New Electronic Design principles inspired by bio systems.
Panel discussion

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Energy drives logic

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

- **Traditional System**
  - Power supply
  - Clock generator
  - Computational electronics
  - Activity levels determine power levels

- **Energy-Modulated System**
  - Power supply
  - Computational electronics
  - Power determines activity
  - Seamless transitions

- Diagrams illustrate the comparison between traditional and energy-modulated systems, highlighting differences in power management and activity levels.
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 microscopes
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.