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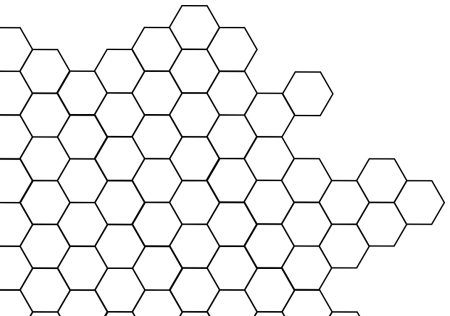
Overview of Research in the HExSA Lab @ IIT

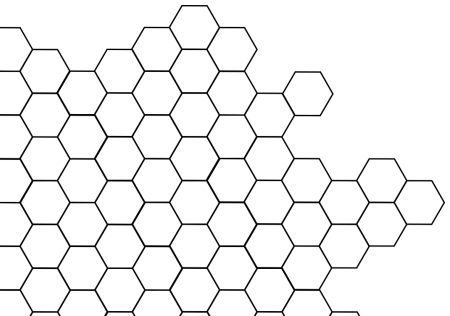
Laboratory for High-performance Experimental Systems and Architecture

PI: Kyle C. Hale

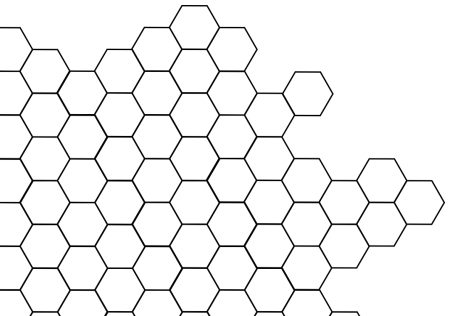


Three Primary Themes

- **High-performance Operating Systems,** runtime systems, and virtual machines
- **Novel programming languages and runtimes** for parallel and experimental systems
- **Experimental and high-performance computer architecture**



Current thrusts



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High-performance Operating Systems and Virtual Machines

- **Nautilus** and Hybrid Runtimes (**with Prescience Lab @ Northwestern**)
- Compiler + Kernel fusion [**The Interweaving Project**] (**with CS groups @ Northwestern**)
- Hybrid Runtime for Compiled Dataflows [**HCDF**] (**with DBGroup @IIT**)
- Address Space Dynamics
- **High-performance Virtualization** [Wasp hypervisor, Palacios VMM[3] and Pisces Cokernels[4]] (**with Prescience Lab @ Northwestern; Prognostic Lab @ Pitt**)
- High-performance networking
- Accelerated Asynchronous Software Events [**Nemo**]
- Computational Sprinting and AI (with U. Nevada, Reno and OSU)

Nautilus and HRTs

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- High-performance ***Unikernel for HPC, parallel computing***[1]
- ***Hybrid Runtime (HRT)***[2] = parallel runtime system + kernel mashup
- Lightweight, fast, single-address space Operating System
- ***Designed to make parallel runtimes efficient and well-matched to the hardware***
- Sponsored by NSF, DOE, and Sandia National Labs
- Collaboration with Prescience Lab[3] at Northwestern

Northwestern University

HOBBES
xstack.sandia.gov/hobbes

Sandia National Laboratories

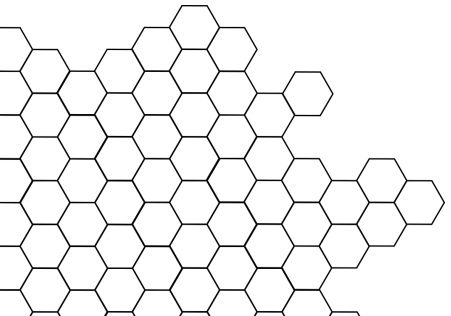
[1]http://presciencelab.org
[2]https://nautilus.halek.co
[3]http://users.eecs.northwestern.edu/~kch479/docs/nautilus.pdf

Virtines

- Don’t isolate at the granularity of a machine
- Virtualize ***functions***! (Virtual subroutines = virtines)

```
virtine int foo() {
    // isolated compute
    return 0;
}
```

this runs in its own, fully isolated, single-use VM!



The Interweaving Project[1]

- Unikernels provide a new opportunity for *combining kernel, user, and runtime code*
- ***Interweave*** them into one binary
- Compiler generates OS code, driver code
- ***Compiler/Runtime/OS/Architecture Co-Design***
- Collaboration with Prescience Lab, PARAG@N Lab, and Campanoni Lab @ Northwestern
- NSF sponsored, $1M, 4 PIs

[1]https://interweaving.org

Northwestern University

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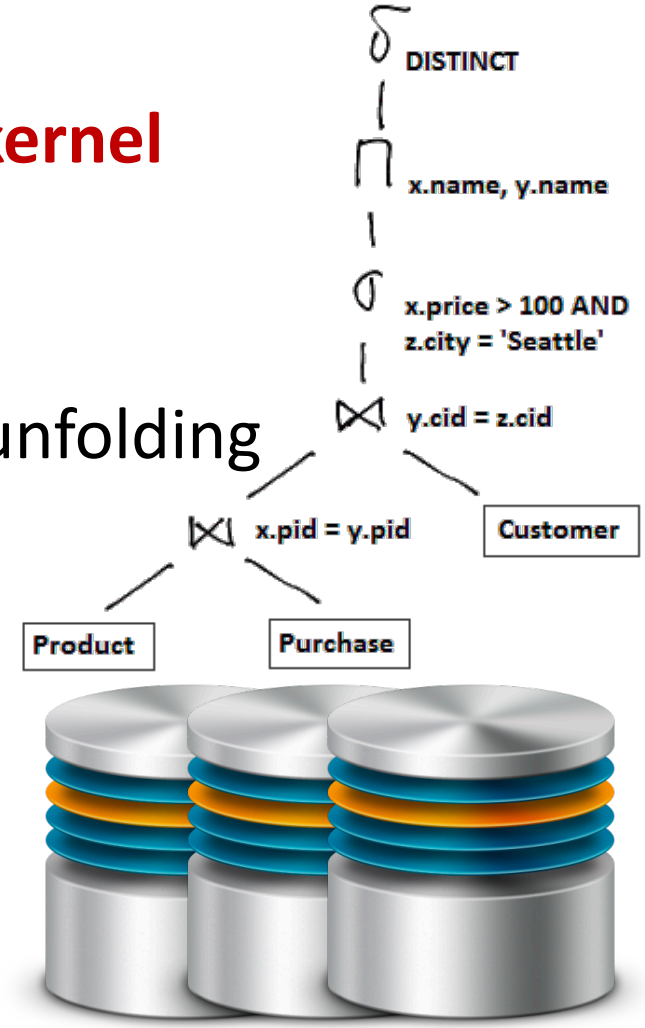
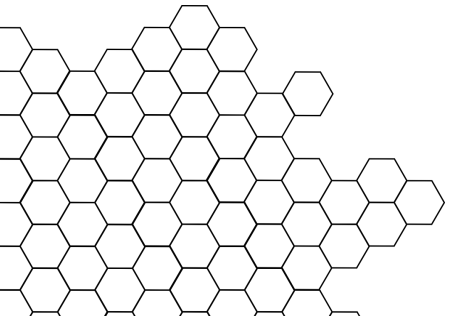
Hybrid Runtime for Compiled Dataflows (HCDF)

- **Co-Design database engine and operating system kernel**
- Compiled queries placed into tasks, scheduled onto specialized hybrid runtime in an OS kernel
- **Runtime extracts parallelism and performance** by unfolding query task graph and tailored hardware access
- Collaboration with DB Group @ IIT

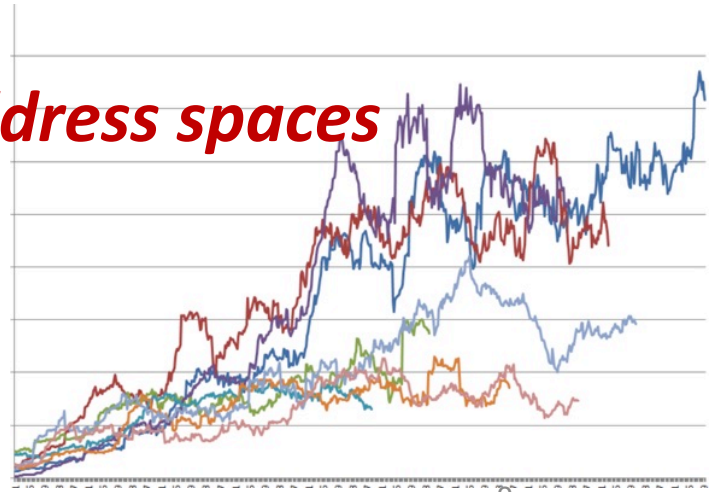




DBGroup

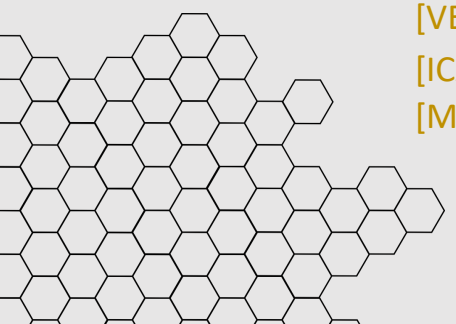
Address Space Dynamics

- Ubiquitous virtualization is putting pressure on address translation hardware and software
- New chip designs also pressing the issue (5-level PTs in next-gen Intel chips)
- We're looking at ***new address translation mechanisms*** (Interweaving Project) [MASCOTS '18]
- These may require understanding ***the structure of address spaces over time***
- ***Can we discover this dynamic structure?***



Multi-kernel Systems for Supercomputing

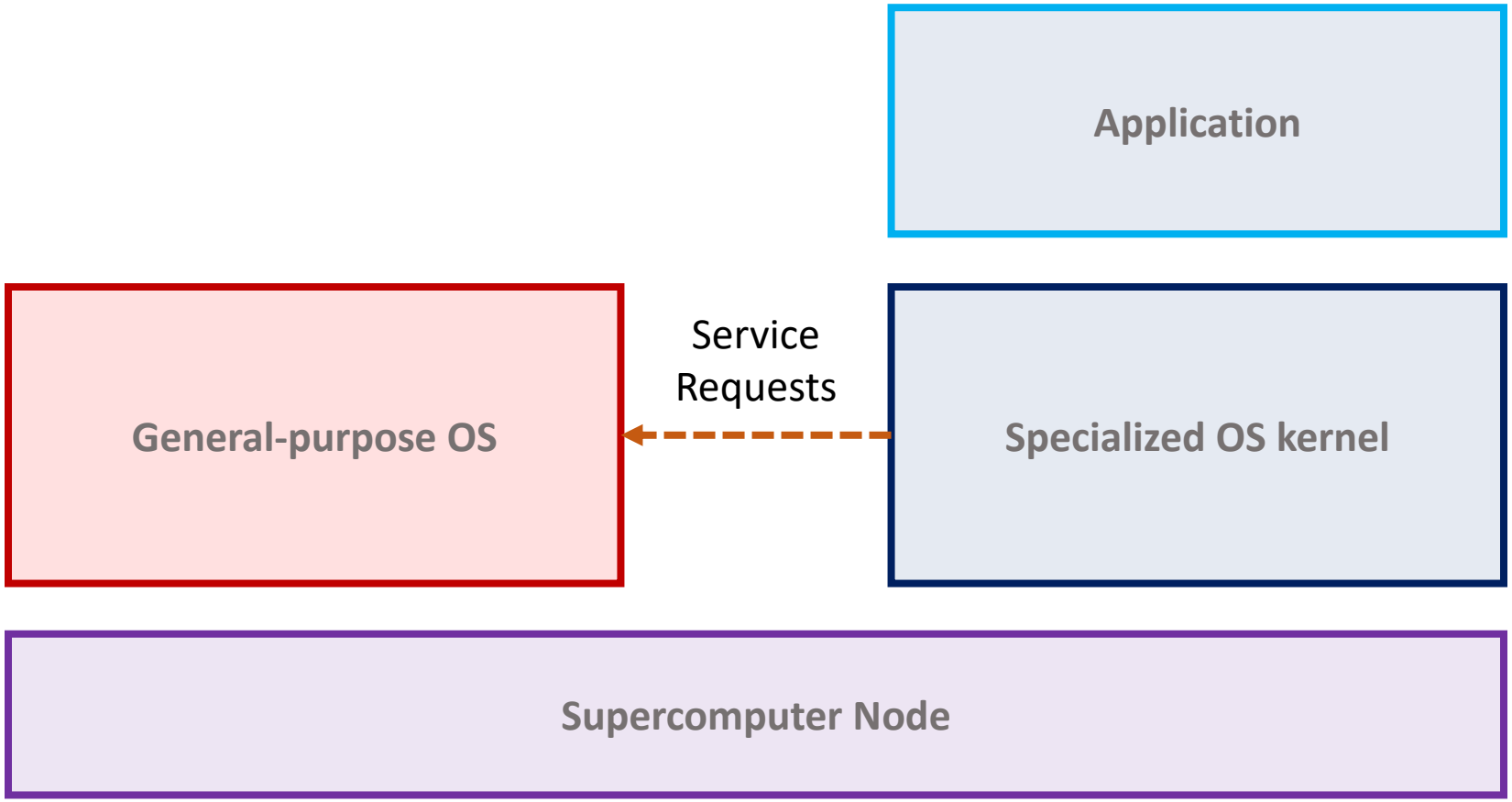
- **Hybrid Virtual Machines[1]** (multi-kernel VMs) [VEE '16]
- **Multiverse:** run legacy apps. on a multi-kernel VM [ICAC '17]
- Modeling system call delegation (**Amdahl's Law for multikernels**] [MASCOTS '19]
- **High-performance Virtualization** [Wasp VMM, Palacios VMM and Pisces Cokernels]
- Coordinated kernels as containers [**SOSR Project**]



[VEE '16] K. Hale, P. Dinda, Enabling Hybrid Parallel Runtimes Through Kernel and Virtualization Support
[ICAC '17] K. Hale, C. Hetland, P. Dinda, Multiverse: Easy Conversion of Runtime Systems into OS Kernels via Automatic Hybridization.
[MASCOTS '19] B. Tauro, C. Liu, K. Hale, Modeling Speedup in Multi-OS Environments.

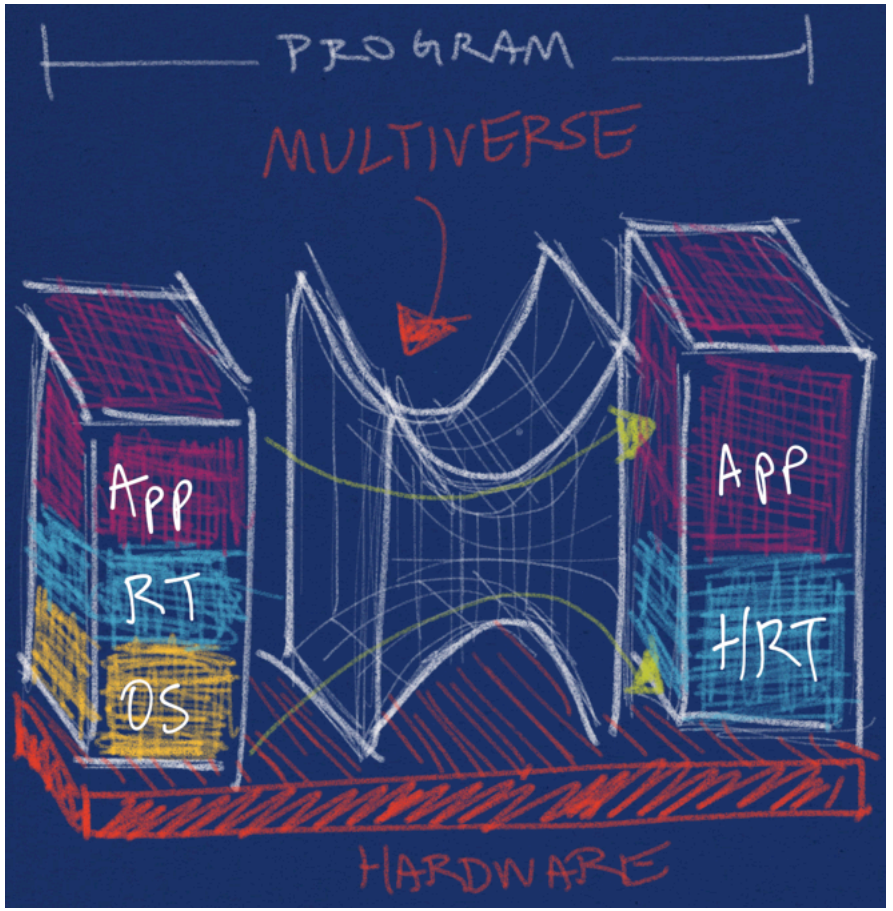
[1]http://pdinda.org/Papers/vee16.pdf

The Multikernel Approach



Multiverse[1]

- Typically must *port* your parallel program to run in Multikernel environment
- **We automatically port legacy apps to run in this mode**
- Uses a ***virtualized* multikernel** approach
- Working example with the Racket[2] runtime system [ICAC '17]



[ICAC '17] K. Hale, C. Hetland, P. Dinda, Multiverse: Easy Conversion of Runtime Systems into OS Kernels via Automatic Hybridization.

[1]http://cs.iit.edu/~khale/docs/icac17-multiverse.pdf
[2]https://racket-lang.org

Coordinated SOS/Rs for the Cloud

- Specialized Operating Systems and Runtimes (SOS/Rs) (e.g. Unikernels) are difficult to use!
- Leverage programming model and interface of ***containers*** to ease this problem => ***Containerized Operating Systems*** [ROSS '19]
- Treat a collection of SOS/Rs within a single machine as a distributed system (requires coordination)
- Collaboration with Prognostic Lab @ Pitt
- NSF-sponsored, $500K (2 PIs)

Pisces
Isolated Lightweight Co-kernels

University of Pittsburgh

Novel Languages and Runtimes for Parallel and Experimental Systems

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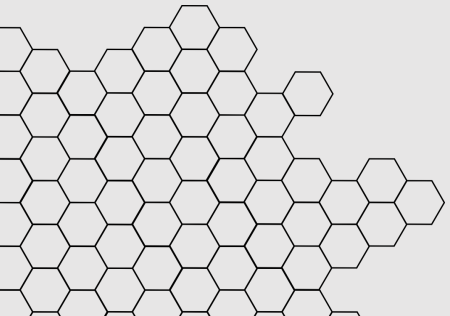
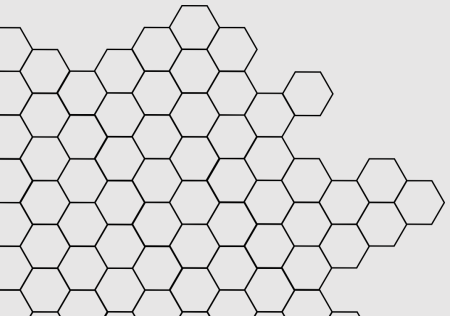
- Exploration of **Julia for large-scale**, parallel computing
- **New systems languages**
- **New virtual machine architectures** for dataflow-oriented programming models (virtual, spatial computing)



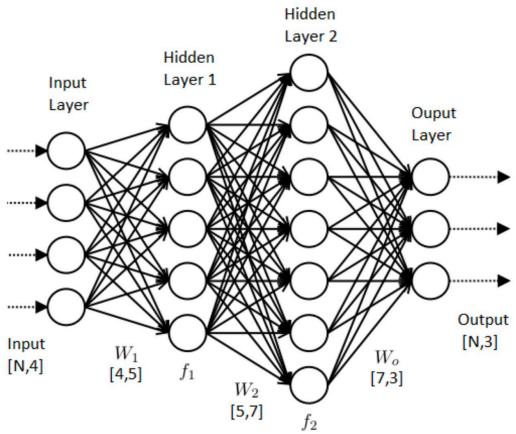
Experimental Computer Architectures

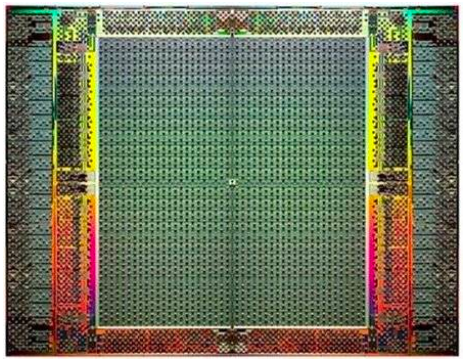
- **State-associative prefetching**: using neuromorphic chips to prefetch data between levels of deep memory hierarchies
- **DSAs for Hearing** Assistance [**with collab. at Interactive Audio Lab @ Northwestern**]
- **Incoherent Multicore Architectures** (**with CS @ Northwestern**)
- Next generation near-data processing systems (CPUs near memory in a mini-distributed system) **(with Rujia Wang and Xian-He Sun, and U. Iowa)**



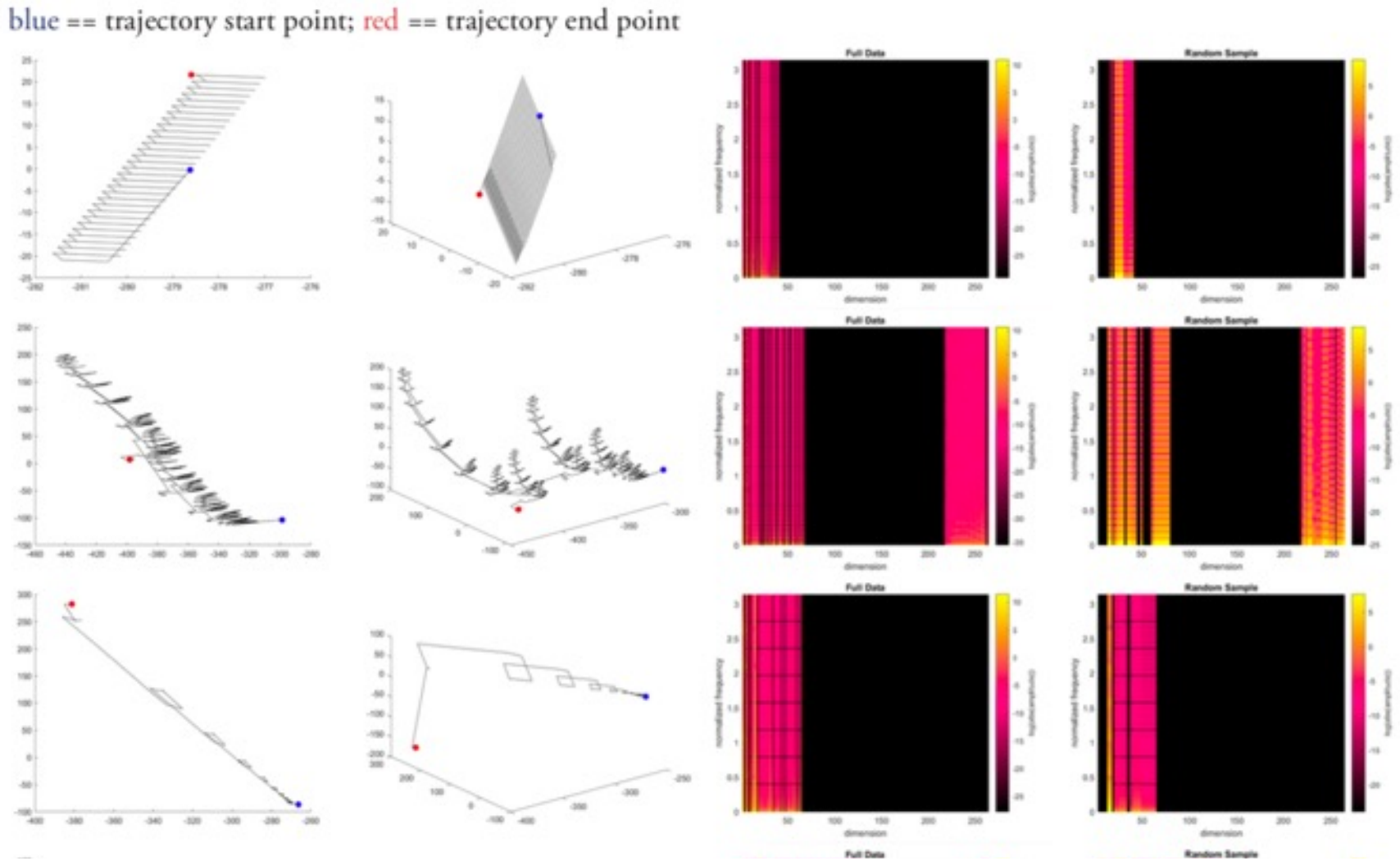
AI-based, Domain-Specific Architectures for Hearing Assistance

- "**Cocktail problem**": Identify speaker in a crowded (loud) room
- **Brain is very good at this**
- **Hearing aids *are not*** (they typically apply some pretty simple signal processing)
- We're looking to design a **new chip architecture for hearing aids based on audio source separation** (a machine learning-based technique)



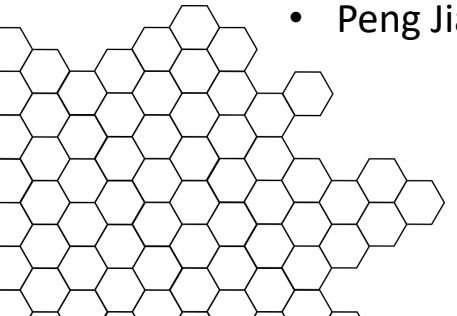


Exploring program dynamics



Collaborators

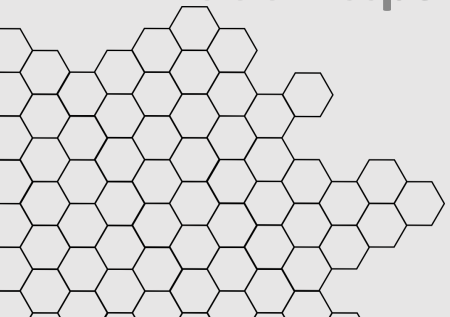
- **IIT**
  - Scalable Systems Laboratory (Xian-He Sun)
  - DB Group (Boris Glavic)
  - DataSys Lab (Ioan Raicu)
  - CALIT Lab (Rujia Wang)
- **Northwestern University**
  - Prescience Lab (Peter Dinda)
  - PARAG@N Lab (Nikos Hardavellas)
  - Campanoni Lab (Simone Campanoni)
  - Interactive Audio Lab (Brian Pardo)
- **University of Pittsburgh**
  - Prognostic Lab (Jack Lange)
- **Ohio State University**
  - ReRout Lab (Christopher Stewart)
  - PACS Lab (Xiaorui Wang)
- **University of Iowa**
  - Peng Jiang
- **University of Nevada @ Reno**
  - IDS Lab (Feng Yan)
- **University of Chicago**
  - Kyle Chard
  - Justin Wozniak
- **Carnegie Mellon University**
  - Umut Acar
  - Mike Rainey
- **Sandia National Laboratories**
  - Kevin Pedretti
- **Pacific Northwest National Laboratories**
  - High Performance Computing Group (Roberto Gioiosa)



We're hiring!

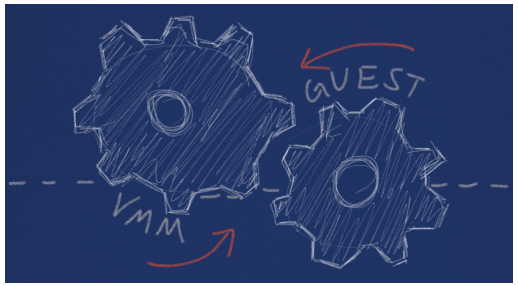
Funded opportunities available (both PhDs and undergrads!)

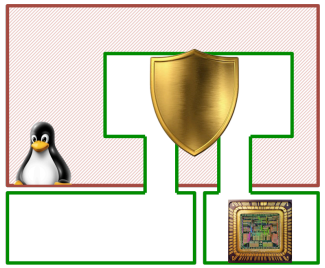
See **https://halek.co**

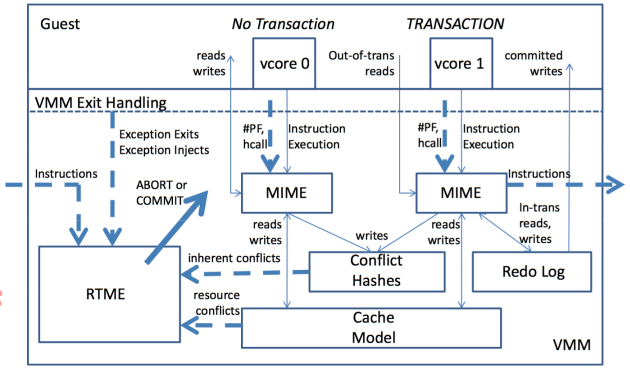


Completed Projects

- Philix Xeon Phi OS Toolkit[1]
- Palacios VMM[2]
- Guest Examination and Revision Services (GEARS[3])
- Guarded Modules[4]
- Virtualized Hardware Transactional Memory[5]

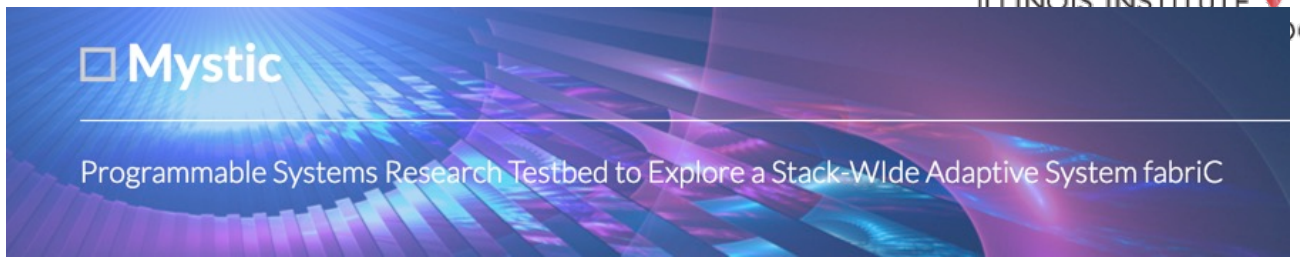






[1]http://philix.halek.co
[2]http://v3vee.org/palacios
[3]http://users.eecs.northwestern.edu/~kch479/docs/gears.pdf
[4]http://users.eecs.northwestern.edu/~kch479/docs/gm.pdf
[5]http://users.eecs.northwestern.edu/~msw978/resources/palacios-htm.pdf

Cool hardware



- **HExSA Rack**
  - Newest Skylake and AMD Epyc machines (many-core)
  - Designed for booting OSes
- **Supercomputer Access**
  - Stampede2 Supercomputer @ TACC
  - Comet Cluster @ SDSC
  - Jetstream Supercomputer @ IU
  - Chameleon Cloud

- **MYSTIC Cluster**
  - 8 Dual Arria 10 FPGA systems
  - 8 Mellanox Bluefield SoC systems
  - Newest ARM servers
  - IBM POWER9
  - Xeon Scalable Processor systems
  - 16 NVIDIA V100 GPUs
  - 100Gb internal network (Infiniband and 10GbE)

Relevant Courses

- **CS 450**: Operating Systems
- **CS 562**: Virtual Machines (last taught F'19, next maybe S '21?)
- **CS 595**: Research Seminars
  - Previously: OS and Runtime System Design for Supercomputing
  - Next time (F '21?): Serverless and Edge Computing
- **CS 551**: Operating System Design and Implementation (grad OS, I'm not teaching this yet)
- **CS 497**: Try out research with me