Why is Neuromorphic Computing Different and Difficult

Basic Neuromorphic Computing Proposition

- Build computers that learn and generalize in a broad variety of tasks, much as human brains are able to do, in order to employ them in applications that require (too much) human effort.

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Todd’s Top 10

10. Neuroscience is too little help (tlh)

- We cannot possibly simulate all the detail of a biological brain
- We don't understand the function of very simple nervous systems
- There are far, far too few "observables" to guide the development of any model or technology

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9. Computational Neural Models are tlh

- Too many assumptions
- Too many parameters
- No general organizing principle
- Models are (usually) incomprehensible
- Unclear connection to applications

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8. Other things that are tlh

- Cortical column hypothesis
- Sparse distributed representations
- Spiking neural networks, STDP
- Hierarchies of simple and complex cells
- *Insert your favorite ideas here*
  - Spatio-temporal, scale invariance
  - Criticality, critical branching
  - Causal entropic forcing

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7. Whole System Requirement

- Brains are embodied and bodies are embedded in an environment (Edelman)
- Testing a neuromorphic computer requires embedding it in a complex body /environment.

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6. Whole System Interdependence

- Brains / bodies / environments are complex systems whose large scale function (almost certainly) cannot be analytically expressed in terms of its lower level structure / dynamics
- System design methodologies are inadequate because the system cannot be decomposed into independent parts

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5. No Path for Technology Evolution

- The benchmark for performance comparison is either
  - A human
  - A well-engineered, domain-specific solution

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4. Massive Computing Resources

- Any model that does anything that anyone will care about requires a massive computational resource for development and implementation
- Development is slow and expensive
- Custom hardware in state of art process is needed for any large scale application
- Software and hardware must co-evolve
  - Cannot develop the algorithms first
  - Cannot specify the hardware first

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3. Competition for Resources

- It is easy for anyone who doesn't like your project to claim that
  - It is making no progress
  - It is not competitive with the state of the art
  - You are doing it wrong
  - Todd is an idiot
- This happened to me regularly at DARPA

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2. Computers can compute anything

- The computer is a blank slate
- We must generate all the constraints to build a neuromorphic computer
- Changing computing architecture only changes the classes of algorithms that it computes efficiently

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1. Brains are not Computers

- Brains are thermodynamical, bio/chemo/physical systems that spontaneously self-organize when exposed to the world
  - Computers are symbolic processors executing algorithms designed by humans
- Brains designed computers.
  - Can computers design brains?

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Additional Thoughts

Machine Learning

- Machine learning algorithms are neuromorphic computing algorithms that actually work. ;)
- Machine learning algorithms have mathematical expressions describing what they do (from which the algorithms are derived).
- By analogy, a neuromorphic computer satisfying the original proposition would require a mathematical formulation of the brain.
  - *Is this possible? or reasonable?*
  - *How would we figure this out?*

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What We Can Do

- Build new kinds of computers that are capable of efficiently executing new classes of algorithms
- Build better machine learning algorithms

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Alternative Neuromorphic Computing Propositions

User Focused NC Proposition

- *We will build a computer to enable (for example)*
  - *computational neuroscientists to efficiently model large neural systems.*
  - *analysts to more easily understand video*

- Comment: This kind of proposition is a long way from an engineering specification.

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Algorithm Focused NC Proposition

- *We will build a computer that efficiently computes certain (classes of) machine learning algorithms*

- Comment: This kind of proposition can lead to narrowly focused systems (ASICs).

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Architecture Focused NC Proposition

- We will build a computer featuring the following architectural concepts (for example)
  - SDR
  - event-based execution, asynchronous communication
  - highly distributed simple cores within a dense memory
  - neural/synaptic/columnar computational primitives,
  - criticality/homeostasis....
- Comments:
  - Before any specification can be created, a description like this is required
  - It isn't obvious from such propositions what the computer will be good at / used for.

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What has changed in 7 years

- End of semiconductor scaling clearly in sight
- Numerous large scale efforts in neuromorphic computing now exist
  - Community has substantially grown
  - Several example systems now exist
- Deep learning algorithms have matured and are being deployed
- BRAIN Initiative and Human Brain Project have been announced/started

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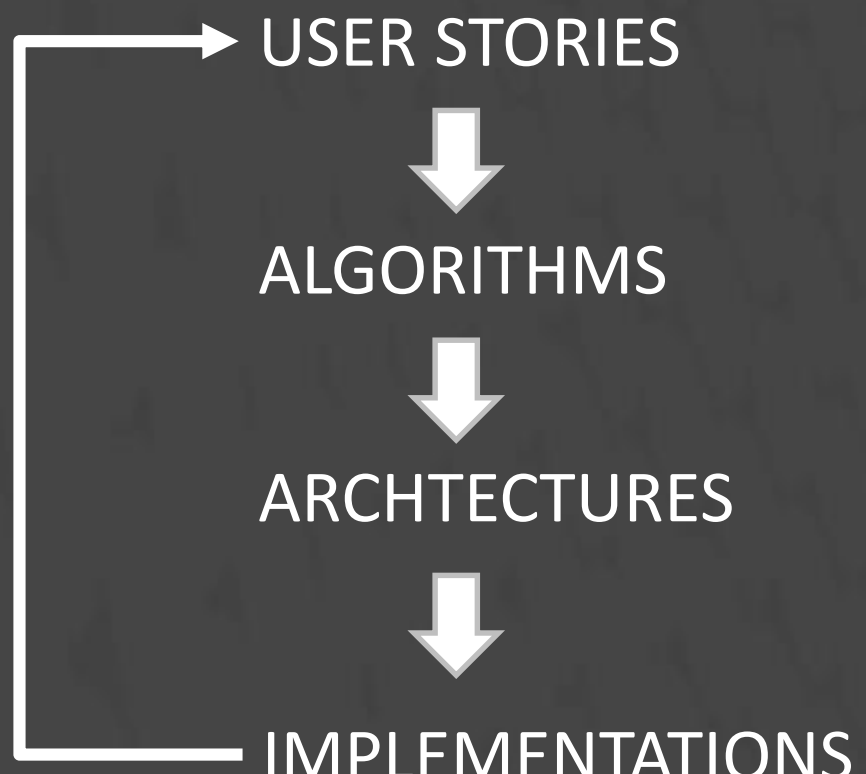
The Evolution of NC Has Begun



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Recommendation

- Separate/classify effort into 2 domains
  - Aspirational efforts focused on the basic NC proposition
  - Practical efforts focused on building new, useful computers
- Avoid the temptation to straddle both domains

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