Decadal Plan for Semiconductors: New Trajectories for Analog Electronics

Question: Hi Jim, do you think there is need for exploring fundamentally new devices along a continuum of charge processing (from sensor, to memory, finally battery?) cutting across the issues you outlined? Pankaj Mehra

Answer: Yes, as was brought up in the Decadal Plan and in Mark Rodwell's statements, new devices along with processing will be required.   Note that "devices" include active and passives including interconnect. Examples are compute in memory devices, ultra-high frequency transistors and associated low-loss interconnects, selective/intelligent "sensors", analog signal processing and selective ML/AI etc.

Question: What the use of Carbon nanotube FETS for linear RF technology

Answer: There is to date no strong evidence that carbon nanotube FETs have advantages in linear RF. There is not yet experimental evidence of of even competitive high frequency small signal peformance, let alone RF power data. I would emphasize addressing linearity by circuit and system level approaches. (For sensor fans out there, there are some interesting things being done with CNTs as sensor elements)

Question: I heard that data is taken from sensors and filter it to process it using smart ADCs to reduce latency and power. Can the panelists through some light on this concept, please? (sorry if this sounds rookee, just want to understand abt it)

Answer: Filtering, signal conditioning and ADC are all required to extract a useful signal towards inference and insight. The implementation can be analog, digital or a hybrid of the two with appropriate tradeoffs in dynamic range, speed, latency and power.   The trend over the last 30 years has been to push the ADC closer to the sensor and more digital domain processing for flexibility, with Moore's Law being a major enabler. Towards the future, tradeoffs are changing and more focus is needed into where and, importantly, how the insight to action is performed. There is potential to build more "intelligence" into the analog-to-inference converter in as an "intelligent ADC" when signal structure is known. Exploration into such an approach may result in lower energy and latency cost, but likely at some loss in flexibility.   See an artical on Analog-to-Information by Marian Verhelst and Ahmad Bahai (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7258493)IEEE Solid-State Circuits Magazine 2015-Vol7, Issue 3.

Question: For all panelists: My question is on the notion that we need more information and not more data. More comments on this would be appreciated. How can we maximize the information and minimize the number of bits at the same time? A side question (can be omitted in this discussion): Is the "Black Square" by Malevich a manifestation of a single-bit pixel or it contains meaningful information?

Answer: For many applications, maximum amount of information is not required or desirable. To have high energy efficiency, we just need the minimal information required for the end applications. The challenge is on how to determine enough is enough since it varies from one application to another. Recent trends in Machine Learning have created a rush to "get all the data that you can grab", and then let machines sort through it to "discover" information: but there is a big cost to this in power for capturing, storing, processing, and moving all this data (this is the "deluge") . This challenge will be one of the research areas for Decadal plan.

Question: Will these components / parts all be sourced from Asia or are there American suppliers /manufacturers that can supply these parts

Answer: There was verbal answer during the Q&A session of the webinar and this is an overall semiconductor/electronics sourcing question. The supply chain is and will continue to be global for components and parts. There will be increased efforts to manufacture more in the U.S. with drive from government funding and incentives but it is unlikely to be totally sourced in America alone or even by strictly American companies. Note, there is significant semiconductor wafer manufacturing in the U.S. --including the "analog-specific More-than-Moore" fabs, though most assembly is off-shore.

Question: You talked about the requirement of memory demands. Can you share what are your thoughts on improving memory designs?

Answer: See Decadal Plan on the Memory and Storage chapter with grand challenge. There will be an upcoming webinar on this topic. Not a focus of the Analog webinar.

Question: Is there a math that starts with the energy carried in the signal and fits computation not just signal recovery into an integrating sensing-computation flow that achieves high “information” gain at low power?

Answer: Overall, establishing a mathematically rigourous relation between energy and information would be very interesting. Generally speaking, any signal greater than thermal noise is information. The thermal noise energy is ~kT or ~1e-21 J ~0.03eV (the thermal noise limit is also known as the Landauer limit on the minimum energy per bit in computation: Emin=kTln2). If an 'atom' of a signal is e.g. a single photon, then its energy is directly related to the color of the light, thus represents information, e.g. E=2.3 eV (green) or E=3 eV (violet) etc. I, personally, would be interested to see if this could be expanded to all types of signal carriers. Though these mathematical calculations are a useful physics limit, practical considerations limit what can be realized.

Question: Are Neural Nets becoming capable of processing the analog information without converting it to digital information first?

Answer: There are such fully analog approaches, but they do not tend to scale well due to analog error accumulation. That said, it still makes sense to consider limited amounts of analog processing before/after digitization when it is energetically attractive, e.g. for in-memory computing. Section 1.5 of the Decadal Plan discusses this.

Question: For such upcoming large systems, what are the advances done in simulator side? I think a simulator combining all of the items which helps optimize at system level will help.

Answer: Section 1.6 of the Decadal Plan (Analog Design Productivity and Predictability) touches this aspect. Simulation time depeds strongly on the abstration level and approximations are needed to simulate a complete system. Verifying a modern system already tends to be slow, so optimization using the same modeling abstrations tends to be prohibitive. It is foreseeable that we need new tools that can drive archtecture optimization wthout excessive simulation.

Question: Is this a problem that needs to be addressed with more knowledgable people, or simply more people with knowledge, learning to work together. In other words, is this a technology (research) problem, or a widespread human talent (education) problem?

Answer: No one person will have all the knowledge but all need to have basic understanding of the system in addition to their specialization. Multiple people with specific knowledge will need to collaborate together. Talent needs to be developed to address these needs. Funding research "centers" with multi-disciplinary researchers is one method to provide this education-- many of the SRC-sponsored research programs have been structured this way with some notable success, and we would expect this to continue going forward.

Question: @Boris, one would think that biological sensors evolved in both their chemical/mechanical/wet architecture as they evolved in their information architecture and evolution of brain across nervous system. Do we have too narrow a definition of machine learning today?

Answer: As discussed, we need to consider the sensing "system" regardless of implementation (chemical, mechanical, electrical, wet...) but we need to be careful to not try and exactly mimic the biological system but rather learn and apply to tools and technologies we have. We don't fully understand the way nature operates but it has evolved into a very efficient solution for what is truly needed to survive: it tends to be very highly specialized/optimized for it's particular function. (It certainly does illustrate that "chemical/molecular" processing and storage can be exceptionally power efficient, though very slow compared to circuit processing.)

Question: The foundations for the semiconductor industry leadership of US went deep when the transistor was invented. So, if any of the few ground breaking research probs are solved in any one specific country, will they gain the leadership position? Or this just a myth??

Answer: Complexity is much higher now and requires multi-disiplinary, multi-technology solutions. It is not likekly that "one" technology or entity can take leadership by itself. Given that complexity, when we look at "progress", it might look like a remarkably smooth ramp, but it is actually achieved by a large collection of innovations building and intereacting with one another. The object of shared visions like the ITRS roadmaps and Decadal plan is to create a framework to acclerate those interactions.

Question: For move to >100GHz, how will propagation losses affect the links and application ranges?

Answer: Both (wavelength/distance)^2 and weather-related atmospheric losses are very high and constrain outdoor terrestrial systems to 100-500m range. Please see https://web.ece.ucsb.edu/Faculty/rodwell/publications_and_presentations/publications/2018_10_14_BCICTS_short_course_rodwell.pdf , page 14, and the references there cited.

Question: So being someone with background in mixed Signal ASIC (Industry + academia) and now doing ML (industry) … i feel the companies are reluctant to adapt such hybrid culture … where do you advice to go, dreaming academia or reluctant industry

Answer: The future will require this "hybrid" approach for success – whether in a single company or via collaboration partnerships. New branches of study such as AL/ML processing at the edge will provide more emphasis on the hybrid approach. Many forward looking companies are seeing this now, the Decadal Plan is partially a reflection of this realization. As the question notes, there is a difference between exploration/research and adoption/deployment: this is where work across academia and industry is so important.

Question: Seems like the ability to abstract different layers is another skill that allows moving up and down the solution

Answer: Yes, finding the right abstactions and interfaces between them will be key to optimizing future systems across the entire stack. Section 1.6 of The Decadal Plan touches this apsect from a simulation perspective. An important additional consideration is leveraging domain knowledge in such abstraction and taking advantage of physics-based ML approaches, which are increasingly gaining traction in the community.

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