Computer Systems Research

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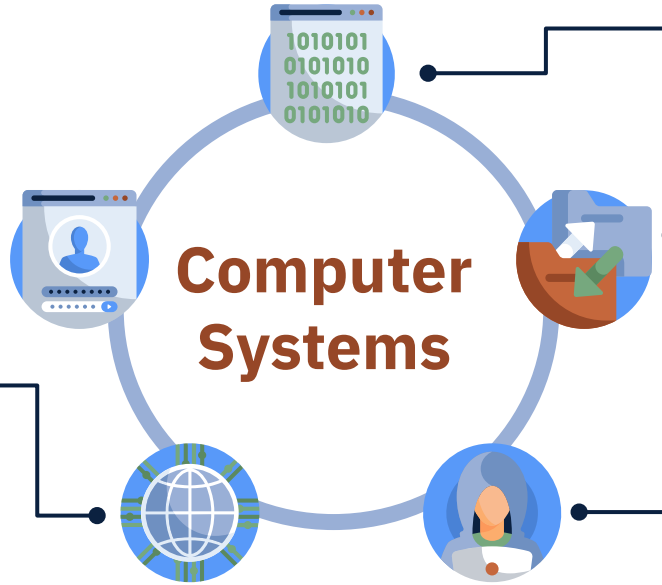
Computer Systems

Infrastructure building
Think of building roads
(instead of Burj Khalifa!)

- Performance
- Power/Energy efficiency
- Security
- Reliability
- Verification

Overview



Hardware

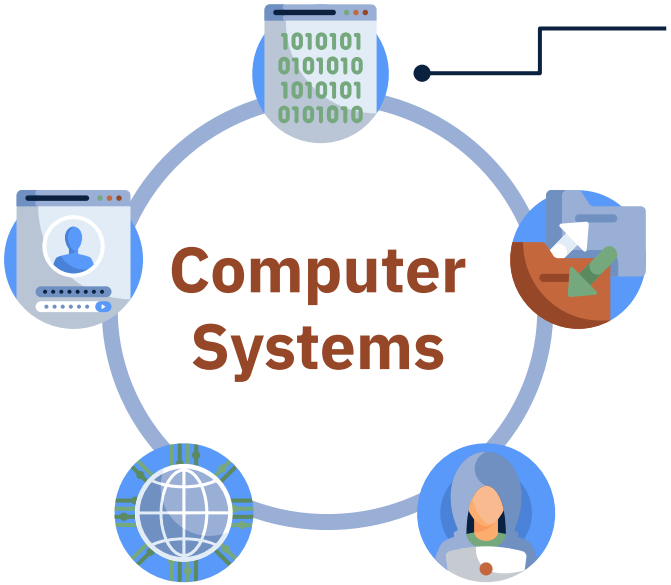
Applications

Operating Systems

Networks

Compilers

Overview



Hardware

CPU/GPU/FPGA/Accelerators
Design, Design Automation,
Security

Research in Hardware

✖ Myth

Hardware is for Electronics Engineers!

✔ Truth

Hardware Design is done using tools and we need CS knowledge to build those tools

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Hardware Design is done using tools and we need CS knowledge to build those tools

Takeaway 1:
Research has no stream!
(but only expertise)

Research in Hardware

- Shrinking transistor sizes over the years enabled a large diversity of devices
  - Multi-core CPUs
  - GPUs
  - FPGAs, Custom Accelerators (Domain specific accelerators)

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  - 3 GHz clock speed ≈ Light travels only 4 inches

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  - GPUs
  - FPGAs, Custom Accelerators (Domain specific accelerators)
- Transistors are already very small
  - 3 GHz clock speed ≈ Light travels only 4 inches
- Future performance or Energy efficiency improvements
  - Better system design and architecture
  - Better tools (HL-HDLs, Synthesis Tools)
- Security
  - Mitigate side-channel attacks
  - Enclaves

Research in Hardware

```
 i1: 0x488d36: and eax, 0x8000
 i2: 0x488d3b: jne 0x488d93
 i3: 0x488d3d: mov rdx, QWORD PTR [rdi+0x88]
 i4: 0x488d44: mov r8, QWORD PTR fs:0x10
 i5: 0x488d4d: cmp r8, QWORD PTR [rdx+0x8]
 i6: 0x488d51: je  0x488d8f
 i7: 0x488d8f: add DWORD PTR [rdx+0x4], 0x1
 i8: 0x488d93: mov rax, QWORD PTR [rbx+0x8]
 i9: 0x488d97: cmp rax, QWORD PTR [rbx+0x10]
          . . .
i10: 0x488d53: mov esi, 0x1
i11: 0x488d58: cmp DWORD PTR [rip+0x353309], 0x0
i12: 0x488d5f: je  0x488d84
i13: 0x488d84: mov rdx, QWORD PTR [rbx+0x88]
i14: 0x488d8b: mov QWORD PTR [rdx+0x8], r8
```

Research in Hardware

Execution without branch prediction

Execution with CORRECT prediction

Execution with INCORRECT prediction

Research in Hardware

Branch Predictor Designs

Algorithmic

- Counters
- History Tables
- Lookup and update rules

ML-Based

- Perceptrons (2001)
- Q-learning based

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Takeaway 2:
Solutions to challenges could be from any (sub)domain!

Research in Hardware

- Methodology and Tools
  - Workload Characterization (DynamoRIO, QemuTrace)
  - Simulations (Gem5, Tejas, Sniper, GPGPU-sim, mcpat, Hotspot)
  - Modeling (SystemC, Bluespec, Chisel, Clash)

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- Conference/Workshops/Schools
  - Computer Architecture Winter School (CAWS)
  - ISCA, HPCA, MICRO, ...
  - DAC, DATE, ICCAD, ...
  - VLSI Design, HiPC

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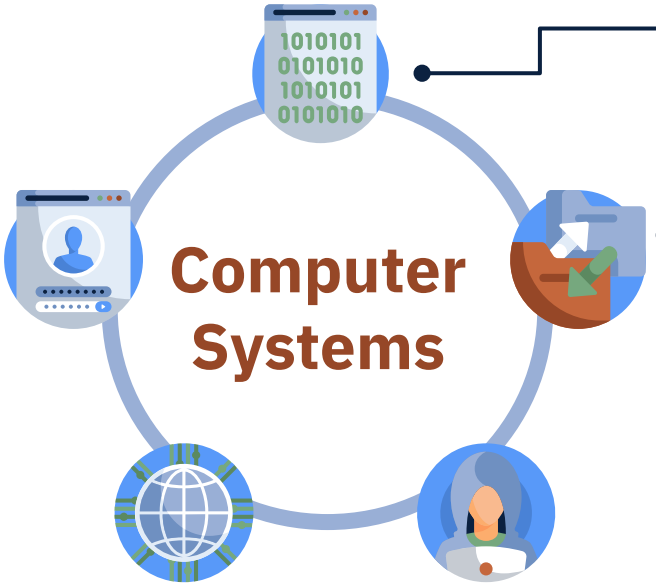

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Operating Systems

OS Design, Virtualization, Storage Systems, Security

Research in Operating Systems

Research Topics:

- OS Design
  - Performance improvements (better VM implementations)
  - Managing Non-volatile Memory (NVMs) and hybrid memory systems
  - Power/energy management
  - Virtualization
- Correctness
  - Race conditions (in-GPU, in-distributed systems)
  - Automatic bug detection techniques
- Consistency in Storage systems (think filesystems)
- Security

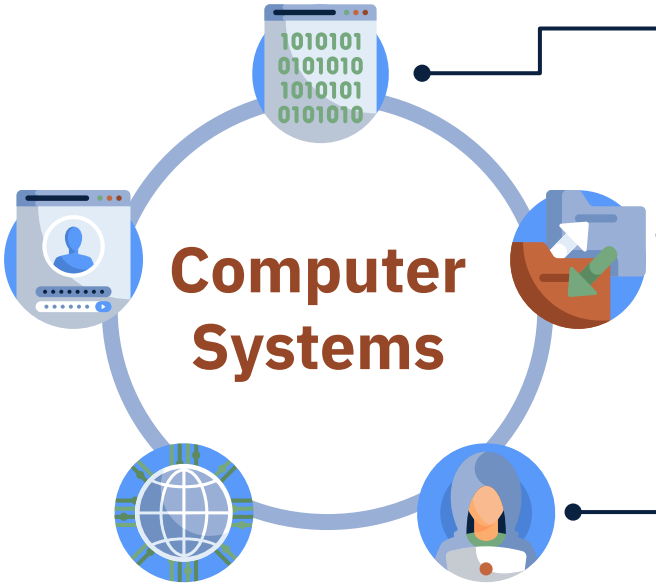
Research is now closely tied with formal verification methods

Research in Operating Systems

- Tools/Frameworks
  - Most operating systems are open-source
  - Linux, FreeRTOS
  - Qemu, VirtualBox

- Conferences/Workshops
  - OSDI, SOSP, ASPLOS, Usenix conferences, ...
  - Summer workshops in the country

Overview



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Domain Specific Languages, Compilation to Heterogeneous architectures, auto-parallelization

Research in Compilers

- Explosion in heterogeneity of computational machines
  - Multi-cores, GP-GPUs, Domain Specific Accelerators
  - Distributedness (Data-center and HPC workloads)

- Multiple objectives (guaranteeing correctness)
  - Single-thread performance
  - Auto parallelization
  - Energy optimization

- Explosion in programming languages
  - New classes of applications
  - Domain-specific languages

Research in Compilers

- Tools/Frameworks
  - LLVM
  - ApacheTVM
  - SeaStar
  - MLIR
  - GCC

- Conferences/Workshops
  - POPL, PLDI, ASPLOS, CASES, ...

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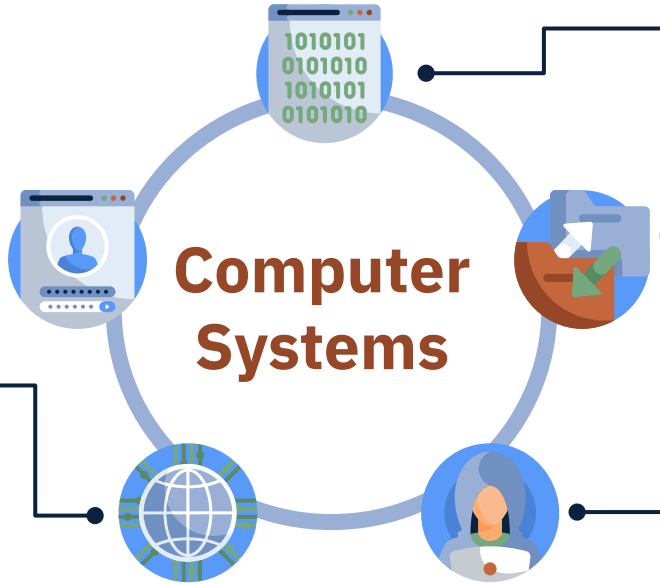

Hardware

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Networks

Distributed systems, Security, IoT frameworks, Privacy, 5G/6G

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Domain Specific Languages, Compilation to Heterogeneous architectures, auto-parallelization

Research in Networks

- Number of networked devices have increased manifold
  - Managing networked devices
  - Managing network policies
  - QoS guarantees
- Infrastructure-free networks
- Vehicular networks, IoT
- Security
- Network forensics

Research in Networks

- Techniques/Tools/Frameworks
  - Queueing theory, Game Theory, AI/ML
  - Kali Linux
  - NS3, OpenFlow
  - WireShark
  - IoT
    - Arduino, NodeMCU, Raspberry Pi, ...
    - Dockers

- Conferences/Workshops
  - Usenix NSDI
  - INFOCOM, GlobeCOM, NCC,
  - Comsnets, SIGCOMM

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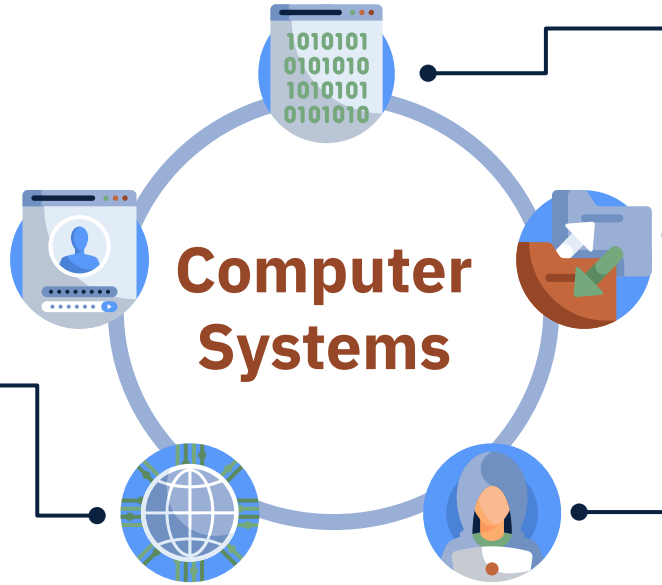


Computer Systems

Hardware

CPU/GPU/FPGA/Accelerators
Design, Design Automation,
Security

Applications

Scalability, Consistency,
Persistence

Operating Systems

OS Design, Virtualization,
Storage Systems, Security

Networks

Distributed systems, Security,
IoT frameworks, Privacy, 5G/6G

Compilers

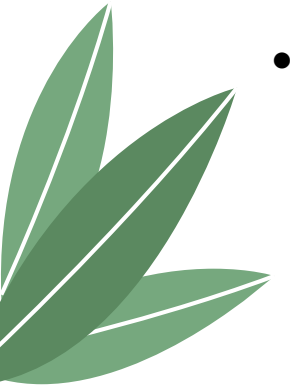
Domain Specific Languages,
Compilation to Heterogeneous
architectures, auto-parallelization

Research Spectrum

- Only 20-25% of Computer Systems PhDs are in Academia (rest are in the industry)
  - Industry for Computer Systems researchers is (largely) recession-proof as well as future-proof
- State-of-the-art
  - Latest and greatest system available
- Industrial research is 3-5 years ahead of state-of-the-art
  - Translational in nature
  - Directions governed by profits
- Academic research is several years ahead of the state-of-the-art
  - Reasonable assumptions about future
  - Never decoupled from Industrial Trends

Skills Necessary

- Programming
  - Version control (git)
  - Competitive programming (not sufficient)
  - Modular, Readable programs
  - Familiarity with a framework is an added advantage
- Techniques
  - Algorithms, Logic, AI/ML
- Patience! (and plenty of it)



Your Journey Starts Here!

Explore

Read as much as possible

Try

Get your hands Dirty!

Apply

Spray and Pray!

Work

Dedicate time and effort on solving problems

Master

CD/CI
Continuous Development/
Continuous Improvement

Thanks!

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