Faculty of Computational mathematics and cybernetics: scientific and educational activity in the field of VLSI design

Lozhkin S.A., Shupletsov M.S.

Goals and objectives

- Research in the field of discrete control systems and application of research results in different applied and engineering problems in the field of VLSI CAD and development.

- Preparation of highly qualified specialists in this field, who combine fundamental mathematical education with practical programming skills and VLSI design skills.
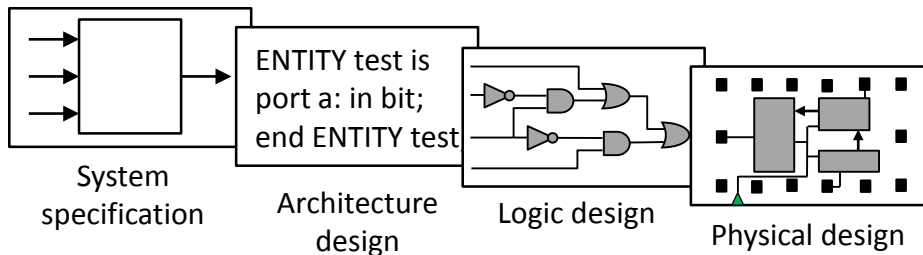
VLSI research and education

- Department of mathematical cybernetics
  - Department head: Alekseev V.B.
  - 6 Full Professors
  - 3 Associate Professors

- Laboratory of discrete control systems and their applications
  - Laboratory head: Lozhkin S.A.
  - 1 Leading scientific researcher
  - 2 Senior scientific researchers
 - 5 Junior scientific researchers

Fundamental research

- Research of complexity, structural and testing properties of different models of Boolean function's implementations

- Research of graph embedding methods and algorithms

- Development of effective algorithms for formal equivalence checking and optimization of programs and circuits
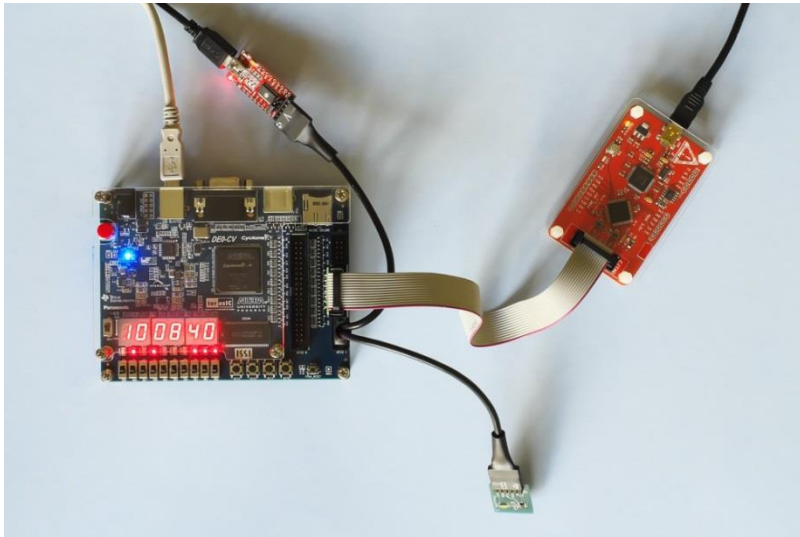
Applied research

System specification · Architecture design · Logic design · Physical design

input: design
input: corresponding design
output: netlists with corresponding cuts
We can therefore analyze on the partitioned corresponding sub-blocks

- Development of VLSI CAD algorithms:
  - Academic VLSI design flow
  - Development of algorithms for specific CAD problems
    - Circuit decomposition algorithms for verification engine
    - Engineering change order algorithms
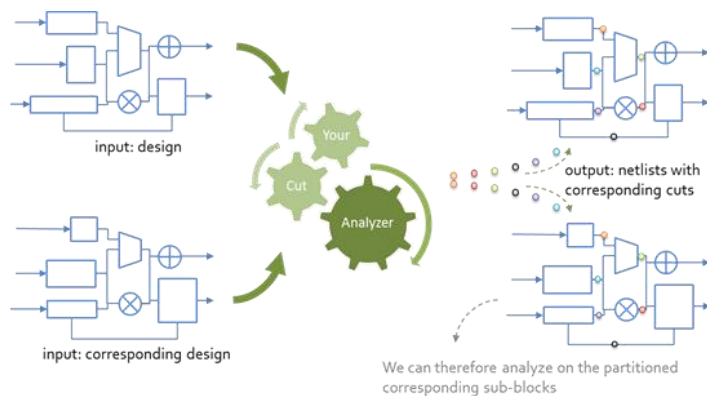
Applied research

- VLSI design prototyping with FPGAs:
  - Hardware acceleration of algorithms
  - Embedded systems
  - Microprocessor prototyping
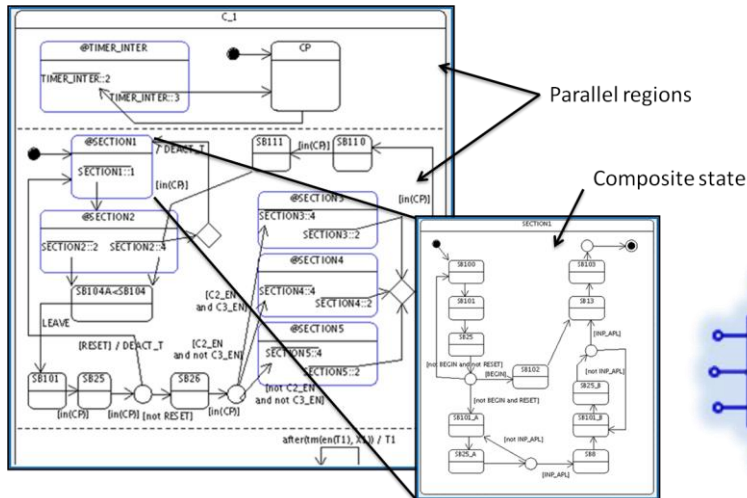 - FPGA-based education of integrated circuit design
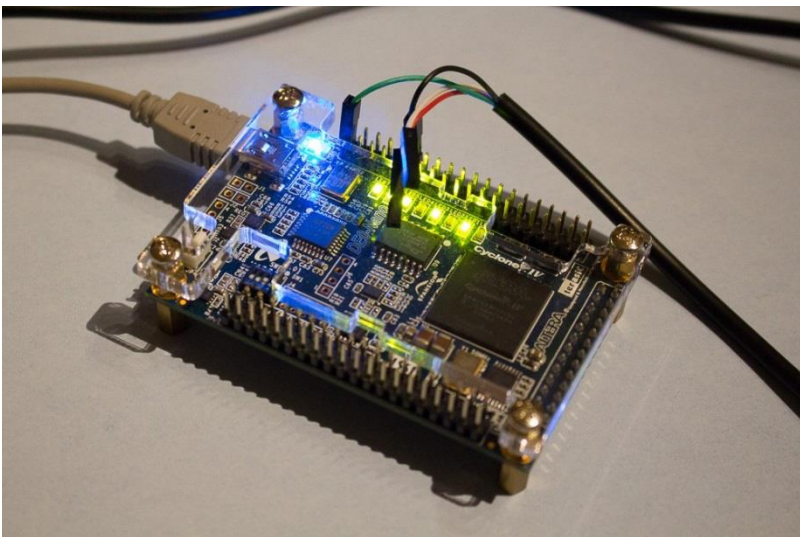
Applied research

void **sort**(std::list<int> & l) {...}
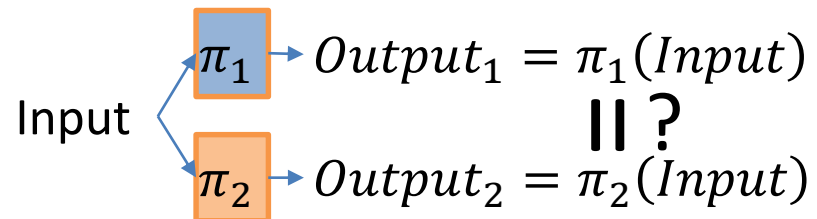
$$\textbf{Sorted}(l) = \forall i \forall j \begin{pmatrix} 0 < i \le j < size(l) \to \\ l[i] < l[j] \end{pmatrix}$$

Check: {true} **sort**(l) {**Sorted**(l)}

Parallel regions

Composite state

```
@P=split//,".URRUU\c8R";@d=split//,"\nrekcah xinU / lreP rehtona tsuJ";sub p{
@p{"r$p","u$p"}=(P,P);pipe"r$p","u$p";++$p;($q*=2)+=$f=!fork;map{$P=$P[$f^ord
($p{$_})&6];$p{$_}=/ ^$P/ix?$P:close$_}keys%p}p;p;p;p;p;map{$p{$_}=~/^[P.]/&&
close$_}%p;wait until$?;map{/^r/&&<$_>}%p;$_=$d[$q];sleep rand(2)if/\S/;print
```

?! print "Just another Perl / Unix hacker";

- Mathematical analysis of programs and circuits:
  - Formal verification
  - Model checking
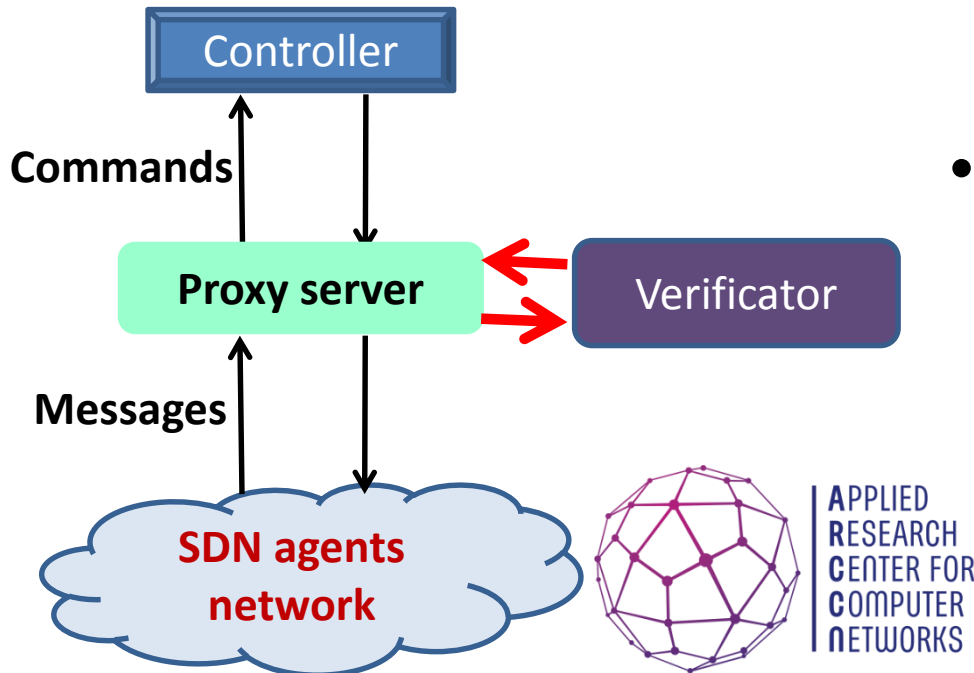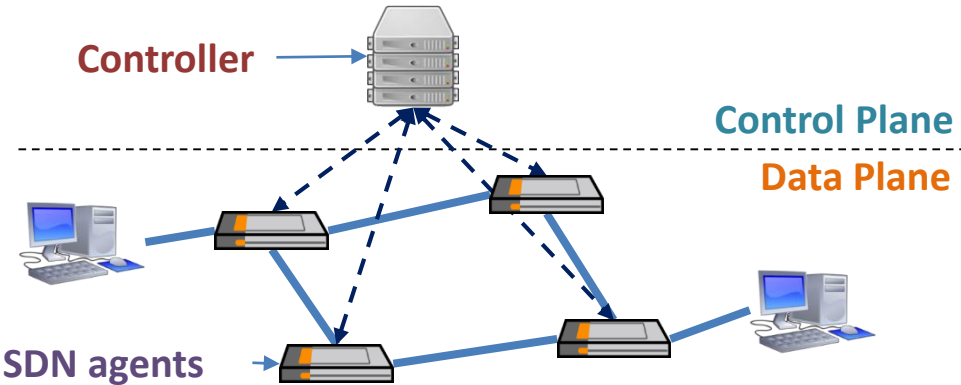 - Obfuscation
  - Static analysis
  - Equivalence checking

- Collaboration with CMC MSU laboratory of computer systems (2010-2012)

Input

$\pi_1 \to Output_1 = \pi_1(Input)$

$\overset{?}{\parallel}$

$\pi_2 \to Output_2 = \pi_2(Input)$

Applied research

- Software-defined networks (SDN):
  - Development of verification and reconfiguration methods for SDNs

- In collaboration with Center of Applied Research of Computer Networks (2013-2014)

Research statistics

- Funding
  - Internal MSU funding program
  - Russian Foundation for Basic Research – 2 grants
- Publication statistics (for year 2015):
  - 1 publication in journal indexed as top 25% by Web of Science
  - 10 publications in journals indexed by Web of Science and Scopus
  - 12 publications in top Russian journals
  - 15 publications in conference proceedings
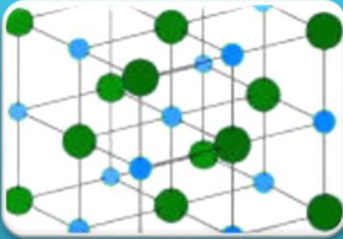- 3 successful Ph.D. equivalent thesis defended in 2015

Structure of educational programs

 2 year undergraduate program in Computer science and Mathematics supported by the Department of Computational Cybernetics (Bachelor's degree)
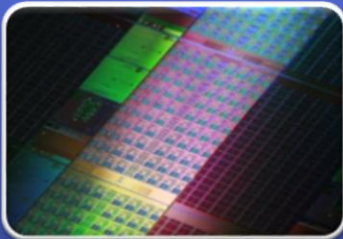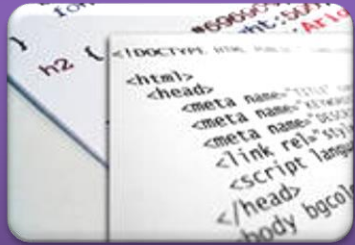
 2 year graduate program "Mathematical Theory and Applications of Discrete Control Systems" (Master's degree)
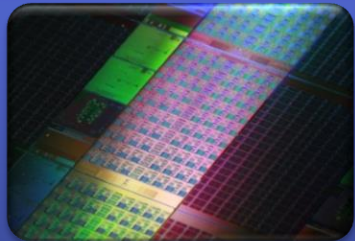
 4-x Ph.D. equivalent program in discrete mathematics and cybernetics (Ph.D. equivalent in physics and mathematics – candidate's degree)
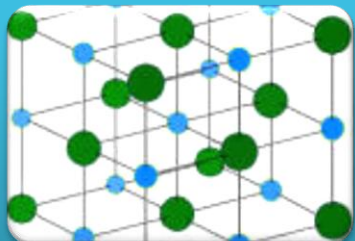
Master's program overview

Practical and programming track

- Data structures and algorithms for VLSI
- Industrial C++ programming
- Hands-on FPGA-based circuit design labs

VLSI CAD and design track

- Hardware design languages
- Advanced computer architecture
- Logic and physical design

Theoretical track

- Theory of control systems (analysis, synthesis and testing)
- Formal verification and analysis of programs and circuits
- Mathematical models of sequential computations

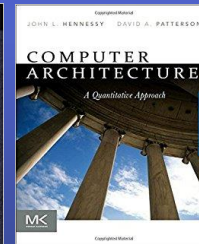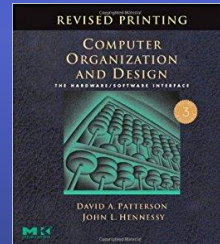# Structure of VLSI design track

Hardware description languages

- Introduction to Verilog HDL
- Design of simple one-cycle processor
- Introduction to MIPS instruction set architecture

Advanced computer architecture

- Pipelined processors
- In-order and out-of-order execution
- Memory caches and virtual memory

FPGA-based VLSI design labs

- FPGA prototyping of a microprocessor
- Hardware implementation of algorithms
- Analysis and modifications of MIPSfpga processor

Invited lectures

- Spring 2013: Two week intense course "VLSI Physical Design: From Graph Partitioning to Timing Closure" by Igor Markov (University of Michigan, USA)

- 40 students from MSU and other top universities in Moscow attended the course
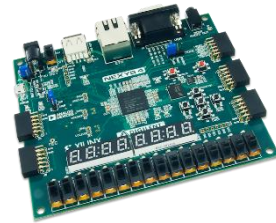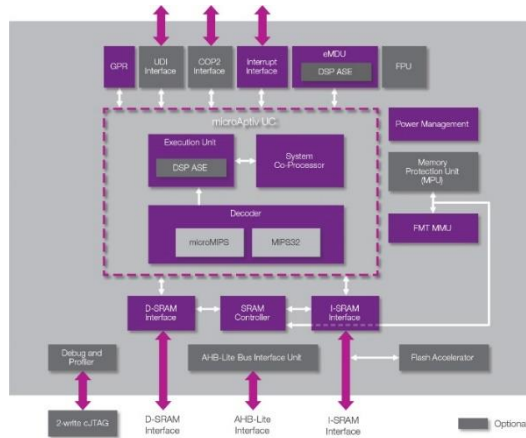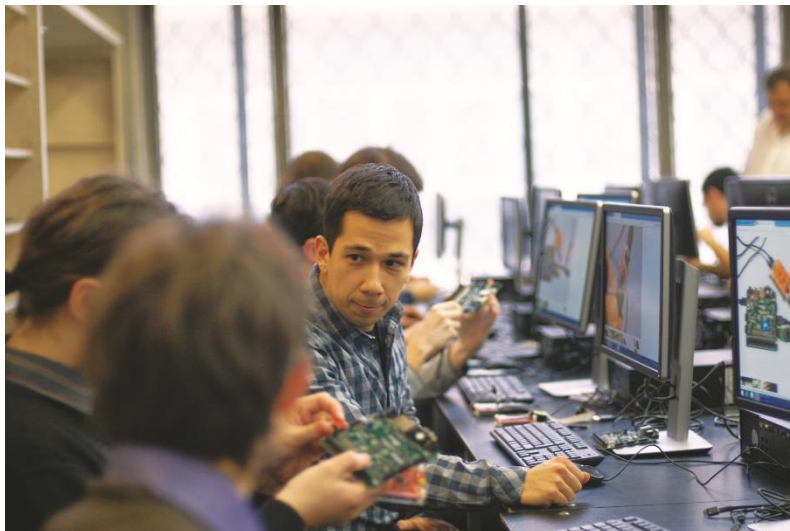
Invited lectures

- Spring 2016: Two week intense course "SAT/SMT solvers and their Application in Software Engineering" by Vijay Ganesh (University of Waterloo, Canada)

- 12 students from MSU attended the course
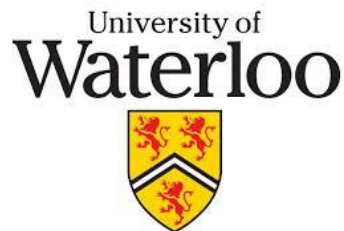
MIPSfpga workshops

- Autumn 2015 and 2016: MIPSfpga workshops in collaboration with Imagination Technologies

International VLSI CAD contests

- MSU students teams annually participate in ICCAD CAD Contest at ICCAD since 2013
- In 2015 MSU team placed 1st in one of the contest's problems

Relations with industry

Mentor Graphics

- **Lectures by Mentor Graphics in the field of physical design CAD**
- **Ph.D. graduates work in Moscow office**
- **Internships for Master's program students**

Cadence

- **Joint seminars and presentations in the VLSI CAD field**
- **Internships and job opportunities for Master's program students**

Intel

- **Joint student laboratory Intel-CMC**
- **Research projects in the past**
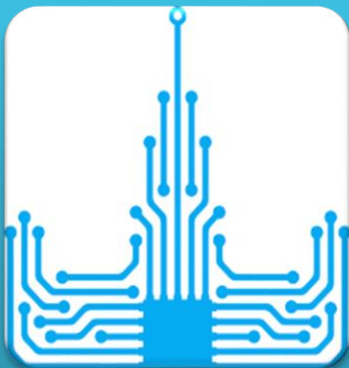- **Lectures by Intel in the field of computer architecture**

IC related centers in MSU

Skobeltsyn institute of nuclear physics

- **Cadence tools license via EUROPRACTICE**
- **Nucleon project – study of super heavy cosmic ray nuclei**

Engineering physics laboratory MSU Faculty of Physics

- **Master's program in microcontrollers programming and FPGA prototyping**
- **MALT system project – multicore system of lightweight microprocessors**