Why ISTC for Cloud Computing?

• Cloud computing has exploded onto the scenes
  ▫ By 2020, most computing may be cloud-based

• Cloud computing promises huge benefits in...
  ▫ resource efficiency and utilization
  ▫ agility and productivity of application dev+deploy
  ▫ system and service robustness
  ▫ data sharing and end user access

• But, hype far ahead of capability & knowledge
  ▫ huge need for research at many levels
ISTC-CC: Institutions & Faculty

- Carnegie Mellon University
  - Greg Ganger (PI), Dave Andersen, Guy Blelloch, Garth Gibson, Mor Harchol-Balter, Todd Mowry, Onur Mutlu, Priya Narasimhan, M. Satyanarayanan, Dan Siewiorek, Alex Smola, Eric Xing

- Georgia Tech
  - Greg Eisenhower, Ada Gavrilovska, Ling Liu, Calton Pu, Karsten Schwan, Matthew Wolf, Sudha Yalamanchili

- Princeton University
  - Mike Freedman, Margaret Martonosi

- University of California at Berkeley
  - Anthony Joseph, Randy Katz, Ion Stoica

- University of Washington
  - Carlos Guestrin

- Intel Labs
  - Phil Gibbons (PI), Michael Kaminsky, Mike Kozuch, Babu Pillai
• Intel oversight
  ▫ Rich Uhlig (Executive Sponsor)
  ▫ Scott Hahn (Managing Director)
  ▫ Chris Ramming (Director of UCO)
  ▫ Jeff Parkhurst (Program Director)

• Board of Advisors (including Rich and Scott)
  ▫ Randy Bryant (Dean of School of CS, CMU)
  ▫ Jeff Chase (Professor of CS, Duke)
  ▫ Balint Fleischer (Gen. Mgr. Data Center Group, Intel)
  ▫ Frans Kaashoek (Professor of CS&Eng, MIT)
  ▫ Pradeep Khosla (Chancellor, UC San Diego)
ISTC-CC’s Research Pillars

Underlying Infrastructure enabling the future of cloud computing

www.istc-cc.cmu.edu
Automation Pillar

• Automation is crucial to cloud reaching potential
  ▪ We suspect that no one here needs to be convinced of this...

• Management is very hard, but cloud makes it worse
  ▪ Much larger scale
  ▪ Much more varied mix of applications/activities
  ▪ Much less pre-knowledge of applications
  ▪ And, we’re adding in platform specialization 😊

• Leaps forward needed on many fronts...
  ▪ Diagnosis, scheduling, instrumentation, isolation, tuning, ...

Specialization Automation Big Data To the Edge
Automation Projects

• **A1: Resource Scheduling for Heterogeneous Cloud Infrastructures**
  - maximizing the effectiveness of a cloud composed of diverse specialized platforms servicing diverse app types
  - enabling software framework specialization via hierarchical scheduling

• **A2: Problem Diagnosis and Mitigation**
  - new tools and techniques for rapid, robust diagnosis of failures and performance problems
  - automated mitigation based on “quick and dirty” online diagnoses
• Talks
  ▫ “Better Problem Diagnosis in the Cloud” – Priya Narasimhan [Thurs am]
  ▫ “Hierarchical Scheduling for Diverse Datacenter Workloads” – Ali Ghodsi [Fri am]

• Posters -- first session
  ▫ Per-Application Server Specialization in Data Centers
  ▫ Enabling End-to-End Latency & Throughput SLOs on Shared Storage
  ▫ SpringFS: Bridging Agility and Performance in Elastic Distributed Storage
  ▫ Dataflow-Analysis-Based Dynamic Parallel Monitoring
  ▫ Tetrisched: Space-Time Scheduling for Heterogeneous Datacenters
  ▫ Automated performance problem mitigation with efficient resource allocations
  ▫ Tachyon: Reliable File Sharing at Memory-speed Across Cluster Frameworks
  ▫ Oncilla: A GAS Run-time for Efficient Resource Partitioning in Accelerated Clusters
  ▫ Experiences with Fault-Injection in a Byzantine Fault-Tolerant Protocol
Big Data Pillar

- Extracting insights from large datasets
  - “Analytics” or “Data-intensive computing”
  - Becoming critical in nearly every domain
    - likely to dominate future cloud data centers

- Need right programming/execution models
  - For productivity, efficiency, and agility
  - Resource efficient operation on shared, specialized infrastructures

Customer Database
~600 TB

HD Internet Video
12 EB/yr

Particle Physics
300 EB/yr

Estimating the Exaflood, Discovery Institute, January 2008
Amassing Digital Fortunes, a Digital Storage Study, Consumer Electronic Association, March 2008
Big Data Projects

• **B1: Big Learning Systems**
  - new programming abstractions and execution frameworks enabling efficiency and productivity for large-scale Machine Learning on Big Data

• **B2: Big Data Storage**
  - exploring trade-offs and new approaches in Big Data storage, including support for high ingress and multi-framework sharing of data
Talks -- Thurs late afternoon (+ 1 Thurs morning)

- “Discretized Streams: Fault-Tolerant Streaming Computation at Scale” – Ion Stoica
- “More Effective Distributed ML via a Stale Synchronous Parallel Parameter Server” – Eric Xing
- “Scaling Big Data Processing with Utility-aware Distributed Data Partitioning” – Ling Liu
- “Parrot + dBug: Fast and Reliable Multithreading” – Jiri Simsa
- “What’s New with GraphLab” – Carlos Guestrin
Big Data at Retreat 2013

- **Posters -- first session**
  - Big Machine Learning: Needs and Directions
  - LazyTable: Distributed Machine Learning with the Stale Synchronous Parallel Model
  - Exploiting Bounded Staleness To Speed Up Big Data Analytics
  - STRADS: A Distributed ML Task Scheduler For Large-Scale Convex Optimization Problems
  - FastHASH: A New Algorithm for Fast and Comprehensive Next-generation Sequence Mapping
  - Discretized Streams: Fault-Tolerant Streaming Computation at Scale
  - Approximating User-Defined Functions in BlinkDB
  - What Test Should I Run? Improving Concurrency Tests using State Space Estimation
  - Scaling Distributed File System Metadata Throughput using IndexFS
  - ShardFS: Scalable Metadata for HDFS
  - Out-of-core Metadata for HDFS
  - DSS Gen-2:Enabling Storage QoS for Virtual Machines
  - Reducing Contention Through Priority Updates
Specialization Pillar

• Specialization is fundamental to efficiency
  ▫ No single platform best for all application types
  ▫ Called **division of labor** in sociology

• Cloud computing must embrace specialization
  ▫ As well as consequent heterogeneity and change-over-time
  ▫ Stark contrast to common cloud thinking

• New approaches needed to enable...
  ▫ Effective mixes of targeted and general platform types
  ▫ Nimble incorporation of new technologies and accelerators

*Low power nodes*

*Many-core*

*Phase-change memory (PCM)*
Specialization Projects

• **S1: Specialized Platforms of Wimpy Nodes**
  - exploring + extending range of apps that run (most) efficiently on such platforms by overcoming OS limits, memory limits, and scalability issues

• **S2: Specialized Platforms of Heterogeneous Multi-Cores**
  - exploring best ways to devise and use heterogeneity on multi-core nodes, considering core types, accelerators, and DRAM/NVM memory, with a focus on cloud’s virtualized, multi-tenancy workloads
Specialization at Retreat 2013

- Talks -- Friday morning

  - “NVM and Hetero Systems” – Karsten Schwan
  - “Rethinking Memory System Design for Data-Intensive Computing” – Onur Mutlu
  - “Fast Networked Key-Value Stores and Cuckoo Hashing” – Dave Andersen
Posters -- second session

- Scalable, High Performance Ethernet Forwarding on x86 Platforms
- MICA: A Holistic Approach to Near-Line-Rate In-Memory Key-Value Caching on General-Purpose Hardware
- Hardware + Algorithms = Seriously Concurrent Hash Tables
- Design Space Analysis for Heterogeneous Systems
- Exploration of Data Warehousing and Graph Applications with GPUs
- ANUMA: Asymmetry-aware Execution Placement on Manycore Chips
- Tiered-Latency DRAM: A Low Latency and Low Cost DRAM Architecture
- Base-Delta-Immediate Compression: Practical Data Compression for On-Chip Caches
- Linearly Compressed Pages: A Low Complexity, Low Latency Main Memory Compression Framework
- RowClone: Fast and Energy-efficient In-DRAM Bulk Data Copy and Initialization
- A Case for Subarray-Level Parallelism (SALP) in DRAM
- MISE: Providing Performance Predictability in Shared Main Memory Systems
- Improving DRAM Performance by Parallelizing Refreshes with Accesses
- A Case for Hardware/Software Cooperative Management of Storage and Memory
To the Edge Pillar

• Edge devices will participate in cloud activities
  ▫ Serving as bridge to physical world (sense/actuate)
  ▫ Enhancing interactivity despite location / connectivity

• Need new programming/ execution models
  ▫ For adaptive cloud
    + edge cooperation

Cloudlet demo
To the Edge Projects

• **E1: Cloud-Assisted Mobile Client Computations**
  - new abstractions and system architectures for dynamic exploitation of edge-local cloud resources to enable rich edge device experiences

• **E2: Geographically Distributed Data Storage**
  - new techniques for geographically distributed data storage/caching that reduce both access latency & reliance on expensive WAN-uplink bandwidth, while providing the desired scalability, fault tolerance, consistency & findability
To the Edge at Retreat 2013

• **Talks** -- Thursday afternoon
  - “What’s New with Cloudlets” - Satya
  - “Stronger Semantics for Low-Latency Geo-Replicated Storage” - Wyatt Lloyd
  - “There Is More Consensus in Egalitarian Parliaments” - Iulian Moraru

• **Posters** -- second session
  - OpenStack++ for Cloudlets
  - Agentless Cloud-wide Monitoring of Virtual Disk State
  - vTube: Efficient Streaming of Virtual Appliances Over Last-Mile Networks
  - Scalable Crowd-Sourcing of Video from Mobile Devices
  - QuiltView: a Crowd-Sourced Video Response System
  - Hyrax: Edge Clouds of Mobile Devices
  - Leveraging Embedded-to-Cloud Framework for Retail Environments
  - Egalitarian Paxos
<table>
<thead>
<tr>
<th>Project</th>
<th>Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 Specialized Platforms of Wimpy Nodes</td>
<td>Andersen[C], Schwan[G], Freedman[P], Kaminsky[I], Kozuch[I], Pillai[I]</td>
</tr>
<tr>
<td>S2 Specialized Platforms of Heterogeneous Many-Cores</td>
<td>Mowry[C], Mutlu[C], Gavrilovska[G], Schwan[G], Yalamanchili[G], Martonosi[P], Gibbons[I], Kozuch[I]</td>
</tr>
<tr>
<td>A1 Resource Scheduling for Heterogeneous Cloud Infrastructures</td>
<td>Joseph[B], Katz[B], Stoica[B], Ganger[C], Harchol-Balter[C], Kozuch[I]</td>
</tr>
<tr>
<td>A2 Problem Diagnosis and Mitigation</td>
<td>Ganger[C], Narasimhan[C], Eisenhauer[G], Liu[G], Schwan[G], Wolf[G]</td>
</tr>
<tr>
<td>B1 Big Learning Systems</td>
<td>Stoica[B], Andersen[C], Blelloch[C], Ganger[C], Gibson[C], Smola[C], Xing[C], Guestrin[W], Gibbons[I]</td>
</tr>
<tr>
<td>B2 Big Data Storage</td>
<td>Andersen[C], Ganger[C], Gibson[C], Xing[C], Pu[G], Schwan[G]</td>
</tr>
<tr>
<td>E1 Cloud-Assisted Mobile Client Computations</td>
<td>Satya[C], Siewiorek[C], Gavrilovska[G], Liu[G], Schwan[G], Martonosi[P], Pillai[I]</td>
</tr>
<tr>
<td>E2 Geographically Distributed Data Storage</td>
<td>Andersen[C], Satya[C], Siewiorek[C], Freedman[P], Kaminsky[I], Pillai[I]</td>
</tr>
</tbody>
</table>
ISTC-CC: Year 2 Publication Highlights

- PACT (Sep’12) – 3 papers
- ICAC (Sep’12) – 3
- ICCD (Sep’12) – 2
- OSDI (Oct’12) – 3
- SOCC (Oct’12) – 6
- Middleware (Dec’12) – 2
- HPCA (Feb’13) – 4
- PPoPP (Feb’13) – 2
- DATE (Mar’13) – 2
- NSDI (Apr’13) – 3
- IPDPS (May’13) – 2
- HotOS (May’13) – 5
- ISCA (Jun’13) – 3
- SIGMOD (Jun’13) – 3
- Mobisys (Jun’13) – 2
- ICWS (Jun’13) – 2
- ICDCS (Jul’13) – 2
- KDD (Aug’13) – 3
- SIGCOMM (Aug’13) – 2
- IRI (Aug’13) – 2

Year 3 (so far):
- ICCD (Sep’13) – 2
- SOCC (Oct’13) – 3
- SOSP (Nov’13) – 4
- MICRO (Dec’13) – 2

85 published papers highlighted in ISTC-CC Newsletter for Year 2 (July’12- Sept’13)
Open Source Code Releases in Year 2

GraphBuilder 1.0 released open source in Jun’13
GraphLab 2.2 released open source in Jul’13

Spark 0.8 release Sep’13 – Apache incubator

Mesos 0.14 released Oct’13 – Apache

Other open source releases on github include:
Eiger, EPaxos, Parrot, Cloudlet OpenStack++, CuckooFilter, RankSelect, MemC3, NVMalloc, etc.

Open Source page: www.istc-cc.cmu.edu/research/ossr/
Also Benchmarks page: www.istc-cc.cmu.edu/research/benchmarks/
ISTC-CC: Year 2 Honors

Highlights of Year 2 Honors

- ACM Fellows – Gibson, Stoica [now 8 in all + 5 IEEE Fellows]
- ABIE Technical Leadership Award – Martonosi
- 2013 R&D100 award – Schwan, Wolf, others
- Founding Editor-in-Chief of ACM TOPC – Gibbons
- LANL Outstanding Innovation Award – Gibson
- Endowed Early Career Professor – Mutlu
- Allen Newell Award – Andersen, Kaminsky
- 2012 SPEC Distinguished Dissertation Award – Meng
- Multiple best paper awards, Program chairs, Conference Chairs, Outstanding dissertation honors, etc
ISTC-CC: Amplifying Funding

New Amplifying Funding awarded in Year 2

- Guy Blelloch (CMU) & Phil Gibbons (IL) – NSF
- David Andersen (CMU) & Michael Kaminsky (IL) – NSF
- Mor Harchol-Balter (CMU) – NSF
- Sudha Yalamanchili (GA Tech) – NSF
- Karsten Schwan, Matt Wolf, Ada Gavrilovska (GA Tech)
- Satya (CMU) – Inst. For Museum & Library Sciences
- Satya (CMU) – Sloan Foundation

- Consortia: AMPlab (Berkeley), CERCS (GA Tech), PDL (CMU)
- Fellowships: Intel (2), Facebook, IBM, Microsoft, NVIDIA, Qualcomm, VMWare

+ Considerable Amplifying Funding carrying over into Year 2

=> Intel support for 25 students, yet working with 87
**ISTC-CC Students @ Intel**

**Full time Employees:**
- Soila Kavulya – CMU
- Min Lee – GA Tech

**Interns (2012 or 2013):**
- Hrishikesh Amur (2012) – GA Tech*
- Chris Fallin (2012) – CMU
- Liting Hu (2013) – GA Tech*
- Sudarsun Kannan (2013) – GA Tech
- Yoongu Kim (2012) – CMU
- Xiaozhou Li (2013) – Princeton*
- Jamie Liu (2012) – CMU
- Dan Lustig (2013) – Princeton
- Alex Merritt (2012, 2013) – GA Tech
- Dipanjan Sengupta (2013) – GA Tech
- Vivek Seshadri (2012) – CMU (1 month visit)
- Priyanka Tembey (2012) – GA Tech

*With embedded ISTC-CC researchers

**Intel Fellowship winners (2013):**
- Dan Lustig – Princeton
- Yoongu Kim – CMU
[10:15-11:05] Research Talks session #1
  ▫ Ion Stoica (UC Berkeley), Priya Narasimhan (CMU)


[11:30-noon] Poster previews (30 secs each) - Babu Pillai (Intel Labs)

[noon-1:20] Lunch /Poster session #1

[1:20-2:40] Poster session #2

[2:40-4:20] Research Talks session #2
  ▫ Mahadev Satyanarayanan (CMU), Wyatt Loyd (ex-Princeton), Iulian Moraru (CMU), Eric Xing (CMU)

[4:20-4:40] Break

[4:40-5:55] Research Talks session #3
  ▫ Ling Liu (GA Tech), Jiri Simsa (CMU), Carlos Guestrin (UW)


[6:15-6:30] Group Photo then Transportation to dinner

[6:30-9:00] Reception / Dinner at Pittsburgh Athletic Club
Retreat Goal: **Benefit the research projects**

- Community building
- **Brainstorming/feedback (but not ARs 😊) on:**
  - ideas & approaches for tackling the research challenges
  - jump-start collaborations
  - synergies & connections
- Learn, share & have fun

Who to see about...
- Poster Previews/Sessions: see Babu Pillai
- Minutes of Madness: see Michael Kaminsky
- Birds-of-a-Feather Breakouts: see Mike Kozuch
- Logistics questions/issues: see Jennifer Gabig