Planes, Trains, and Data Centers

Mendel Rosenblum
Talk Agenda

- What will be new applications that need data centers?
  - Controlling autonomous entities

- Some brainstorming about controlling autonomous devices
  - A funding proposal

- What will the data center be doing in the future?
  - Big Control

- Summary of "Infrastructure for Collaborative Device Swarms"
  - NSF Expedition Pre-Proposal
Disclaimer: Most material in talk from someone else

- NSF Pre-Proposal: Infrastructure for Collaborative Device Swarms
  - John Ousterhout
  - Balaji Prabhakar
  - Pat Hanrahan
  - Mac Schwager
  - Guru Parulkar
  - Dan Boneh
  - Sachin Katti
  - Mykel Kochenderfer
  - Christos Kozyrakis
  - Phil Levis
  - Keith Winstein
Background: Search for next-gen data center apps

● Existing data center driving applications
  ○ High Performance Computing (HPC) - Parallel computing
    ■ Mainly simulations
  ○ Communication
    ■ Messaging, social networks
  ○ Big Data
    ■ Search, machine learning with neural networks
  ○ Cloud Computing
    ■ All non-embedded computing

● Wild and crazy idea: All embedded computing
  ○ Big Control
    ■ Autonomous vehicles, drones, Internet of Things, ….
Focus: Centralized versus distributed control

● Some previously implemented distributed system have been moved to more centralized implementations

● Internet
  ○ Early vision: Data center in middle of the country
  ○ First app: Distributed email system
  ○ Current incarnation: Gmail running in a data center in Council Bluffs, Iowa

● Network packet routing
  ○ Version 1: Border gateway protocol (BGP) - Fully distributed route state computation
  ○ Current hot idea: Software-Defined Networking (SDN) - Centralized control

● What about autonomous entities?
  ○ Can we get examples from nature?
What about nature?

- Most believe there is not centralized control of life
  - Notwithstanding Intelligent Design

- Kirstin Petersen's bio-inspired robots
  - **Robot Collectives** - Control based on social insects
    - Termites - Simple control systems but good at construction tasks
      - Highly fault tolerant and scalable (e.g. Deborah Gordon’s Ants and TCP slow start)
      - Fully distributed
    - Robots have sensors and actuators
    - Simple control without communication

- Argument against:
  - Impact communication has had on humans
    - Language, books, telephone, Internet

http://www.eecs.harvard.edu/~kirstin/Pics/Robots/Kali&Isis.jpg
Robot to Robot Communication

- Mac Schwager's **robot swarms**
  - Communicate to self-organize to do something
    - Example: Drones searching a disaster area
  - Robots build shared knowledge of system-wide state
    - Used to guide local decision making
    - Wonderful CS problem: Distributed consensus algorithms
  - Ideal disk communication model
    - Can use radio to communication with nearby drones

- Low power radio not a requirement - Could communicate to a controller
  - Pat Hanrahan's observation: Motors used way more power than electronics
    - Radios/CPU: Milliwatts
    - Motors: Watts
Communication latency and reaction times

● Some times:
  ○ Current Internet round-trip: 100s of milliseconds
  ○ Speed of light to Iowa and back: 10s of milliseconds
  ○ Human reaction times: ~1 sec
  ○ Anti-lock brakes reaction time: a few milliseconds
  ○ Anti-collision systems: a few milliseconds

● Max's drones:
  ○ Safety systems kept drones one meter apart

● Speed of light argues that not all control can be centralized
  ○ But much control can be centralized
Centralized versus distributed control tradeoff

● Distinction in proposal:
  ○ Reflex behaviors - Control decision made by the device itself
  ○ Planned behaviors - Control decision from centralized control

● Reflex behaviors
  ○ Safety systems and ???

● Planned behaviors
  ○ Global optimization and ???
Existing Big Control Example: Waze

- Popular GPS-based geographical navigation application
- Deploy sensors in many vehicles on the roadways
  - Cell phone-based sensors collect location, speed, accidents, road hazards, closures, traffic cameras, police
    - Incent users using good directions and badges
- Determine global state of roadway systems from current sensors and historical behavior
  - Make accurate prediction of travel time and best route (incentive)
- Control: Send updated navigation instructions to users
  - More of a hint than a command (Reflex component uppity)
    - Slow start algorithm
Balaji's Societal Networks

- Transportation networks - Bus and trains
  - Incomplete sensor information
    - Time user swipe in at a stop
    - Time user swipe out at a stop
    - When carriages run
  - Can restructure hidden state of system
    - Can infer carriage loads, wait times, etc.

- Found basic technique to be widely applicable
  - Example: From network round trip packet times compute network switch queue depths
Experience with inference

- **Erroneous input must be handled**
  - Sensors can and do return bogus values (e.g. GPS position in downtown canyons)
  - Data cleaning step needed

- **State reconstruction can be expensive**
  - Example: Solving large set of linear equations
    - A traditional HPC workload
  - Speed of reconstruction could be limit applications

- **Looking like we might need some significant computing resources**
Applications for state reconstruction

● **Dashboard**
  ○ Display a visual representation of state providing the operator and users with insight
    ■ Use human processing to analyze the state
      ● Experience: Demonstrated transit systems state previously only visible via intuition
    ■ Highlight events of interest
      ● Notification system

● **Scheduling and control**
  ○ Optimize the system. Examples:
    ■ Unbunch the busses, respond to flash mobs
    ■ Update the routing to avoid switch queues
What if/counterfactual questions

● Can initialize a simulator with the current state and dynamic behavior
  ○ Explore states impractical to drive the system into

● Example:
  ○ What would happen if we shut down a lane this week? (e.g. Fort Lee, New Jersey)
  ○ What would the effect hurricane evacuation traffic?
  ○ What would happen if we added this new workload to the network?

● If this doesn't need a data center worth of compute, nothing does
Conclusion

- Having near infinite computing resources accessible via 10-100 ms round-trip communication time will be useful.

- And we are part of the:

![PlatformMLab](image)

- Just need a platform to make this easy to do...
Big Control: Infrastructure for Collaborative Device Swarms
Passé: Big Data ⇒ Exciting: Big Control

- Example applications:
  - Millions of self-driving cars - Maximize throughput, avoid congestion
  - 10,000 indoor drones tracking contents of large distribution center
  - Natural disaster response with drones scanning millions of acres

- Platform Challenges
  - Scale
  - Collaboration
  - Low latency
The Proposal Figure
Big Control Platform

- Scalable State Management and Notifications
  - High sensor input rate
    - High performance storage
    - Notification
    - Real-time fault-tolerance
  - Low-Latency Data centers
    - Low-latency RPC system
    - Core-aware thread scheduling
    - Scheduling at data center scale
    - Low latency storage
Big Control Platform

- Data Ingestion and Inference
  - Capture state of device swarm
  - Example: Large, octree point cloud-like
Big Control Platform

- Declarative Planning
  - Higher level declarative interface
Big Control Platform

Predictable Low Latency Wide Area Network
- Decouple the control and data planes of the network
- Virtualize the hardware network
- 20ms => 1ms

Swarm Security
- Secure connectivity
  - Cryptographic integrity
- Prevent sensor attacks
  - Byzantine behavior
Big Control Platform

Services
Real robotics problems
Application Examples

- 3D scanning of cities and campuses
  - Control drones with scanner to cover buildings from all necessary vantage points

- Automated agriculture
  - Drones inspect thousands of individual plants in a field

- Bus fleet management
  - Control self-driving buses based on traffic, passenger demand, weather, etc.
Grand Challenge Disaster Recovery

- After disaster send in trucks that release thousands of drones

- Area of interests
  - Coordinated search
  - Real-time sensing and inference
  - Data integration
  - Mobilizing ground vehicles
  - Small package delivery
Thank You