



SDN Controller Design

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SDN Controller Design

- What Controllers Do
- Controller Design Axes
- Types of Controllers
- Single Instance Controllers
 - Beacon Design Choices
 - Standard Applications
 - Performance
- Multiple Instance Controllers

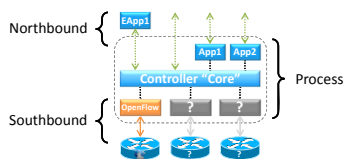


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What do Controllers do?

- Communicate with network hardware using “Southbound” API(s)
- Build network graph/state
- Run Applications
- Export “Northbound” and other APIs



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Controller Design Axes

- Language
 - Use any language you want!
 - ...but your choice does have consequences

C C++ Java Haskell Python Ruby Javascript

PERFORMANCE

Javascript Ruby Python Java Haskell C++ C

EASE OF DEVELOPMENT

C C++ Python Java Ruby Javascript Haskell

LANGUAGE/LIBRARY MATURITY

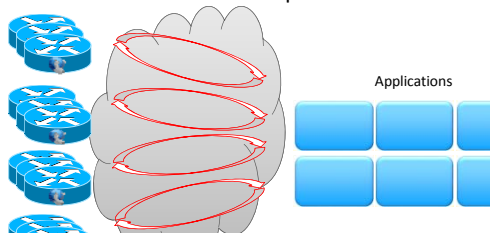


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Controller Design Axes

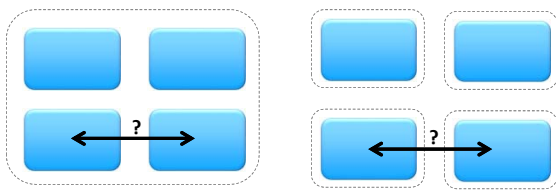
- **I/O Loop**
 - 1 thread, n threads, queues, batching?
 - Performance and fairness implications



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Controller Design Axes

- **Applications**

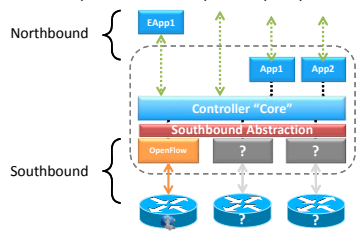


- **In-Process**
 - Function Calls
 - Interfaces
 - Message Passing
 - Discovery
- **Unique Processes**
 - IPC (Sockets)
 - RPC (Binary/REST/Web Services)
 - Message Passing
 - Discovery

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Controller Design Axes

- **Application Programming Interface (API)**
 - Southbound (Raw, Abstract)
 - Northbound (Individual Applications, Full Graph)
 - Rest, Web Services, SNMP, CLI, etc



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Types of Controllers

- **Single Instance**
 - Open Source
 - R&D
- **Multiple-Instance**
 - Mostly closed source, commercial (changing...)
 - Failover
 - Performance Scalability

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Single Instance Controllers

Name	Lang	Platform(s)	License	Original Author	Notes
OpenFlow Reference	C	Linux	OpenFlow License	Stanford/Nicira	Example only
NOX	Python, C++	Linux	GPL	Nicira	No longer actively developed
Beacon	Java	W/M/L, Android	GPL (core), FOSS Licenses for your code	David Erickson (Stanford)	runtime modular, web UI framework, regression test framework
Maestro	Java	W/M/L	LGPL	Zheng Cai (Rice)	
Trema	Ruby, C	Linux	GPL	NEC	includes emulator, regression test framework
Floodlight	Java	W/M/L	Apache	BigSwitch Networks	Fork of Beacon
POX	Python	W/M/L	Apache	Murphy McCauley (UCB)	
(Mc)Nettle	Haskell	W/M/L	Apache	Andreas Voellmy (Yale)	McNettle: multithreaded, unreleased
RYU	Python	W/M/L	Apache	NTT	

Lots of general design talk...

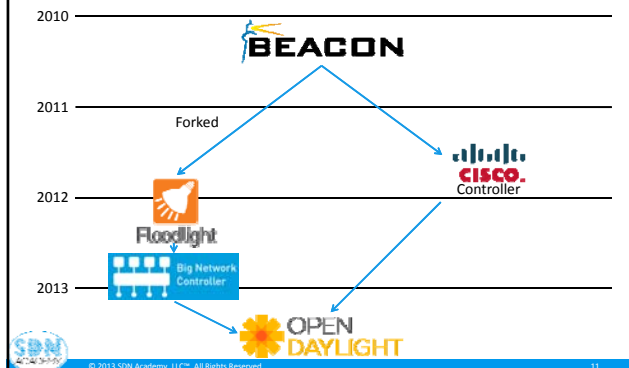
- Lets discuss a specific set of choices
 - Beacon
- Why Beacon?
 - The controller David is most familiar with ☺
 - ... not here to sell you on Beacon
 - Why decisions were made
 - Shares a common set of functionality
 - You may already be affected by its choices



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Beacon Pedigree Chart

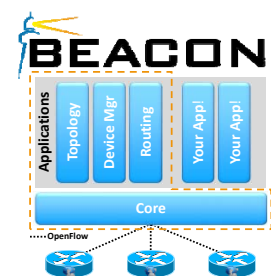


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Beacon Design Choices

- Language: Java
 - “Developer Friendly”
 - High Performance
 - Mature Tools/Libraries
 - Cross Platform
- I/O Loop: Multithreaded

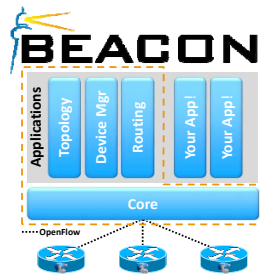


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Beacon Design Choices

- Apps: In Process
 - Modular (more later)
- API
 - Southbound: OpenFlow
 - Northbound: REST



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Beacon - Core

- Connects to switches
- Publishes IBeaconProvider service
- Other apps use IBP

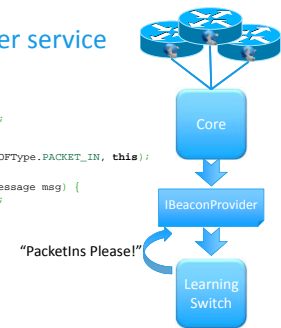
```
protected IBeaconProvider beaconProvider;

public void startUp() {
    beaconProvider.addOFMessageListener(OFTYPE.PACKET_IN, this);
}

public Command receive(IOFSwitch sw, OFMessage msg) {
    OFPacketIn pi = (OFPacketIn) msg;
    ...

    return Command.CONTINUE;
}
```

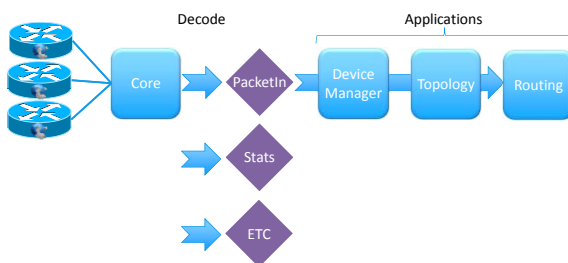
- Creates a pipeline...



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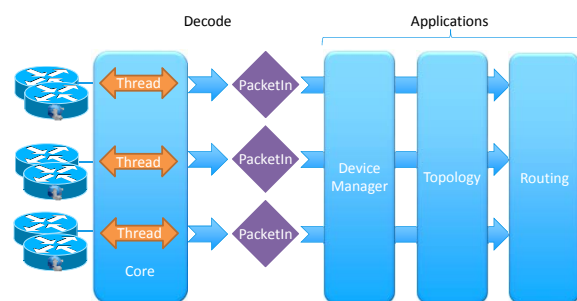
Beacon - Pipeline



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Beacon - Fully Multithreaded



- Each app gets OFMessages from all threads



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Beacon – Application Interaction

- Service abstraction
- Create an interface for service contract

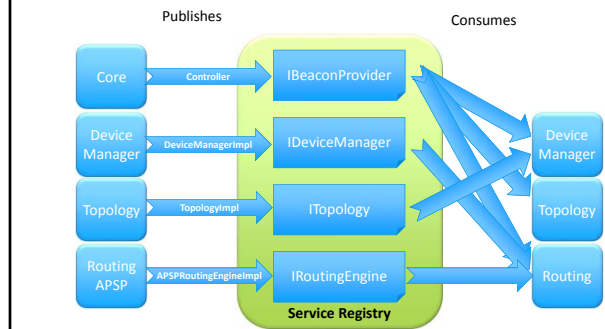
```
public interface ITopology {  
    /**  
     * Retrieves a map of all known link connections between OpenFlow switches  
     * and the last time each link was known to be functioning  
     * @return  
     */  
    public Map<LinkTuple, Long> getLinks();  
}
```
- Export an object instance that implements the interface to the service registry
- Other applications' objects import and use services
- Enables easy service extension



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Beacon - Service Registry



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Beacon – Runtime Modularity

- Dynamic
 - Similar to real Operating Systems running apps
 - Stop, Start, Install, Replace while running
- Uses
 - Application restart
 - Online App Store
 - Live Updates
 - Debugging
- Enabled by OSGi, but does add overhead



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Beacon - State

- Decentralized
 - Applications store their own data
 - Export services interfaces to query and register for events (updates)
- Currently soft-state only
 - Persistence engines can be added to extend existing capabilities
 - Existing projects have done this with Beacon



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Basic Controller Applications

- Available in most (all?) Controllers
- In Beacon these are named:
 - Hub and Learning Switch
 - Device Manager
 - Topology
 - Routing

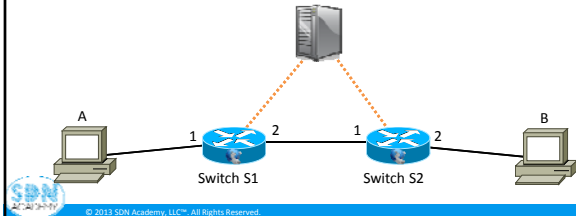


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Full Path Routing

- Send from A to B – with at most 1 Packet In
- What info does the controller need?
 - Host Locations
 - Network Topology



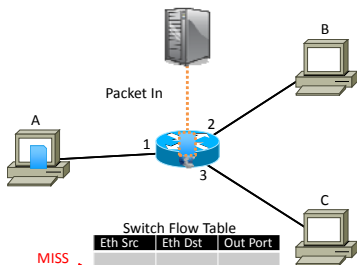
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Device Manager

- Packet A -> B

Devices		
Eth Address	Switch	Port
A	1	1



Switch Flow Table		
Eth Src	Eth Dst	Out Port

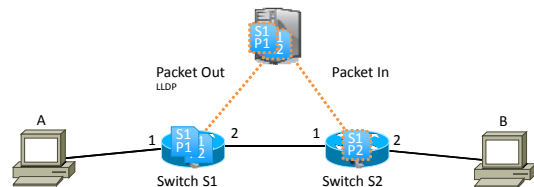


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Topology

Links			
Src Switch	Src Port	Dst Switch	Dst Port
S1	2	S2	1



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Routing

- Performs 'routing' between devices
 - Not layer 3 IP routing
- Depends on
 - Device Manager
 - Topology
- Swappable Routing Engine
 - Djikstra
 - All Pairs Shortest Path
 - Static

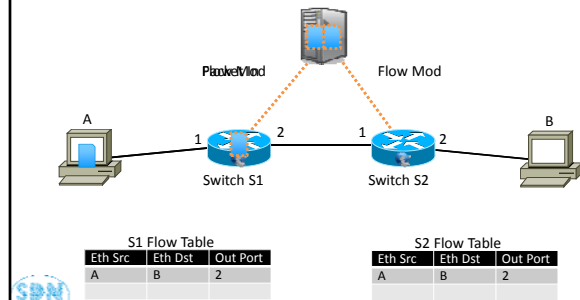


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Routing

- Packet A -> B



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Performance Considerations

- Number of events processed (and acted on)/s
- Usually benchmarked with Cbench
 - Primitive, used mostly to test I/O loop and programming language capabilities
- What performance do you need?
 - Reactive
 - Proactive
- I/O designs are important



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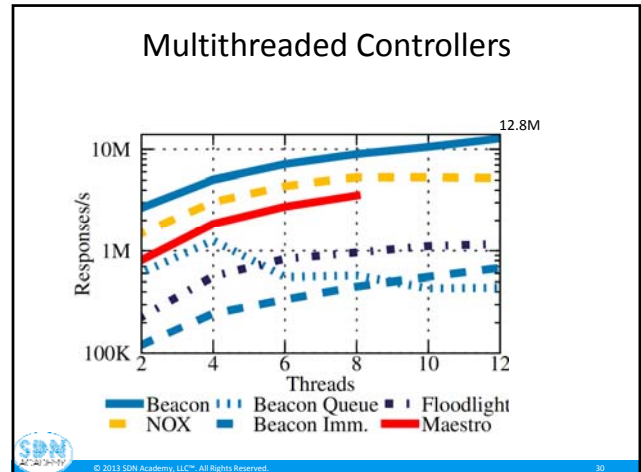
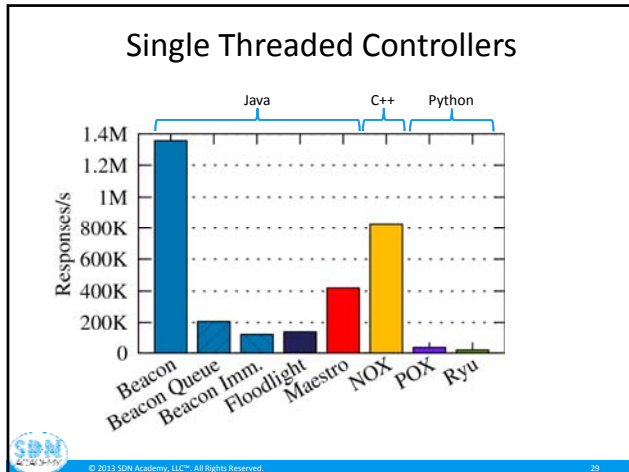
Performance Benchmarking

- Used Cbench
- Run on EC2, cluster compute instance
 - Easily reproducible
- Throughput mode



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Multiple Instance Controllers

Name	Lang	Platform(s)	License	Original Author	Notes
Onix	C++		Commercial	Nicira	
Big Controller	Java	VM/Linux	Commercial	BigSwitch Networks	Built on Floodlight
Programmable Flow			Commercial	NEC	
OpenDaylight	Java		Eclipse		
ONOS	Java			Open Networking Lab	

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- ### Scalable Controller Considerations
- **Sharing state**
 - Eventually consistent database
 - Distributed Hash Table
 - **Leader**
 - Consensus Protocols
 - What does the leader do differently
 - **API**
 - How to expose to applications
 - **Failure modes**
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Takeaways

- Many controller design points
 - Tradeoffs with each of them
 - Some of these may already be picked for you
- Beacon's design decisions and why
- Understanding of basic controller applications
- Controller Performance
- Multi-instance Controller Considerations



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Learning Switch Exercise

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Outline

- Review Hub and Switch Functionality
- OpenFlow Messages
- Hub and Switch + OpenFlow
- Visual primer for the Exercise

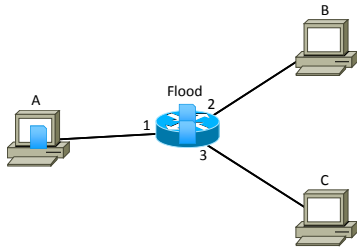


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Review: Hub Functionality

- Packet A -> B

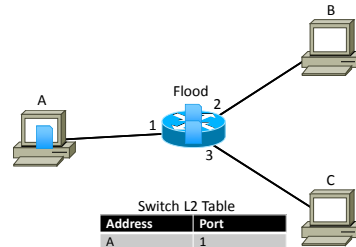


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Review: Switch Functionality

- Packet A -> B

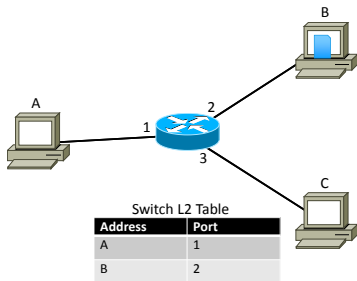


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Review: Switch Functionality

- Packet B -> A



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OpenFlow Messages

- Packet In (OFPacketIn)
 - Sent to the Controller on a flow table miss
 - Packet data, incoming port
 - Buffer id, if switch kept a copy of the packet
- Packet Out (OFPacketOut)
 - Packet data or buffer id
 - Action(s) to take on the packet, ie. output port



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OpenFlow Messages

- **Flow Mod (OFFlowMod)**
 - Add, Modify, Delete from the switch's flow table
 - Header field(s) to match (OFMatch)
 - Action(s) to take when matched (OFAction)
 - Buffer id of packet to release (optional)

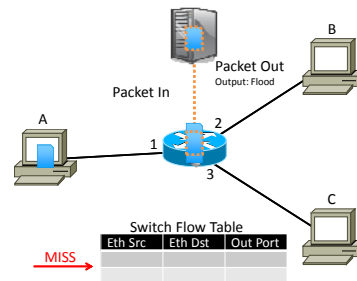


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Hub + Controller

- **Packet A -> B**

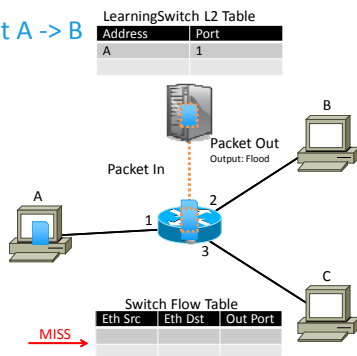


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Switch + Controller (Phase 1)

- **Packet A -> B**

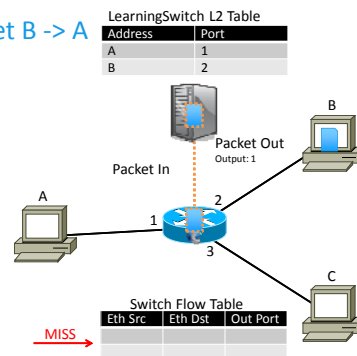


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Switch + Controller (Phase 1)

- **Packet B -> A**

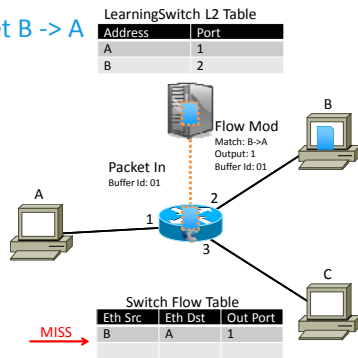


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Switch + Flows + Controller (Phase 2)

- Packet B -> A



Eclipse Primer

- Launching
 - Source code of interest
 - Starting and stopping Beacon
 - Perspectives: Plug in Dev, Debugging
 - Ensuring only 1 instance of Beacon running
 - Debugging
 - Solution if stuck
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