Introduction to Network Booting
Free Yourself From Your Hard Drive!

Joshua Oreman

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Massachusetts Institute of Technology

Independent Activities Period, January 6, 2010
1. Conceptual overview
   - Motivation
   - Essential pieces
   - The system boot process

2. Network booting technology
   - Standard architecture
   - Beyond the standards: gPXE
   - Storing the boot code

3. Demonstrations
   - What lies ahead

Q&A throughout the presentation
Outline

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A typical large site

- Many, many similarly- or identically-configured systems
- Each boots up independently, from its own hard drive, and then tries to access shared network resources
- Very fast, powerful network
- Nothing gets done if the network is down
- Most interesting user/business data is stored on the network, not locally
- High-performance, finely tuned central servers already essential to getting things done (Kerberos, AFS, mail, ...)

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The problem with local booting

A supercomputer cluster...
- Local drives used pretty infrequently
- Local drives fail very often
- And they're expensive!

An office building...
- Employees like to customize their systems
- Distributed updating is hard

MIT!
- New systems constantly needing identical configuration, installation
- Users’ machines incompatible with course needs
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The big idea

Get rid of the client machines’ hard drives entirely!

How it works

- Instead of starting from the hard drive, clients execute a small bootstrap program in ROM.
- Bootstrap program autoconfigures the network, fetches the operating system kernel, and executes it.
- OS kernel mounts a networked drive as its main system disk.

Advantages for large sites

- Files that are the same for everyone only exist in one place: upgrading is a breeze.
- One more fancy central server is more than paid for by saving lots of consumer-level hard drives.
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But most of all...

it’s fun!
Networking basics

A computer network is **layered**:

- **Link layer**: transports data frames between physically connected hosts; **Ethernet**
- **Internet layer**: handles routing packets to hosts on other networks; **Internet Protocol (IP)**
- **Transport layer**: provides data integrity, multiplexing, and connection semantics;
  - Complex: Transport Control Protocol (TCP) creates a reliable data stream between hosts. Everything arrives, in order, without duplication.
  - Simple: User Datagram Protocol (UDP) provides unreliable transmission of independent packets. May be lost, reordered, or duplicated.
- **Application layer**: handles the useful part of the connection, file data or email or ...
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Network configuration for local boot

- Dynamic Host Configuration Protocol
- Client knows nothing about its role in the network
- Server supplies network configuration to each computer
- Differentiate between systems by MAC address

Figure: A DHCP session
Network configuration for local boot

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Internet Systems Consortium DHCP Client V3.0.6
All rights reserved.
For info, please visit http://www.isc.org/sw/dhcp/

Listening on LPF/eth0/00:16:3e:58:d1:cf
Sending on LPF/eth0/00:16:3e:58:d1:cf
Sending on Socket/fallback
DHCPDISCOVER on eth0 to 255.255.255.255 port 67 interval 3
DHCPOFFER of 18.181.1.231 from 18.181.0.221
DHCPREQUEST of 18.181.1.231 on eth0 to 255.255.255.255 port 67
bound to 18.181.1.231 -- renewal in 41858 seconds.

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Changes for network booting

- The **same protocol** (DHCP) is used to get IP, DNS, router
- Additional DHCP options fill in the gaps:
  - Server to load files from (next-server)
  - Filename of kernel to load (filename)
  - OR Remote disk to boot from (root-path)
- With this information the bootloader can access the network normally
- TFTP: very *simple* protocol to fetch image
- Proxy DHCP: extension allowing different servers to specify network configuration and booting information
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Server provides a **hard disk image** to clients.

- High-speed RAID and a fast network can give better performance than consumer hardware
- Windows can’t boot from a network filesystem, but can boot from SAN
- But two clients can’t write to the same image

- Very light CPU load on the server, but clients gain benefit of server’s cache

Often a hybrid approach is best: SAN for the root filesystem, NFS/AFS for user data
Network attached storage (SAN)

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**Copy-on-write**

- **Copy-on-write (COW)** makes SAN booting easier
  - One read-only image is provided to all clients, but it looks writable.
  - Writes actually go to a separate file, unique to each client, that only contains the modified information.
  - Reads come from the COW file if the block is there, the base image if not.
  - Upgrades: change the base image and delete all the COW files.

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If at all possible, involve COW. Copy-on-write (COW) makes SAN booting easier. One read-only image is provided to all clients, but it looks writable. Writes actually go to a separate file, unique to each client, that only contains the modified information. Reads come from the COW file if the block is there, the base image if not. Upgrades: change the base image and delete all the COW files.
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- BIOS is the very first thing run when you power on, burned into a chip inside your computer.
- Main job is to initialize hardware, catalogue boot devices and start an operating system from one.
- Since the BIOS doesn’t know everything, option ROMs allow its functionality to be extended.
- ROMs called during power-on self test to extend or replace BIOS functionality.
- Hook interrupts:
  - Provide access to new types of hard disk (int 13h)
  - Trap the “boot system” call to netboot (int 19h)
  - On newer systems, ROMs can register as boot devices and appear in menus.
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Initial loading occurs in **real mode**, so it can use the BIOS and option ROMs.

- **Goal**: load enough for the OS to manage the rest on its own
  - Kernel image
  - Device drivers for hard disk or network card
  - Filesystem drivers
  - Network layer

- For Linux, drivers are in an initial ramdisk (initrd) containing code to load them and mount a root filesystem
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Pivoting to a full system

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- Once real-mode loading is done, the loaded drivers are used to let the OS access its boot device for itself.
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- Avoids resource conflicts—OS kernel can manage everything.
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PXE’s problems

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default Debathena
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Etherboot to the rescue!
gPXE to the rescue!

**gPXE**: an extensible, powerful, open-source network bootloader

- Drivers for dozens of network cards, including almost all those in common use
- Stacks for Infiniband and 802.11 wireless
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**Figure:** Two ways of configuring a SAN boot

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**Figure:** Two ways of configuring a SAN boot

- Invoked from DHCP root-path option or gPXE sanboot command
- SAN boot protocols:
  - **iSCSI:** routable, reliable, complicated, some overhead
  - AoE (ATA over Ethernet): unroutable, less reliable, very simple, fast blast
- Naming a disk to boot from: the root path
  - **iSCSI:** server:protocol:port:lun:iqn
  - Initiator Qualified Name: date and DNS establish ownership
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Idea: gPXE packaged as a PXE Net Boot Program, so gPXE’s features are available without burning it into ROM

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- New images can be flashed
- ROM identifies the PCI device it’s associated with

- BIOS and ROMs execute in real mode, so only 1MB of memory is accessible.
- Total size of ALL ROMs cannot exceed 128kB! Extremely limiting.
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  - Better scripting
  - SAN ISO booting support
  - Move some functionality into modules
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  - Load files out of filesystems on SAN disks
  - Boot your XVM on a local machine
  - “Netbooting for everyone”
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Wrap-up

Much more information is available at http://etherboot.org/

Think this stuff is awesome? Get involved!
Stop by the SIPB office sometime, W20–557.

Want to get paid for working on gPXE?

Thanks to Marty Connor for providing demo hardware, assisting with demos, and being an all-around great project leader!