Integrated living technology:
electronic and molecular integration towards hereditary cell-sized robotic systems.

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Outline

- Living Technology – the essence
- The importance of the cellular scale
- Electronics, not just interfacing but local integrated control
- How is electronic-molecular integration possible?
- Why living technology? What are the applications?
- Where do we stand now? What are the next steps?

Living Technology – the essence

A refining definition:

Living Technology as a discipline seeks to explore the possibilities, limitations, and potential benefits and dangers of making technology not only more life-like but ultimately alive. Living Technology is not just biomimetic (like self-cleaning tiles) but makes strong use of the core properties of living systems such as autonomy and self-reproduction.

It recognizes the enormous advantages of living systems over conventional technology in terms of distributed information processing, natural embedding, robust performance, economy in fabrication, sustainability, creativity and evolvability as well as human compatibility. It analyzes and abstracts the root source of these advantages and seeks to extend them to solve technical challenges by linking novel information architectures, materials and systems.

It recognizes the advantages of technical systems in robust limitedness, controllability, programmability and isolated performance levels, and researches means of achieving superior safety and environmental and socio-economic impact for living technology.

The importance of the cellular scale

- Current life orchestrates molecular interactions at the scale of cells
- Cells provide the central key organizational unit in all living organisms
- Cells provide a clear boundary and identity for living systems
- Cells provide a unique, clear and tough target for Living Technology
- The cellular scale of 1-30 µm lies just at the edge of the domain of efficient diffusive information exchange (via Brownian motion)
- In the body, the major highways (blood, lungs, lymph …) branch all the way down to the scale of cells and this also constrains our interface with the body in medicine.

Electronics, not just interfacing but local integrated control

- Electronics interfaces in many ways with living systems, with diverse sensors down to single ion channels and single molecule detectors and diverse actuators ranging from micro- and nanoelectrodes to mechanical ultrasound.
- Electronics integrates signal processing along internally wired transistor networks in increasingly low power and nm scale tech.
- Electronic integration together with biotechnology has been embraced by major organizations such as Philips, Imec and others as their major future role.
- The miniaturization of electronic chips down to cellular size is both achievable and now in progress. *
- Such electronics need to address power and communication as well as sensing and actuation and control.

Electronic microprocessors: scaling down to cell size.

Current 4bit-microprocessor electronics: complexity benchmark, not only architecture.
Silicon on sapphire and other techniques to reduce leakage current.

Projection JSMR beyond MICREAgents Sep 2017

90 nm node

resolution

5 nm node

Size µm/ Techn. nm	Transistors	Voltage core/IO	Memory (SRAM)	Electrodes size	Supercap capacity nF	Load pW for 1000s
140/ 180	**2238**	1.8/3.3	843	28	4900	2000
140/ 130	**4290**	1.2/2.5	1613	28	4900	2000
100/ 90	**4360**	1.2/2.5	2002	20	2500	1000
70/ 65	**4185**	1.2/2.5	1867	14	1225	500
45/ 40	**4050**	1.1/2.5	1674	9	506	200
32/ 28	**4096**	1.0/2.5	1575	7	256	100
24/ 22	**3732**	0.9/1.8	1435	5	144	60
12/ 10 *	**4608**	V 2x	1737	2.5	36	15
6 / 5 °	**3475**	V 2x	1336	1.2	9	3.6
3 / 3 ?	**3136**	V 2x	1206	0.6	2.2	0.9

140 µm

particle size

red blood cells

3 µm

* 2017 ° 2019

maintains transistor count on particle

http://www.europractice-ic.com/technologies_TSMC.php?tech_id=40nm

How is electronic-molecular integration possible?

- Electrochemistry – sensing and actuation and mediation via coatings
- Catalytic electrochemistry e.g. of DNA cascades
- Bipolar powering of remote molecular processes in solution
- Nanopores and channels : ion channels integrating with electronics
- Supercaps and local power
- Light and EM-radiation remote mediation : biophotonics
- Lensless imaging and photodetectors
- Phase transition control via molecular interactions & redox signals

Why electronic living technology? What are the applications?

Electronic living technology is required to solve remote intelligent control and remedial tasks: in otherwise inaccessible locations

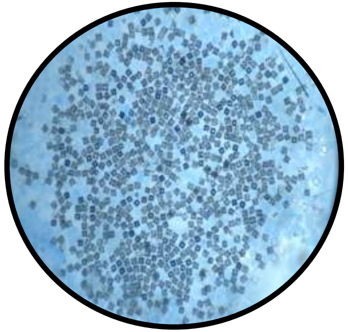
- The small and fine-grained: e.g. cell scale, myriad branched capillaries
- The remote: e.g. the body, the environment, space …
- The hostile: e.g. industrial waste, radioactive cleanup, synthetic chemistry …
- The ubiquitous: e.g. surface fouling, repair from people to buildings
- The complex: information collection and human filtering for complex environments

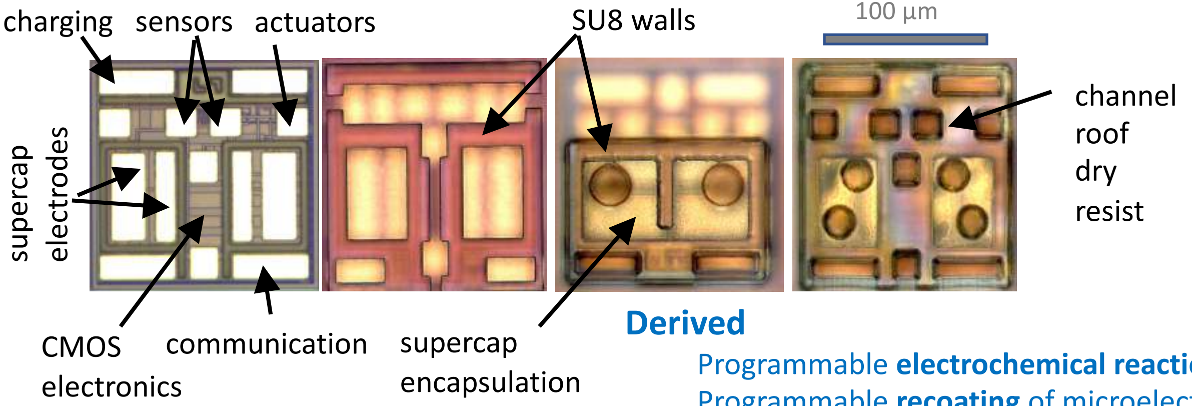
Where do we stand now? What are the next steps?

- Concepts available with proofs of principle for lablets at ca. 100µm
- Concepts available with initial forays for robotic actuation down to the scale of cells 10µm and via DNA down to the nanoscale
- Increasing activity in big electronics firms and medicine in this direction : needs LT guidance and input
- Need to establish an international service foundry (like Europractice) for electronic interfaced LT
- Integration with work on remote micro-intelligence – AI in the small

Fundamental

1. **Microscopic size** for pourable local function at cell scale
2. **Programmable electronics**: from FSM to microcontroller
3. Programmable microelectrode surfaces: **actuators and sensors**
4. **Self-matching cavity*** forming superstructure
5. On-particle **rechargeable power** source : supercap
6. **Local communication** through solution: with dock, each other





MICREAgents project

2012-2016 EU

EON seed grant 2016-17

Derived

- Programmable **electrochemical reactions & sensing**
- Programmable **recoating** of microelectrodes
- Programmable chemical **micro-containment**
- Programmable **docking** and detachment
- Programmable **motion** and navigation
- Information-controlled **self-replication**
- Controlled local synthesis, regulation and diagnostics
- Applications *in vitro, in enviro, in vivo, in corpori*

lablet key functionalities

* Restricted entry structure such as channels with lid and open ends or half open chambers.