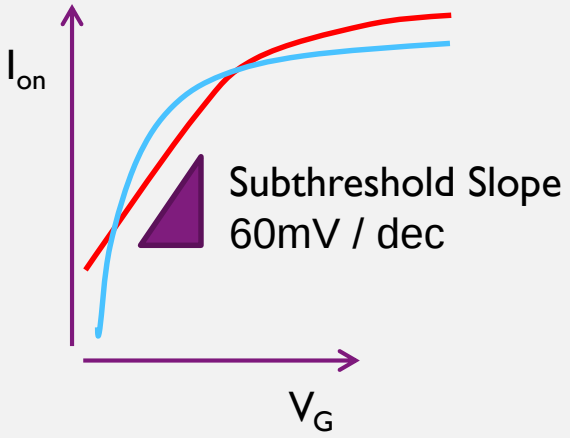
NEAR-THRESHOLD COMPUTING
THE CHALLENGES

Variability

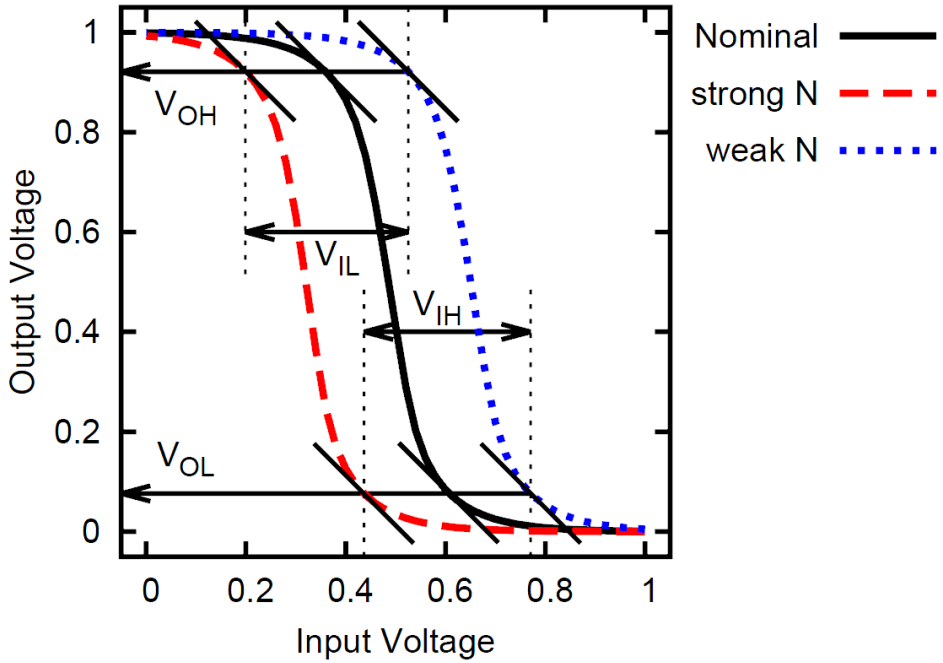
Locating NTC



- **Better subthreshold slope**
  e.g. Tunnel-FET



NOISE MARGIN MODEL

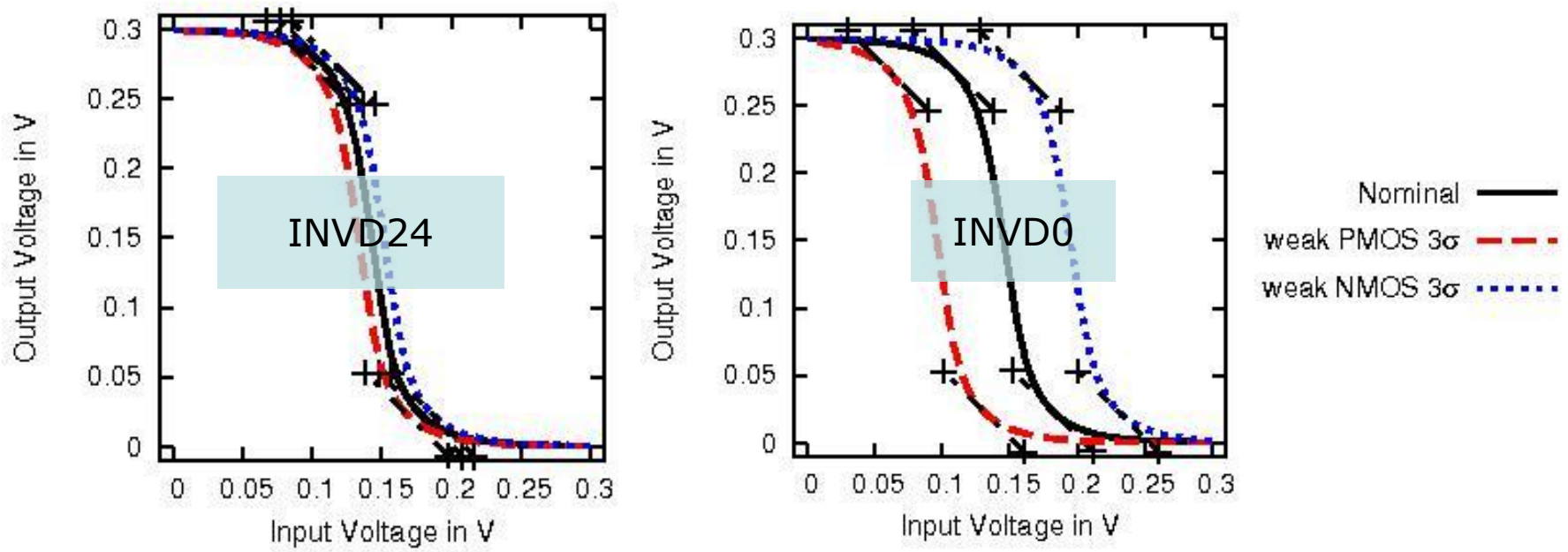


$$NM_{\mathrm{H}} = V_{\mathrm{OH}} - V_{\mathrm{IH}}$$

$$NM_i = c_0 \cdot V_{\mathrm{DD}} + c_1 + c_2/\sqrt{N_i}$$

Addressing the Noise Margin

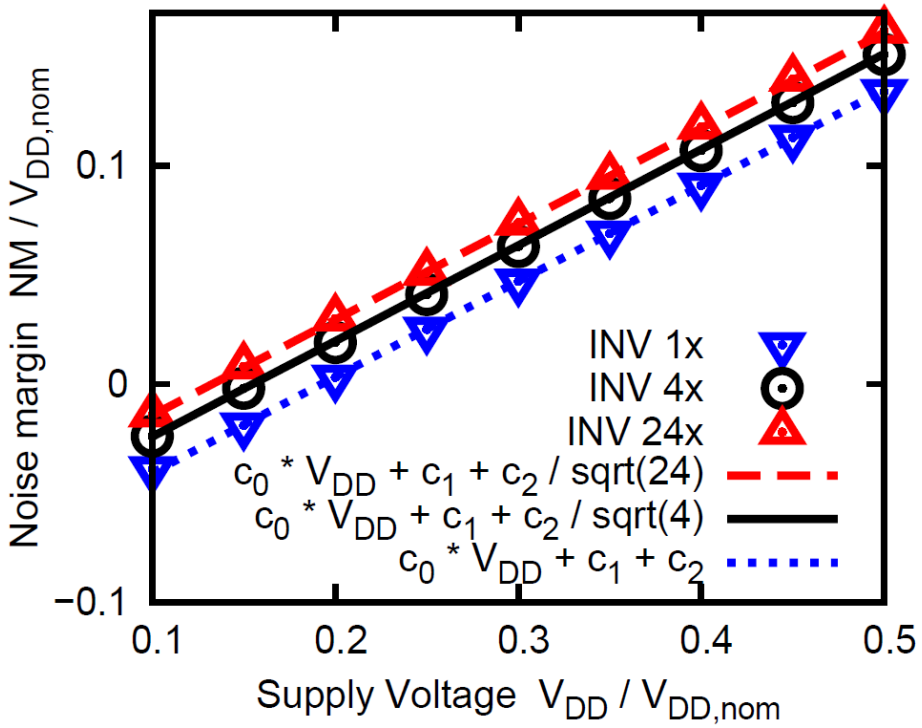
- Bigger is better.
- Limit stack-height.



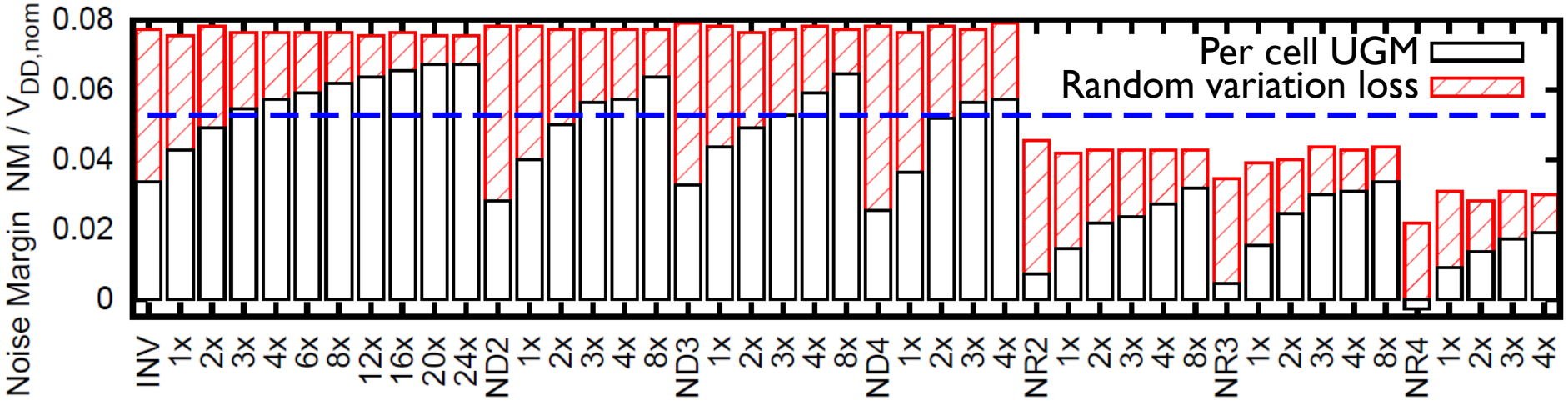
SCALING OF THE NOISE MARING

$$NM_i = c_0 \cdot V_{\mathrm{DD}} + c_1 + c_2 / \sqrt{N_i}$$

Finger count N_i

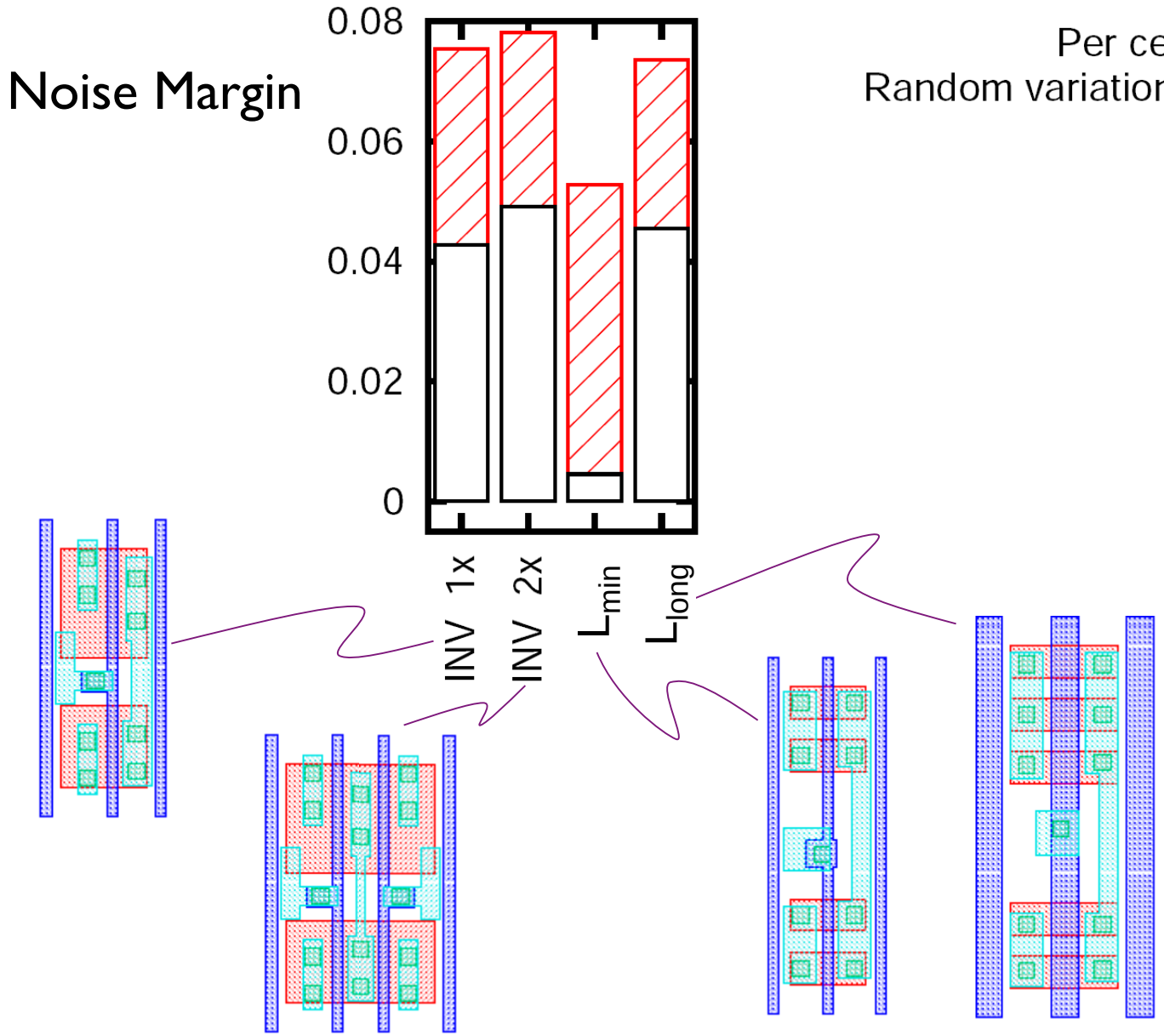


NOISE MARGIN DISTRIBUTION OF DIFFERENT CELL TYPES AND DRIVES



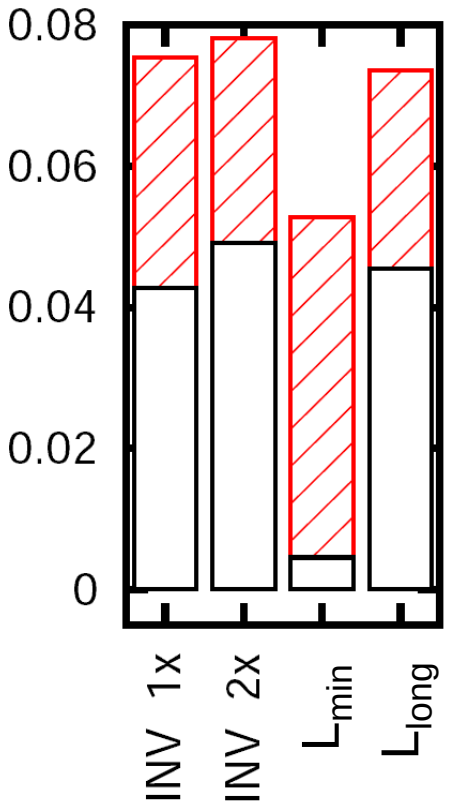
→ Non trivial cell design.

NM ASSESSMENT T_0

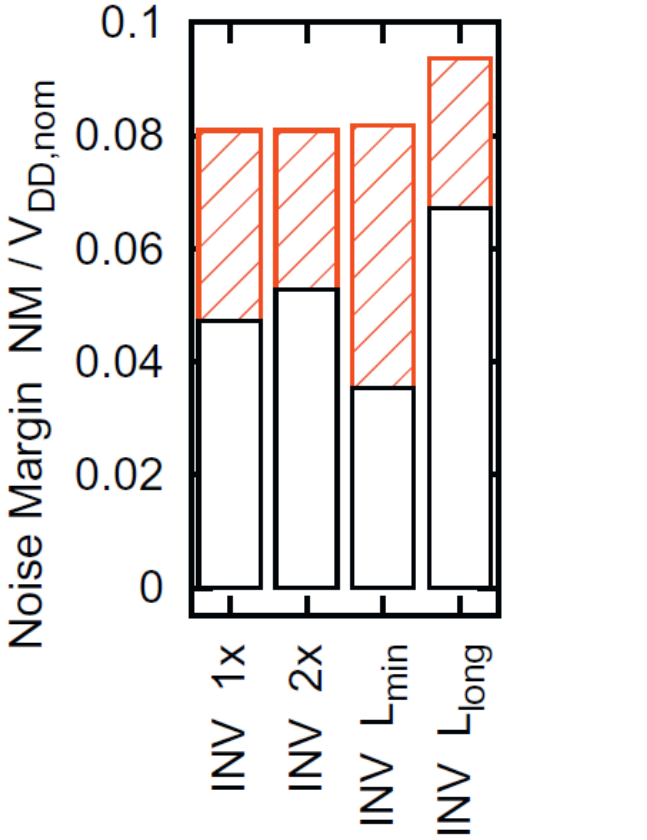


NM ASSESSMENT T_0

Noise Margin



β_{opt}

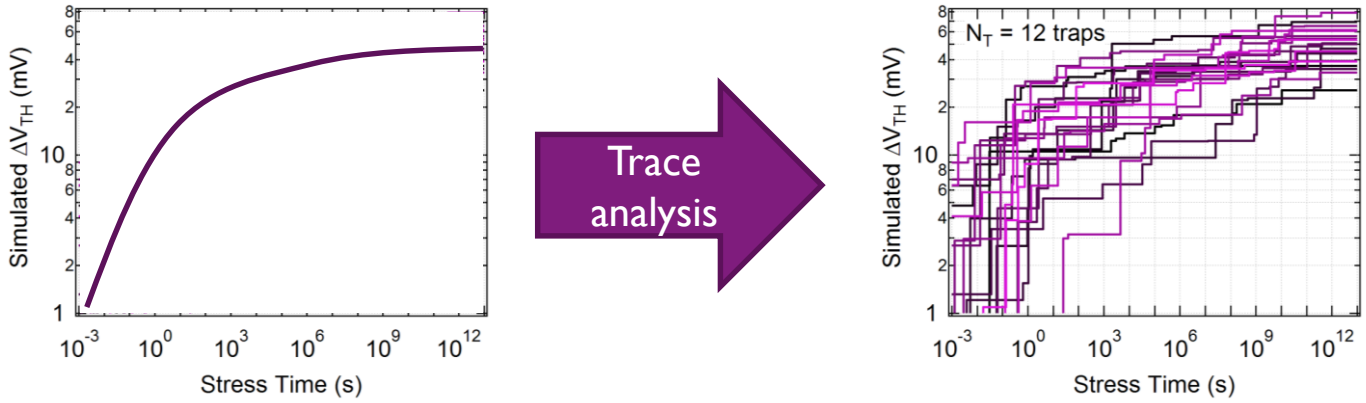


- De-skewing
- Less variability

  e.g. finFET, fd-SOI

NM ASSESSMENT: TIME DEPENDENT

- Aging has significant impact on devices behavior.



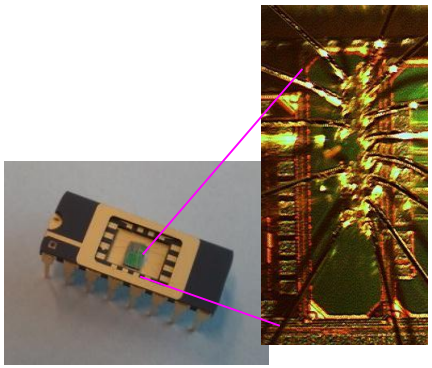
- Trace dependent behavior.
  → Complex reliability analysis.

THE BENEFITS AND **CHALLENGES** OF NEAR-THRESHOLD COMPUTING FOR WEARABLE DEVICES

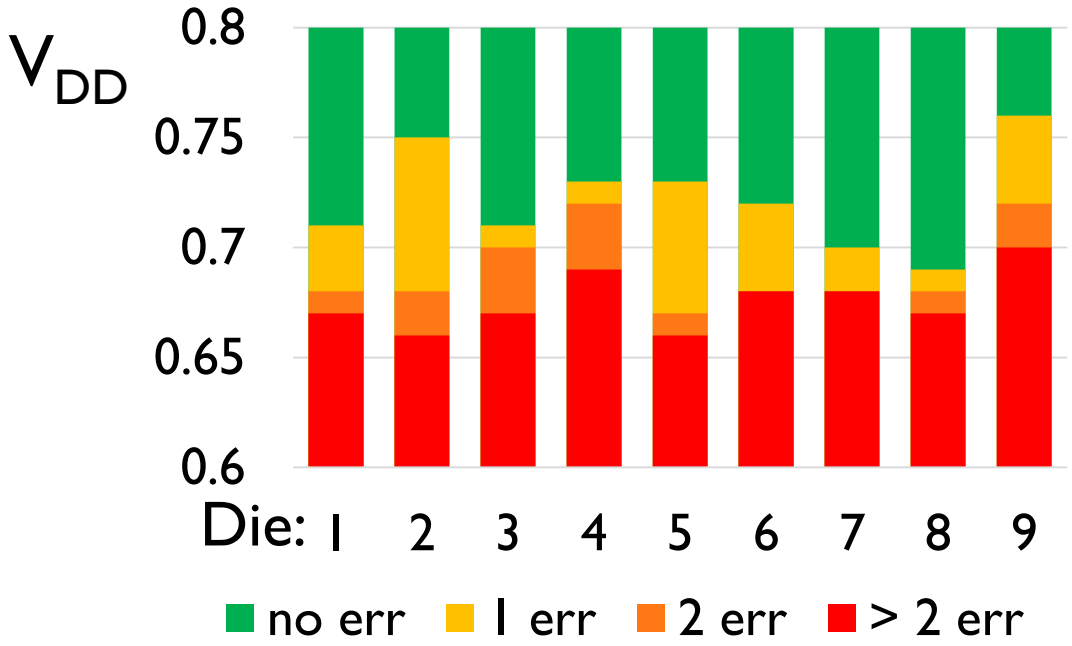
- *MEMORIES*

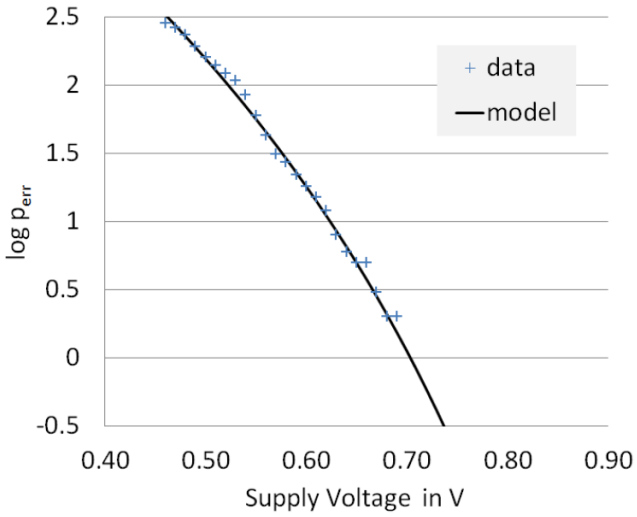
NTC AND MEMORIES

Silicon measurement & modeling:



V_{DDmin}: RW Errors vs. supply voltage

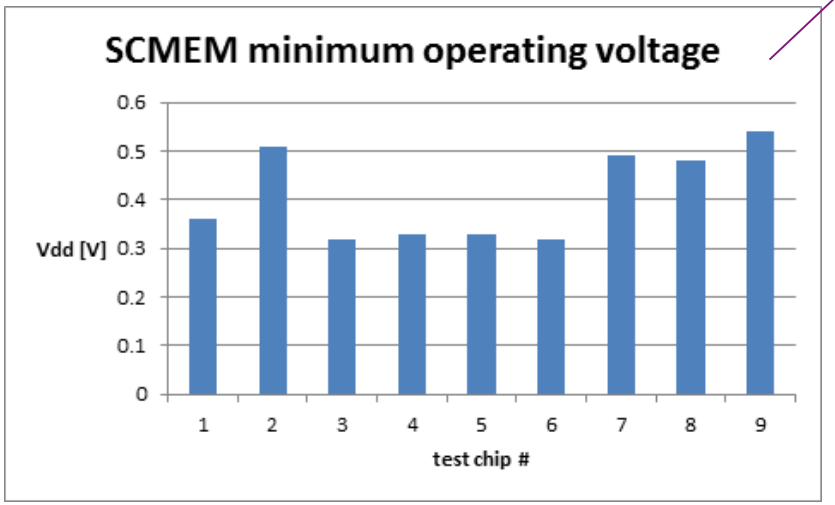


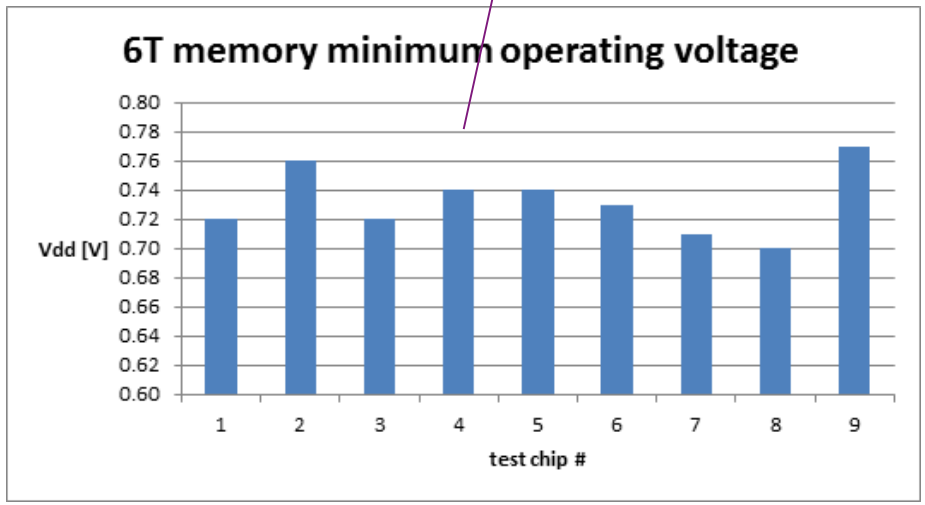


NTC AND MEMORIES

Solutions

- ECC
- Cell based memories (cf. figure)
- Architecture (cf. next slides)
- Algorithm

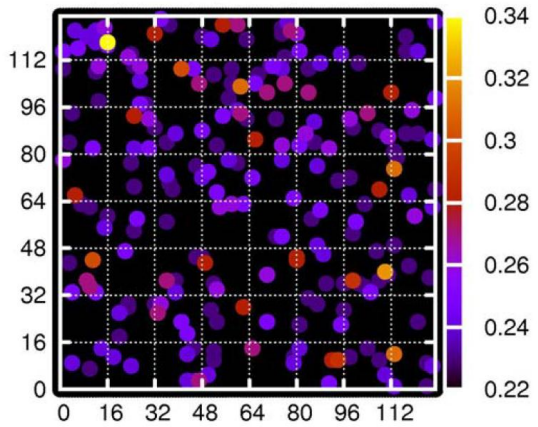


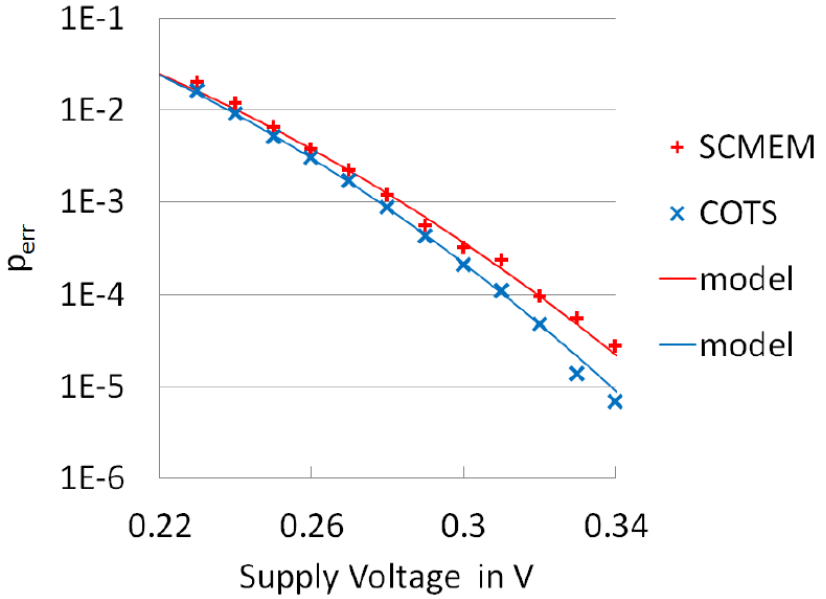


NTC AND MEMORIES

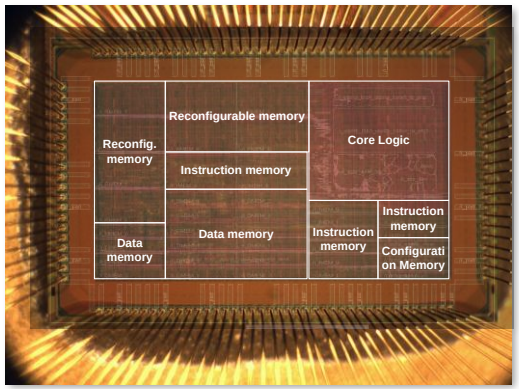
Silicon measurement & modeling:

Date Retention Voltage (DRV)





EXAMPLE: ULTRA-LOW POWER SRP



[Konijnenburg, ISSC 2013]

SoC

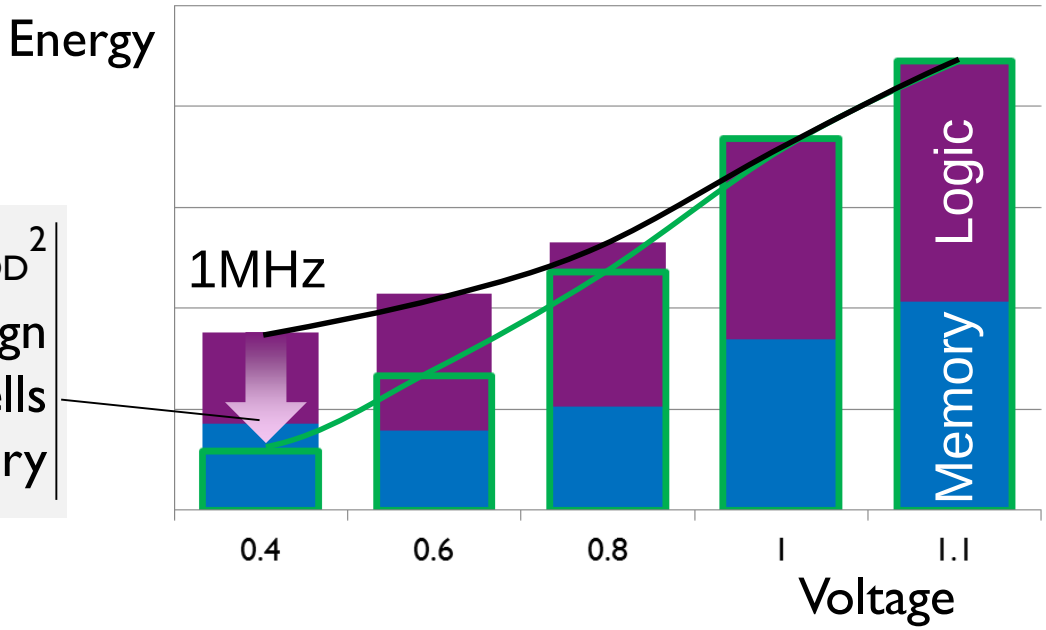
- Samsung Reconfigurable Processor (SRP)
- 9 cores
- CMOS 40nm LP
- Wide-range 1MHz ... 150 MHz

Scaling with V_{DD}^2

Libray re-design

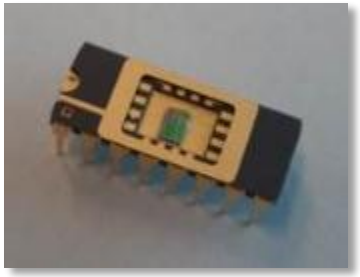
Custom cells

Memory

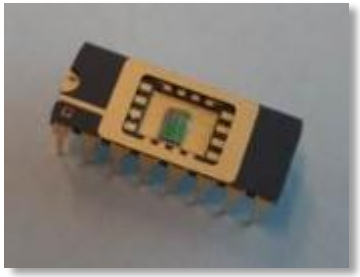


SOLVING THE MEMORY BOTTLENECK

1.1V → $P_{100\%}$

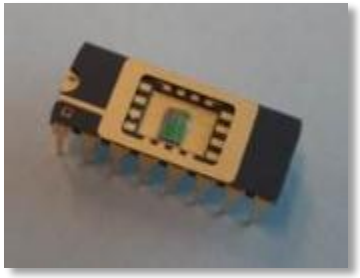


0.??V

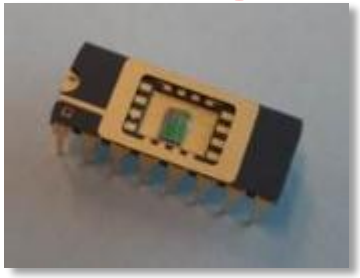


SOLVING THE MEMORY BOTTLENECK

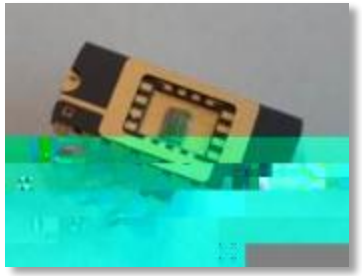
1.1V → $P_{100\%}$



0.75V → ½ $P_{100\%}$



0.55V → ¼ $P_{100\%}$

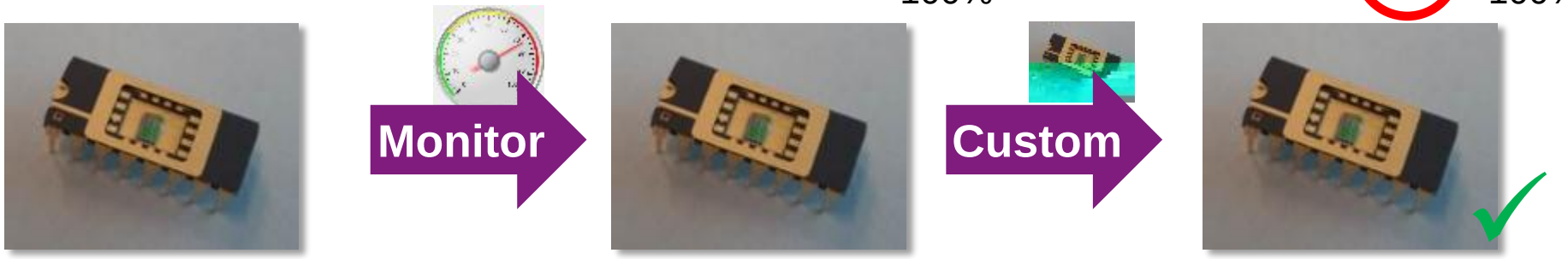


CELL BASED MEMORIES FOR NTC

Low-Voltage Operation

SOLVING THE MEMORY BOTTLENECK

1.1V → $P_{100\%}$ 0.75V → ½ $P_{100\%}$ 0.55V → ¼ $P_{100\%}$



- **Memories limit supply voltage scaling at $V_{DD,min}$**
- **$V_{DD,min}$ << specified limit**
- **Operation @ actual $V_{DD,min}$ → P_{dyn} & P_{stat} ↓**

➔ Pro-actively set $V_{DD,min}$ + mitigate errors

CONCLUSION

The **benefits** and **challenges** of
Near-Threshold Computing (**NTC**) for
wearable devices

- Run-time from hours to weeks ... to fully autonomous
- Specific challenges have to be addressed
  - Performance
  - Leakage
  - Variability
  - Supply generation
- Solutions cross design hierarchies from
  - Technology selection
  - Digital design (flow, cells, monitoring)
  - Architecture
  - Algorithm level


SCMEM
Commercial