


ILLINOIS INSTITUTE OF TECHNOLOGY

High-Performance Computing Research

Zhiling Lan
Professor of Computer Science
lan@iit.edu
Office: 208E



ILLINOIS INSTITUTE OF TECHNOLOGY

Self Introduction

- **Ph.D. in Computer Engineering**, Northwestern University, 2002
- **Professor** of Computer Science
- **Guest Research Faculty** at Argonne National Lab
- **Research Interests:** high-performance computing (HPC), parallel and distributed systems
 - <http://www.cs.iit.edu/~lan>

2

ILLINOIS INSTITUTE OF TECHNOLOGY

My Research Group

Welcome to the SPEAR (Systems for Performance, Energy, And Resiliency) team's web page!

The team conducts research spanning various areas of parallel and distributed systems including cluster management, interconnection networking, performance modeling and simulation, power and energy efficiency, and fault tolerance. Our mission is to design scalable methods and software for large-scale HPC, AI, and data analysis. The team has a strong collaboration with the ALCF and MCS divisions at Argonne National Lab.







3

ILLINOIS INSTITUTE OF TECHNOLOGY

Students

▪ **Current**

- Yuping Fan (PhD)
- Xin Wang (PhD)
- Yao Kang (PhD)
- Boyang Li (PhD)
- Melanie Cornelius (MS=>PhD)
- Matt Dearing (PhD)
- Dustin Favorite (MS)
- Sahil Sharma (BS/MS)
- Zhong Zheng (BS/MS)

▪ **Alumni**

- Eduardo Berrocal (PhD, Intel)
- Sean Wallace (PhD, Cray Inc.)
- Xu Yang (PhD, Amazon)
- Li Yu (PhD, Google)
- Zhou Zhou (PhD, Salesforce)
- Wei Tang (PhD, Google)
- Ziming Zheng (PhD, Tripadvisor)
- Jingjin Wu (PhD, Global Energy Research Institute)
- Yawei Li (PhD, Google -> Uber)
- Yongen Yu (MS, VMWare)
- Jiexin Gu (MS, Google)
- ...

4

What is High-Performance Computing

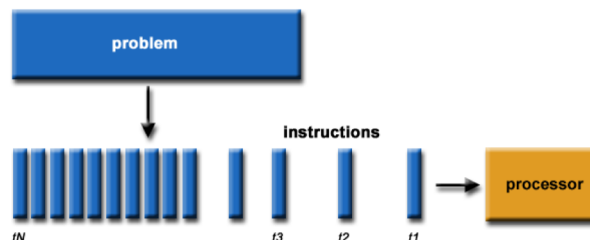
- Aka **supercomputing**
- Use of **supercomputers** for running *advanced applications* efficiently, reliably and quickly
 - **Supercomputer:** high-end computer with extremely fast processing capabilities, usually contains many processors
 - **Application:** typically from the fields of science and engineering, e.g., CFD, weather forecasting, ...
 - Emerging AI, data analytics, IoT
 - **Parallel processing:** to divide a large problem into smaller ones to be solved concurrently



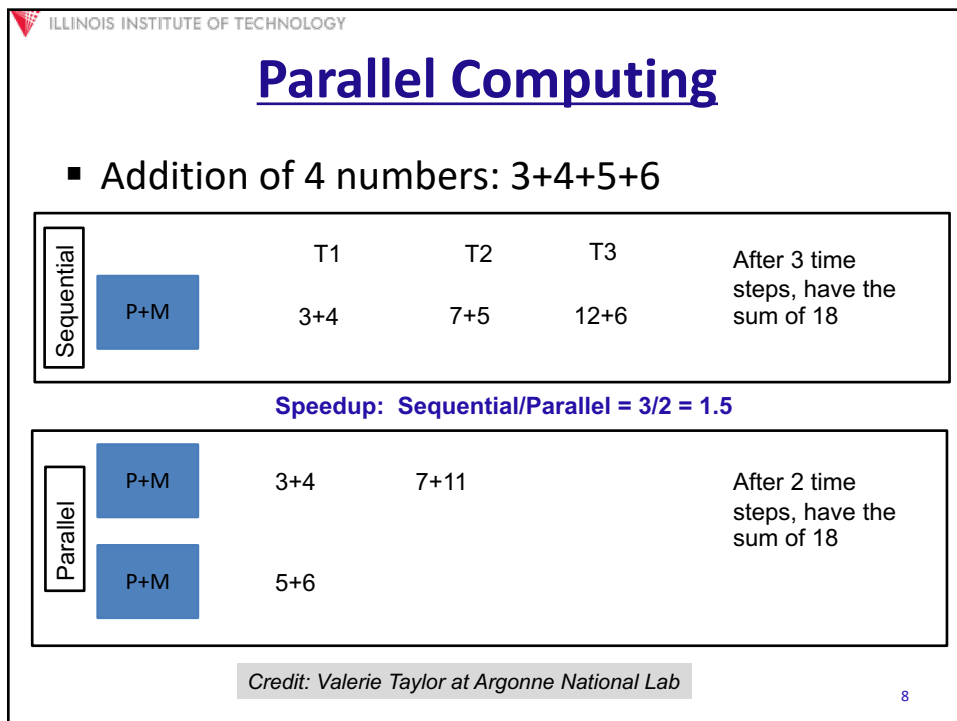
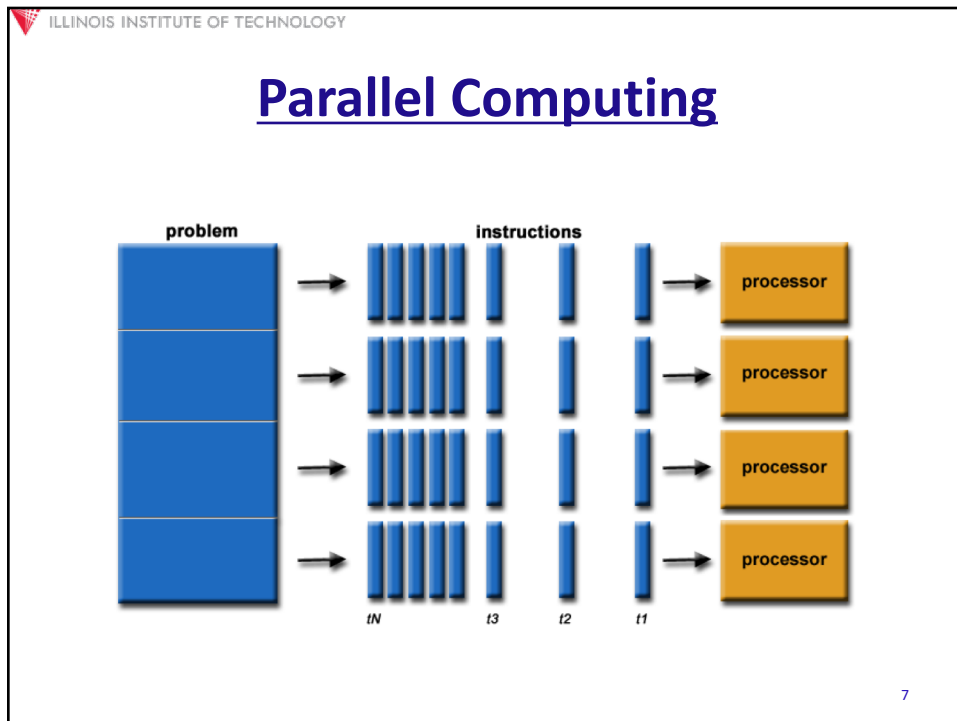
5

Serial Computing

- Traditional, software has been written for serial computation
 - A problem is broken into a discrete series of **instructions**
 - Inst. are executed sequentially (one after another)
 - Executed on a single processor
 - Only one inst. executes at any moment in time



6



ILLINOIS INSTITUTE OF TECHNOLOGY

Scale Up: Problem Size & Processors

Numbers to Add	Speedup 2 Processors
4	1.5
20	1.9
40	1.95
200	1.99
400	1.995

Number of Processors (400 Numbers)	Speedup
2	1.995
4	3.95
16	14.25
32	23.47
64	33.25

9

ILLINOIS INSTITUTE OF TECHNOLOGY

Parallel Processing: Add Communication

Sequential

	T1	T2	T3	
P+M	3+4	7+5	12+6	After 3 time steps, have the sum of 18

Speedup: Sequential/Parallel = 3/12 < 0.25

Parallel

P+M	3+4	<div style="position: relative; height: 40px;"> </div>	7+11	After 12 time steps, have the sum of 18
P+M	5+6		10 cycles	

10

Scale Up: With Communication

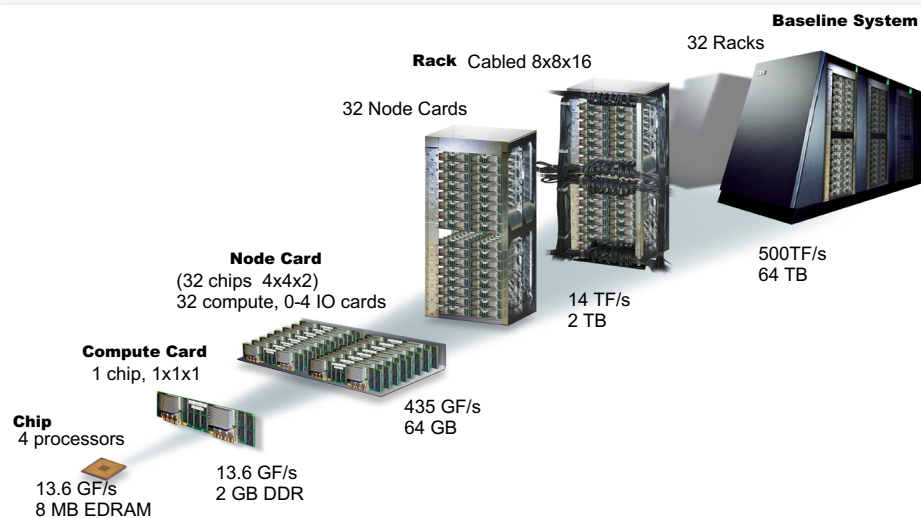
Numbers to Add	Speedup 2 Proc	With Comm	Number of Processors (400 Numbers)	Speedup	With Comm
4	1.5	0.25	2	1.995	1.90
20	1.9	0.95	4	3.95	3.30
40	1.95	1.30	16	14.25	8.31
200	1.99	1.81	32	23.47	5.96
400	1.995	1.90	64	33.25	5.41



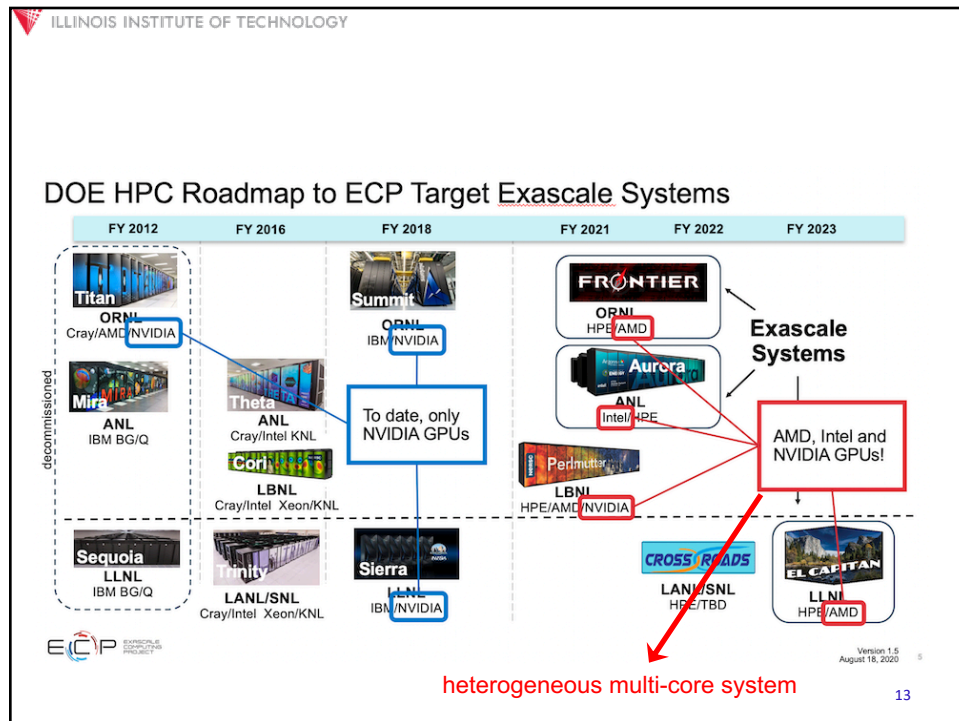
Parallel programming is challenging!

11

What is Supercomputer?



Lecture 1 Page 12



ILLINOIS INSTITUTE OF TECHNOLOGY

Argonne Leadership Computing Facility

ALCF Resources | Science | Community and Partnerships | About | Support Center

HOME / AURORA

Aurora

AURORA DOCUMENTATION

Get Ready for Aurora's Arrival

Check out our Aurora Guide so that you can begin preparing your code for the ALCF's forthcoming exascale system.

AURORA TRAINING

Aurora Early Adopter Series

The Aurora Early Adopter webinar series is designed to help researchers and developers ramp up their efforts to optimize applications for exascale.

KEY SPECIFICATIONS

SUSTAINED PERFORMANCE

≥1 Exaflop DP

LEADERSHIP PERFORMANCE

For HPC, data analytics, AI

UNIFIED MEMORY ARCHITECTURE

Across CPU and GPU

<https://alcf.anl.gov/aurora>

14

ILLINOIS INSTITUTE OF TECHNOLOGY

What is Exascale?

1,000,000,000,000,000,000
AN **EXASCALE** COMPUTER WILL PERFORM **ONE QUINTILLION OPERATIONS PER SECOND.**

An exascale computer can perform as many calculations per second as about **50 MILLION LAPTOPS.**

Current projections for power consumption of exascale computers is put at **100 MEGAWATTS** – the same amount of power as **ONE MILLION 100-WATT** lightbulbs.

AN EXASCALE COMPUTER WILL BE 1,000 TIMES FASTER than today's most powerful supercomputer, **FUJITSU'S K COMPUTER.**
Today's fastest supercomputers are **GIGANTIC** requiring space the size of a football field.

2018?

Scientists hope to build an exascale computer by 2018 with the **Europe, China, Japan and the U.S.** all investing hundreds of millions of \$\$\$.

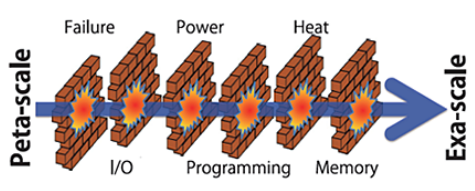
The processing power will transform sciences such as **astrophysics and biology** as well as improving **climate modelling and national security.**

15

ILLINOIS INSTITUTE OF TECHNOLOGY

Research Challenges


- Energy and power challenge
- Memory and storage challenge
- Concurrency and locality challenge
- Resilience challenge



Various walls to go through

Peter Kogger, et al., "ExaScale Computing Study: Technology Challenges in Achieving Exascale Systems", DARPA, 2008.


16

 ILLINOIS INSTITUTE OF TECHNOLOGY

My Research

- Develop **system software** for
 - Resource management and job scheduling
 - Power and energy efficiency
 - Fault tolerance (resilience)
 - Networking and communication modeling
 - Performance analysis and modeling

17

 ILLINOIS INSTITUTE OF TECHNOLOGY

Current Research Projects

- **MINT**: Multi-resource **IN**telligent**T** management of hybrid workloads (*NSF funded*)
- **SEEr**: Scalable, Energy-Efficient HPC environment for AI-enabled science (*NSF funded*)
- **IRON**: Interference **Reduction** on massively parallel platforms (*NSF funded*)
- **MUMMI-R**: Experimental-based Research on Effective Models of Parallel Application Execution Time, Power, and Resilience (*NSF funded*)
- **Cobalt**: A High Performance, Multi-Dimensional Batch Scheduler for Pre-exascale and Beyond Systems (*DOE funded*)
- More details on my webpage:
 - <http://www.cs.iit.edu/~lan/>

18

ILLINOIS INSTITUTE OF TECHNOLOGY

Workload Management

- Resource management and job scheduling
 - A system software sitting between users and hardware platform
 - Users specify job requirement, e.g., computation and time
 - User jobs are placed into queue to wait for execution
 - Decide **when** and **where** to execute user jobs

ILLINOIS INSTITUTE OF TECHNOLOGY

Application & System Evolutions

Hybrid Applications

HPC AI/ML

Data Analytics

Workload Management

Heterogeneous System

Compute Nodes

- Various proc types
- Different mem capacities
- HBM, NVDIMM, etc.
- Local storage (NVMe)

I/O Nodes

Burst Buffer (Global)

Open questions:

- **Hybrid workloads** with various resource requirements
 - Compute-, memory-, communication-, IO-intensive
- **Heterogeneous system** with different processors & deep memory/storage hierarchies
- Various **user demands**
 - Response time, on-demand, wait time, ...

ILLINOIS INSTITUTE OF TECHNOLOGY

MINT (Multi-resource Intelligent management of hybrid workloads)
To catalyze a harmonic HPC, AI, and data analytics environment

```

graph TD
    A[Workload Characterization & Modeling] --> B[Intelligent Multi-Resource Scheduling]
    B --> C[Implementation & Evaluation]
    C --> D[Dynamic Resource Allocation]
    D --> A
    
```

An **intelligent** workload management framework

- To promote the use of large-scale supercomputers for emerging data-centric applications (**HPC4AI**)
- To exploit advanced AI technologies, especially multi-objective reinforcement learning, to empower job scheduling and resource allocation in HPC (**AI4HPC**)

21

ILLINOIS INSTITUTE OF TECHNOLOGY

Collaborators

22

ILLINOIS INSTITUTE OF TECHNOLOGY

Student Opportunities

- Sahil Sharma (BS/MS, 9/2019- 5/2021) (Project: DNPC)
- Avery Peck (BS/MS, 1/2020- 12/2020)
- Sergio Servantez (BS, 1/2019-5/2019) (Project Link)
- Zhen Huang and Black Ehrenbeck (BS, 1/2019-5/2019) (Project Link)
- Sergio Servantez (BS, 8/2018-12/2018) (Project Link)
- Zhen Huang, Blake Ehrenbeck, Brianna Bransfield (BS, Student Cluster Competition at SC2018, 8/2018-11/2018)
- Zhen Huang (BS, CS Scholarship, 1/2018-5/2018)
- Blake Ehrenbeck (BS, NSF REU, 7/2017-9/2017)
- Arushi Rai (BS, NSF REU, 7/2017-9/2017)
- Shreyas Moudgalya (BS, 10/2016-11/2016)
- Aleksandra Kukiello (BS, NSF REU, 5/2016-8/2016)
- Jia Hao He (BS, NSF REU, 2/2016-3/2016)
- Tarun Gidwani (BS, NSF REU, 8/2014-10/2014)
- Asad Patel (BS, NSF REU, 8/2014-12/2014)
- Runran Wang (BS, REU summer, 2010)
- Kunlun Guo (BS, REU summer, 2010)
- Janusz Nosek (BS, REU summer, 2009)
- Soo Min Park (BS, 2007)

Requirements:

- CS351 & CS451
 - Five former CS451 students had summer internships at Argonne
- C/C++, Python
- Various research projects
- If interested, send me an email with your CV and transcripts!

23

ILLINOIS INSTITUTE OF TECHNOLOGY



Contact: Zhiling Lan
 Email: lan@iit.edu
<http://www.cs.iit.edu/~lan>