An Italian Research Group on Logic Synthesis

(Switching Logic Meets Old and New Problems)

ANNA BERNASCONI, VALENTINA CIRIANI, ENRICO TRONCI,
GABRIELLA TRUCCO AND TIZIANO VILLA

The 2nd Italian Workshop on Embedded Systems (IWES 2017)

Rome, Italy -- 7-8 September 2017

Group presentation

- Politecnico di Milano
  - Fabrizio Ferrandi
- Università degli Studi di Milano
  - Valentina Ciriani, Luca Frontini, Valentino Liberali, Gabriella Trucco
- Università di Pisa:
  - Anna Bernasconi, Fabrizio Luccio, Linda Pagli
- Università degli Studi di Roma «La Sapienza»
  - Federico Mari, Annalisa Massini, Enrico Tronci
- Università degli Studi di Verona
  - Tiziano Villa
- Politecnico di Torino
  - Stefano Quer, Giampiero Cabodi

National Workshops

- Since 2005 annual meeting on logic synthesis to discuss:
  - recent research results
  - open problems
  - project proposals
- Up to now 13 editions hosted by various universities
- Programs and some presentations of past editions available at http://sintesilogica.di.unimi.it/
- Edition of 2013 co-located with DSD 2013 in Verona featured international speakers

Joint Projects

Some units participated under the umbrella of CINI to an European call for H2020 FETPROACT-01-2016 with a project entitled "TEAMwORk: Autonomous evolutionary algorithms with memristive opto-electronic systems"

Some Directions of Active Research

- Politecnico di Milano
  - Ferrandi: High-level synthesis, Physical design, Combinational and sequential synthesis
- Università degli Studi di Milano
  - Ciriani, Frontini, Liberali, Trucco: Combinational synthesis, Emerging technologies, Synthetic Biology, Computational complexity and algorithms
- Università di Pisa
  - Bernasconi, Luccio, Pagli: Combinational synthesis, Computational complexity and algorithms
- Università di Roma
  - Tronci, Mari, Massini: Model checking for automatic analysis and synthesis of mission or safety critical reactive systems
- Politecnico di Torino
  - Quer and Cabodi: Reachability analysis and verification of combinational and sequential systems, Decision diagrams
- Università degli Studi di Verona: Combinational and Sequential Synthesis, Formal methods for cyber-physical systems

Three-level Espresso and Beyond

- XOR-AND-OR synthesis: SPP and k-SPP forms
  - SPP: OR of ANDs of XORs of literals → Example: $f = (x_1 \oplus x_2)(x_3 \oplus x_4) + x_2(x_3 \oplus x_4)$
  - k-SPP: OR of ANDs of XORs of at most k literals

- Decomposition techniques extending Shannon cofactoring:
  - cofactoring with respect to more complex functions instead of single literals
  - factorizations that modify the Hamming distance among the on-set minterms, so that more logic minimization may be performed on the projections
  - projection onto overlapping subsets in order to favor area minimization avoiding cube fragmentation (i.e., cube splitting for the cubes intersecting more subsets)
  - synthesis techniques based on the use of Boolean relations and autosymmetry

Emerging technologies

CMOS technology

- Transistor size have been shrunk for decades
- The trend reached a critical point

The Moore's Law era is coming to end

New emerging technologies

- Biotechnologies, molecular-scale self-assembled systems
- Graphene structures
- Switching lattices arrays

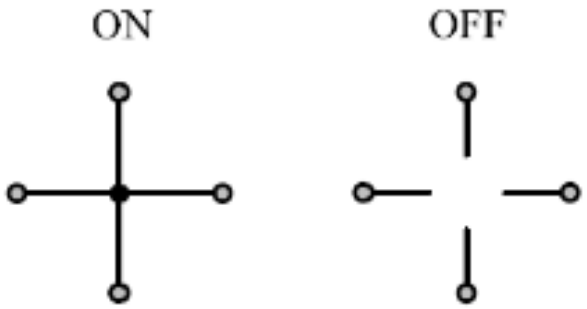
These technologies are in an early state

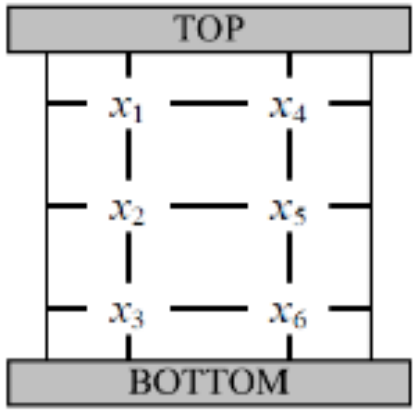
A novel synthesis approach is necessary, focused on the properties of the devices
Synthesis efficiency can be the main factor for a technology choice

Emerging technologies: switching lattices

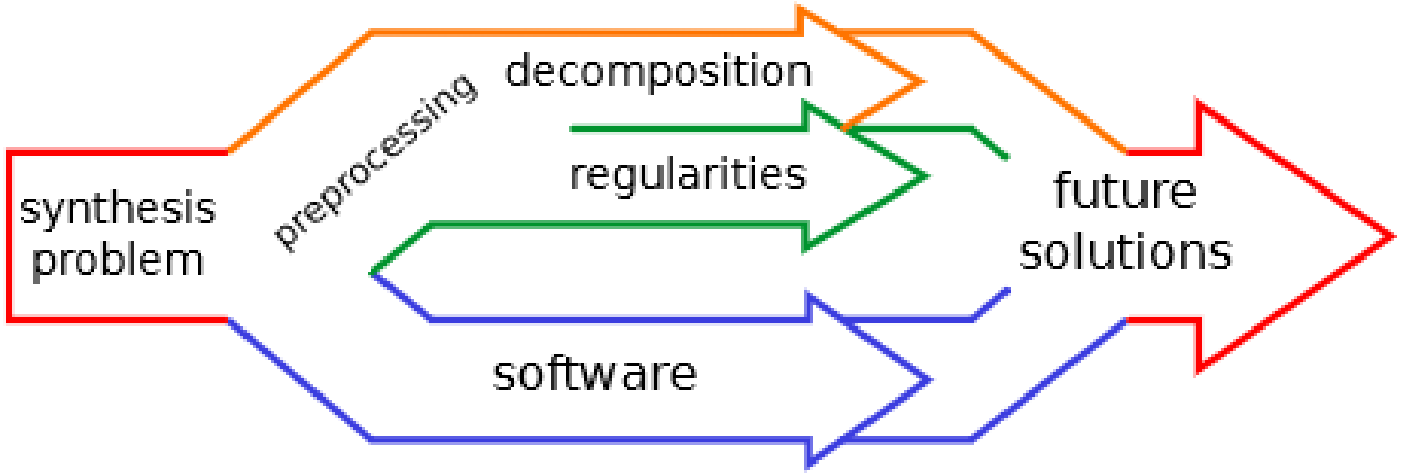
Switching Lattices are **two-dimensional** array of **four-terminal** switches

- When switches are ON all terminals are connected, when OFF all terminals are disconnected
- Each switch is controlled by a boolean literal, 1 or 0
- The boolean function f is the SOP of the literals along each path from **top** to **bottom**
- $f = x_1x_2x_3 + x_1x_2x_5x_6 + x_4x_5x_2x_3 + x_4x_5x_6$





Emerging technologies: switching lattices



To optimize lattice synthesis there are different approaches, but common goals:

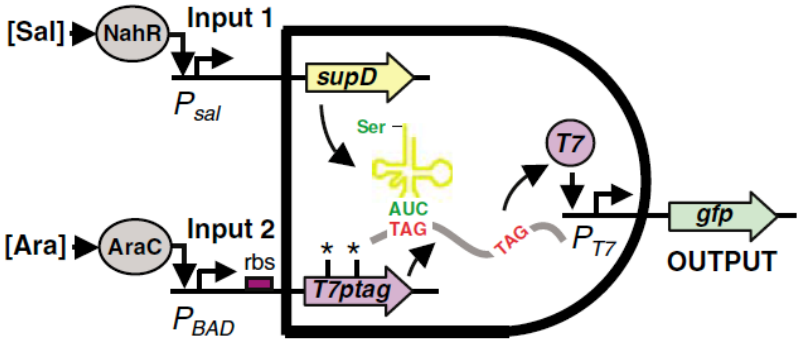
- Produce optimal-size lattices
- Reduce synthesis time
- Create efficient methods for sub-optimal lattice synthesis

Synthetic biology

Some definitions

a) Design and construction of new biological parts, devices and systems (e.g., tumor-seeking microbes for cancer treatment)
b) Re-design of existing natural biological systems for useful purposes (e.g., photosynthetic systems to produce energy)
c) Synthesis of complex, biologically based (or inspired) systems which display functions that do not exist in nature. This engineering perspective may be applied at all levels of the hierarchy of biological structures – from individual molecules to whole cells, tissues and organisms. In essence, synthetic biology will enable the design of ‘biological systems’ in a rational and systematic way

Synthetic biology



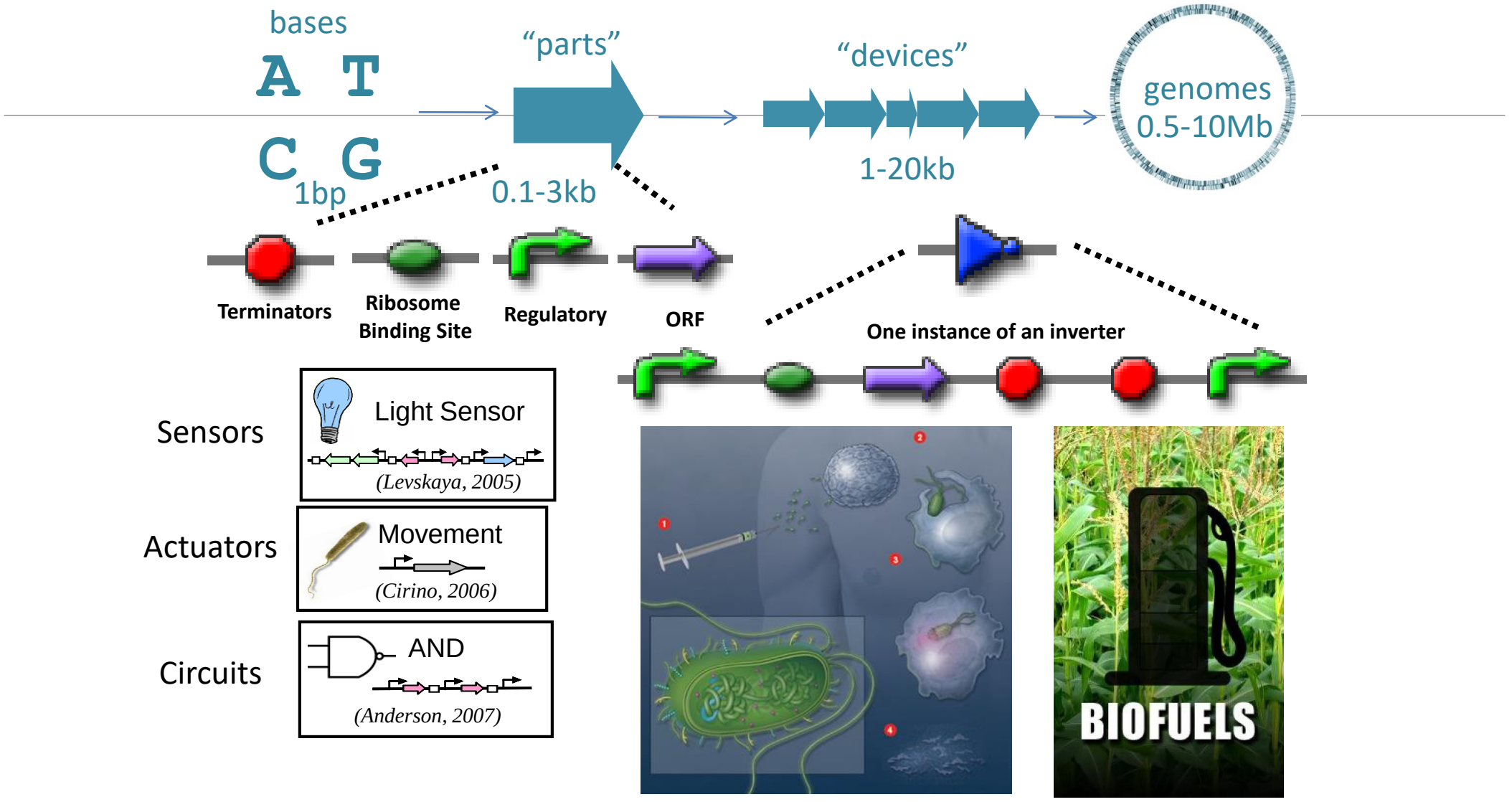
Four principles not typically found in genetics, genomics, or molecular biology

Abstraction: don't focus on the DNA sequences, but think of the parts as units in a circuit diagram. Abstraction means you can used parts/devices/systems without having to worry about how they work. DNA is used to make parts. Parts are assembled into devices. Devices are connected to make systems.

Modularity: parts, devices and systems can be connected as self-contained units and combined in any combination you want.

Standardization: many aspects of the designs are standardized to improve overall function. One example is the standard way parts, devices, and systems are connected so that new designs will fit with old designs.

Design and modeling: before building, build a model and test the devices capacity. This not only improves design but tests basic biological assumptions that could be false


bases
A T
C G
1bp
"parts"
0.1-3kb
"devices"
1-20kb
genomes
0.5-10Mb
Terminators
Ribosome Binding Site
Regulatory
ORF
One instance of an inverter
Sensors
Light Sensor
(Levskaya, 2005)
Actuators
Movement
(Cirino, 2006)
Circuits
AND
(Anderson, 2007)
BIOFUELS

Synthetic biology: examples

EXAMPLE 1

The genetic logic synthesis problem: given a Boolean function $f : \{0; 1\}^n \rightarrow \{0; 1; x\}^m$ (where x denotes a don't care) and a finite genetic logic library, synthesize a DNA sequence *S* which can realize *f*

EXAMPLE 2

Synthesis and Optimization of Recombinase-Based Genetic Circuits: how to construct arbitrary Boolean functions using recombinased-based logic gates

- Recombinases: a kind of genetic recombination enzymes common in nature controlling gene expression and modifying genome structures in living organisms

Conclusion

- Interested groups please contact us to be informed on future activities
- We look forward to joint proposals for EU calls on strategic topics where logic synthesis may play the role of an enabling technology (CINI proved to be an efficient interface to federate different groups)
- May organize reference portal for logic synthesis with news, contacts and source code ?