New Electronic Design principles inspired by bio systems. Panel discussion

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Energy drives logic

Power Prop

The more you get
The more you give!

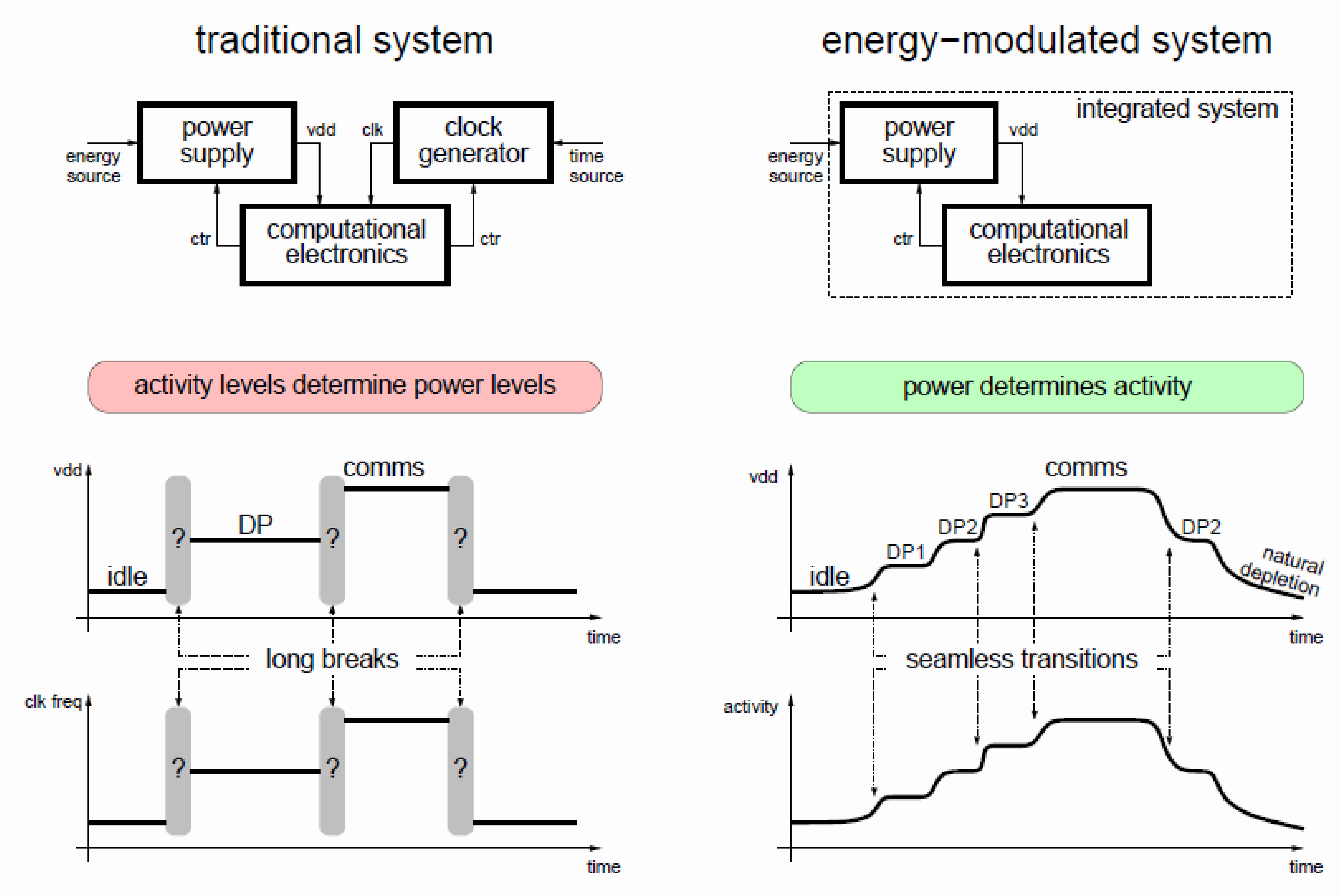
My Background

- 35 years in designing and automating the design of self-timed (aka asynchronous) systems, characterised by:
  - inherent concurrency,
  - amenable to token-based computing paradigms,
  - event-driven and causality-based processing,
  - parametric variation resilience,
  - close-loop timing error avoidance and correction,
  - power-proportionality,
  - digital and mixed-signal interfaces

My bio-inspired "experiments"

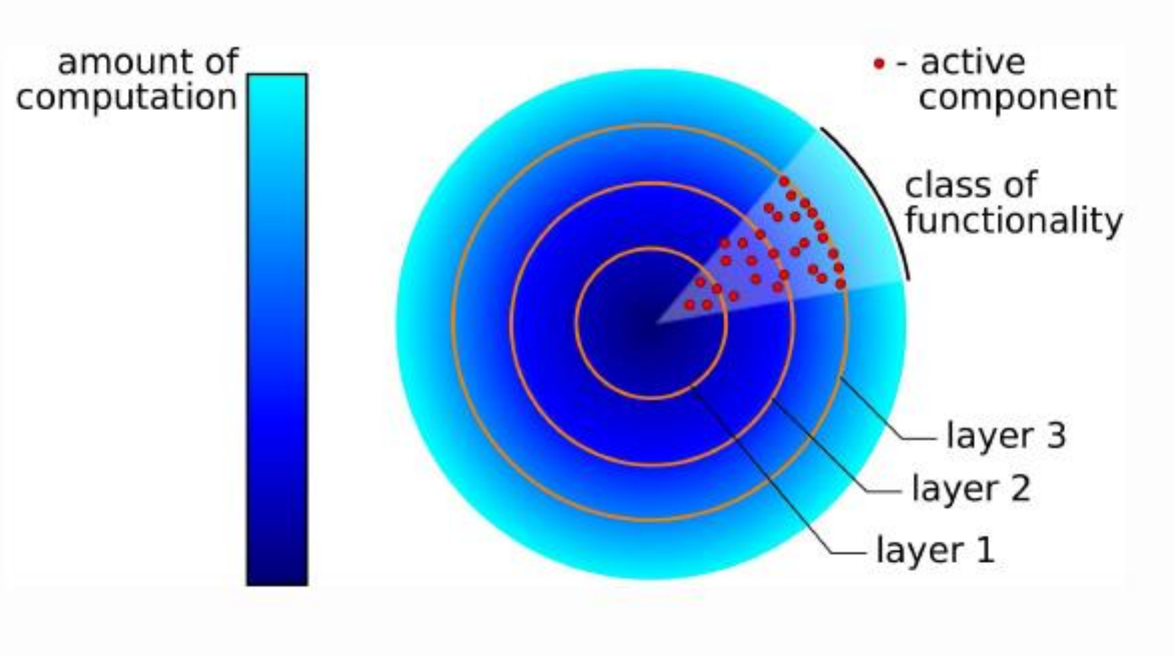
- energy-modulated and power-adaptive computing,
- significance-driven approximate computing,
- real-power (cf. real-time!) computing,
- power layering in systems architecting,
- computing with survival instincts,
- computing with central and peripheral powering and timing,
- exploiting bustiness and regularity of processing

Traditional vs energy-modulated view



Power-modulated multi-layer system

- Multiple layers of the system design can turn on at different power levels (analogies with living organisms' nervous systems or underwater life, layers of different cost labour in resilient economies)
- As power goes higher new layers turn on, while the lower layers ("back up") remain active
- The more active layers the system has the more power resourceful it is



Q1: Learning lessons from Biology for EDA

a. Stochastic behavioural modelling -> Using macro-state approach as opposed to micro-state (controlled fidelity); micro- and microsscopes
b. AMS verification -> Dynamic/adaptive rate and variable significance metrics (by the way, what is bio-equivalent of verification!?)
c. Circuit resilience to PV -> Self-timed (delay-insensitive) circuits
d. FB-based error correction -> Variable granularity error representation
e. Digital and analog in the few electron limit -> Noise-based computing (exploration of choices)
f. Parallelised computation -> Emulator approach using partially ordered event-driven computing on many-core fabrics
g. Evolutionary algorithms -> Apply evolution at the right abstraction level with a distinct functional qualities (e.g. IP for ultra low power)

Q2: Lessons from Bio

- Transfer to highly functional, space-limited, D&A systems with extremely low energy consumption
  - We need to switch from performance-driven (constraint) energy-efficient (cost) paradigm to energy-driven and space-limited (constraint) performance-optimised (cost) system design
  - Energy/power-proportional performance is a key; hence computing control should be from power source and allocation control
  - “Computation” should be quantified in Problem Solutions per Joule or Decisions per Joule
- Build a hybrid computer utilising interface between bio layer and electronic layer
  - These layers must be concurrent and cooperative, each with its specific role, not one subordinate (like function call) of the other
  - Analogy to multi-layered (e.g. reptilian, mammalian, neo-cortex) brain - bio responsible for sensing, recognition (instincts) activity and electronic layer for numerical, analytic and reasoning activity
- Killer applications:
  - Robotics, autonomous vehicles, remote space
  - Radiation and chemical sensors, smell sensors, psycho-sensors
  - Domains: medical, safety, security, entertainment

Q3. New tools for designing bio and bio-inspired systems

- New simulators:
  - Emulators (with touch and feel effect)
  - Play-in/play-out simulators
  - Behaviour miners
  - “Micro- and macroscopes” and accelerators
- New solvers (not hard SAT-solvers) – e.g. for verification:
  - Trend determinants
  - Approximators, Guessers
- New optimisation engines
  - “Heuristicators” (learners of simple rules from experience)
  - Decision-making Fabrics
- New test generation
  - Varying aggressiveness and Devil-advocate-based testing
  - Behaviour and structure (test-time) learning tests

Q4: Analogy between chip aging and degradation and cell aging and degradation suggest solutions to the IC lifetime variability

- When cells degrade (stress, aging) they process energy into actions more slowly, i.e. their energy-utilisation in terms of the speed of burning calories degrades.
- This is basically Age-aware aspect of energy-driven real-time
- Interesting question: Does the total or time and space profiled switching activity wear the cells?
- We need to study the mechanisms of the rate of joule-burning in aging chips; they should be related to the Vthreshold degradation etc.
- What are wear mechanisms in circuits related to their functionality profiles and behavioural patterns?

Q5:Relationship between circuit-level and system architecture

- How coupled are circuit-level approaches to overall system architecture?
  - They are sometimes strongly coupled: examples include use of asynchronous circuit designs in the architectures with variable timing-bands, decentralised control (GALS) and arbitration; wake-ups and event-driven
- It appears that for AMS systems with growing digital aspects (for mode switching, reconfiguration, monitoring and calibration) asynchronous logic design is particularly good, for example in asynchronous DC-DC converters (lower response time, smaller ripple, smaller inductors size, higher power efficiency)

Q6: Vision for bio inspired and hybrid cell-electronic

- 5/10 year vision:
  - Bio-inspired: “Compute where energy flows” will be commonplace; massively parallel computers (with a heterogeneous processing elements and event-based processing)
  - Hybrid: Bio-sensors and bio-energy generators
- 20 year vision:
  - Bio-inspired: From energy-driven to survival-driven:
    - For individual systems – design time and run-time
    - For systems as a kind, i.e. IP’s “DNA” banks
    - For design methodologies, i.e. Know-how’s “DNA” banks
  - Hybrid: e.g. Robots with massive bio-sensory abilities; Detectors of radiation, smell, psycho
  - Super-futuristic: detectors of extra-terrestrial communications!

Finally, the biggest challenge is …

- For semiconductor systems, it is how to achieve **massive informational connectivity** of parts at all levels of hierarchy or spatial layers of powering and timing?
- I hypothesize it can only **be addressed** in hybrid cell-microelectronic systems.
- **Information (and hence, data processing) flows should be commensurate to energy flows**, only then we will be close to thermodynamic limits.