

18-640 Foundations of Computer Architecture

Lecture 21: “Cloud and Mobile Computing”

John Paul Shen

November 20, 2014

http://www.slideshare.net/marin_dimitrov/introduction-to-cloud-computing-3814141

<http://www.slideshare.net/jamesbroberg/introduction-to-cloud-computing-ccgrid-2009#btnNext>

➤ Recommended Reading Assignment:

- Antero Taivalsaari, “Liquid Software Manifesto,” COMPSAC, 2014.

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18-640 Foundations of Computer Architecture

Lecture 21: “Cloud and Mobile Computing”

A. Cloud Computing Basics

- a. Types of Clouds
- b. Types of Services

B. Mobile Software Trends

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A. Cloud Computing Basics

[James Broberg, CCGRID, 2009]

[Karthik T.S., 2010] [Siwat Jirawiwatpat, 2010]

GRID COMPUTING

Distributed and Dynamically Networked Computers

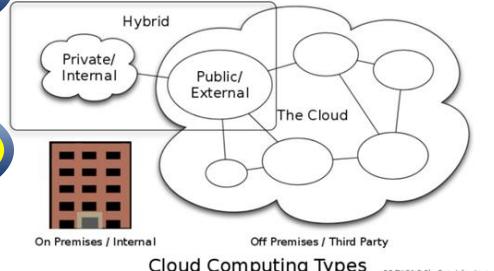
CLUSTER COMPUTING

Shared File System and LAN Connected Multi-computers

MULTIPROCESSING

Shared Memory Multicores or Multiprocessors

Types of Clouds?



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What is Cloud Computing?

<http://www.slideshare.net/PradeepBhatia1/cloud-computing-12724233>



"Cloud computing is a style of computing where massively scalable IT-related capabilities are provided as a service across the Internet to multiple external customers"



"Cloud computing: A pool of abstracted, highly scalable, and managed infrastructure capable of hosting end-customer applications and billed by consumption"



"Clouds are hardware-based services offering compute, network and storage capacity where: Hardware management is highly abstracted from the buyer, Buyers incur infrastructure costs as variable OPEX, and Infrastructure capacity is highly elastic"



"Cloud computing is Web-based processing, whereby shared resources, software, and information are provided to computers and other devices (such as smart phones) on demand over the Internet."

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Common Attributes of Cloud Computing

- Pooled Computing & Storage
 - Resource Virtualization
- Delivered Over the Internet
- Elastic Capacity Scaling
- Self Provisioning
- Pay-per-Use Pricing
- Provide Resources as a Service

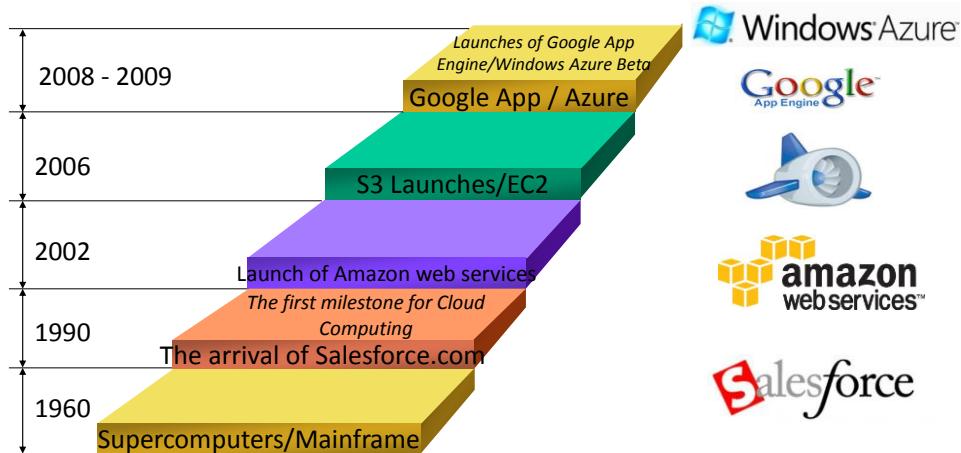


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Evolution of Cloud Computing



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Why Cloud Computing?

Reduces TCO

- Savings on Capital Investment
- Savings on Data Center Space, Power and Cooling
- Minimizes Operational costs



Reduces Risks

- Eliminates capacity planning and sizing
- Prevents 'success disaster'
- Eliminates scalability issues and risk of failure



Better Budget Utilization

- Re-invest saved Capex on new initiatives
- Focus on business, not on infrastructure
- Save on operations manpower



Remain Competitive

- Quicker Time to Market
- Create dev and test environments on the fly
- Rely on speed & stability of the Cloud provider



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Enabling Technologies

➤ Virtual Machines

- Main Players: [VMWare](#), [XenSource](#), SWsoft/Parallels, Microsoft
- Commodity multi-core, 64-bit servers; HW assisted virtualization, e.g. Intel VT, (runs unmodified OS at near native speeds), Integration of VM into mainstream server OS's.
- Improves utilization of servers; allow agile deployment; on demand live migration

➤ Virtualized Storage

- Distributed FS: Google File System (GFS), Hadoop Distributed File System (HDFS)
- Cluster FS: VMware vStorage VMFS, XenServer Storage Pool

➤ Web Services

- SOAP: XML Messages, Webservice Description Language, WS-*
- REST/RESTful: GET, POST, PUT, DELETE for HTTP, more lightweight HTTP/JSON schemes

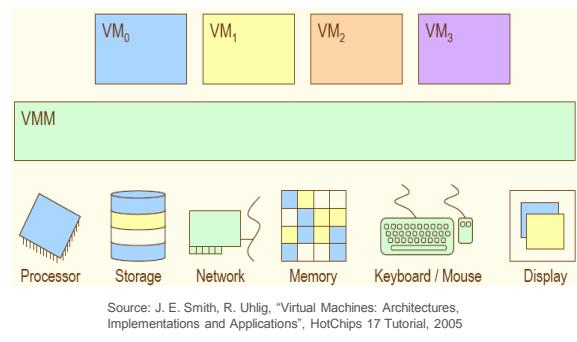
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Virtualization as an Enabler – Introduction

- Enable multiple virtual processing environments (VMs) to run independently on a single physical device
- Decoupling software layer from hardware and OS
- Either share processing resources or work on own dedicated ones
- VMM (Virtual Machine Monitor) arbitrates requests to access system resources

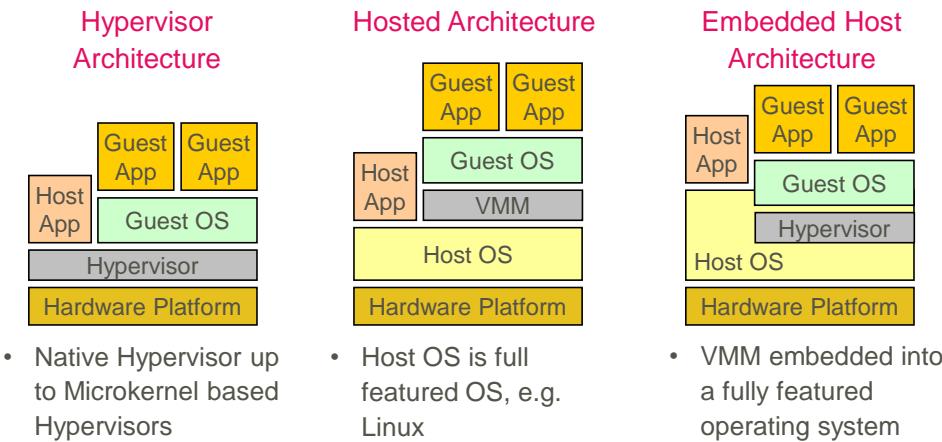


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Virtualization as an Enabler – Architectures

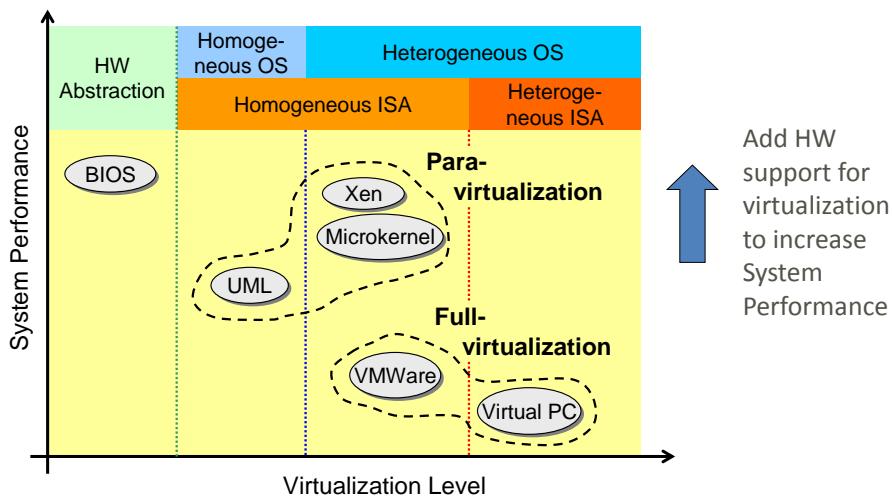


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Virtualization as an Enabler – Approaches



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Web Services

w3schools.com
the world's largest web development site
educate yourself!
beginners and experts

Search w3schools.com:
Google Custom Search

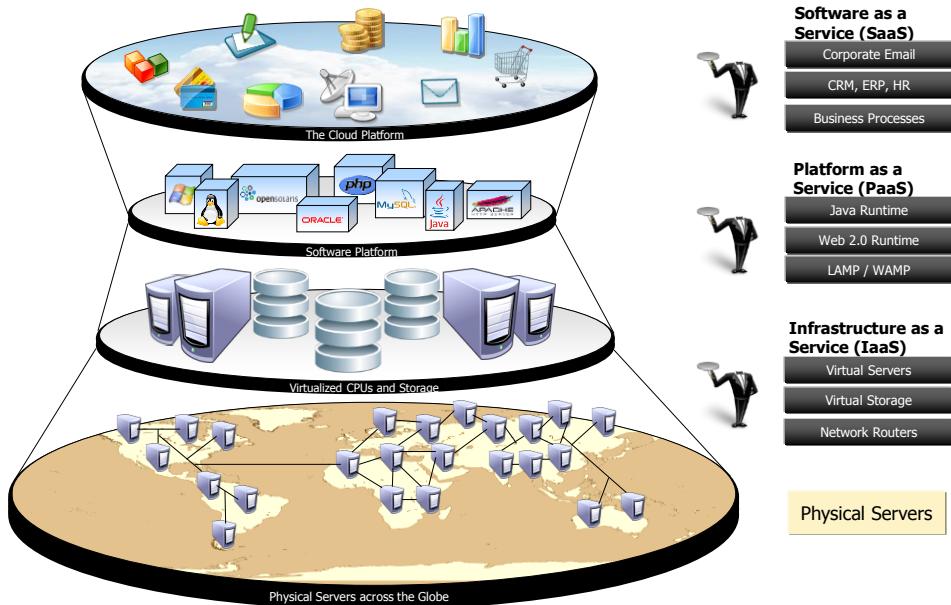
| | | | |
|--|---|---|--|
| HTML/CSS | HTML | CSS | JavaScript |
| Learn HTML Learn HTML5 Learn CSS Learn CSS3 Learn Bootstrap |  HTML Tutorial HTML Tag Reference |  CSS Tutorial CSS Reference |  JavaScript Tutorial JavaScript Reference |
| JavaScript | SQL | PHP | JQuery |
| Learn JavaScript Learn JQuery Learn jQueryMobile Learn AngularJS Learn AJAX Learn JSON Learn Google Maps |  SQL Tutorial SQL Reference |  PHP Tutorial PHP Reference |  JQuery Tutorial JQuery Reference |

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What's Inside a Cloud?

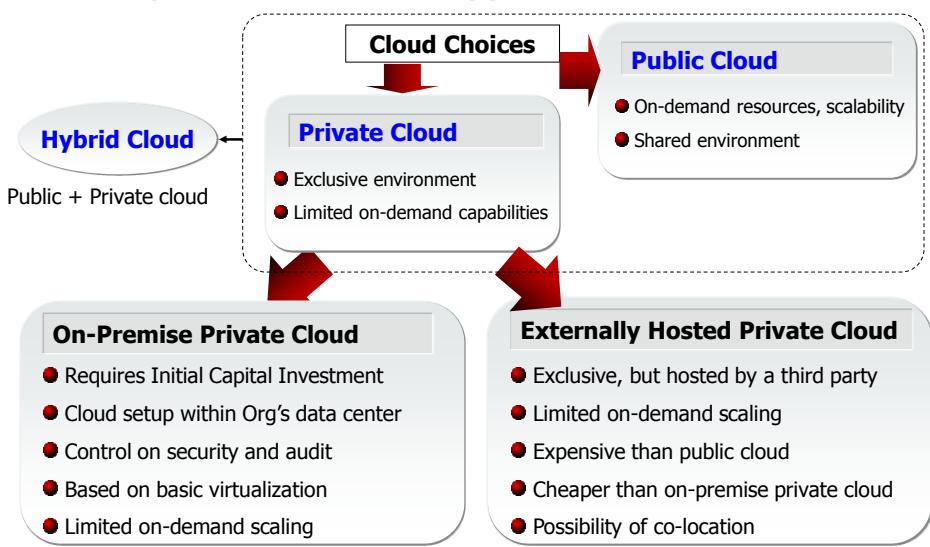


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Cloud Implementation Types: Public vs. Private



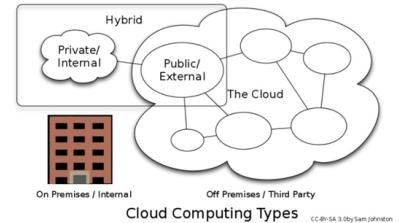
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Private Cloud

- Owned and managed by the enterprise
- Limits access to enterprise and partner network
- Retains high degree of control, privacy and security
- Enables business to more easily customize service
- Accessed from "inside" the firewall



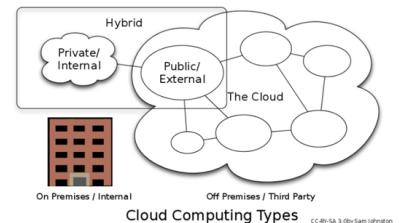
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Public Cloud

- Owned and managed by service provider
- Delivers select set business process, application or infrastructure services on a “pay per use” basis
- Highly standardized
- Limited customization options
- Accessed from "outside" the firewall



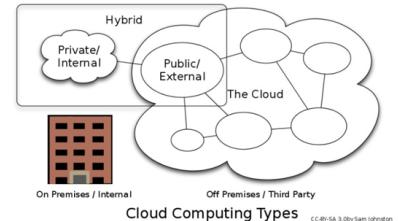
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Hybrid Cloud

- A hybrid infrastructure takes advantage of both public and private clouds:
 - Services provided over the Internet—the public cloud
 - Services provided by the enterprise data center—the private cloud
 - Overflow from private to public cloud

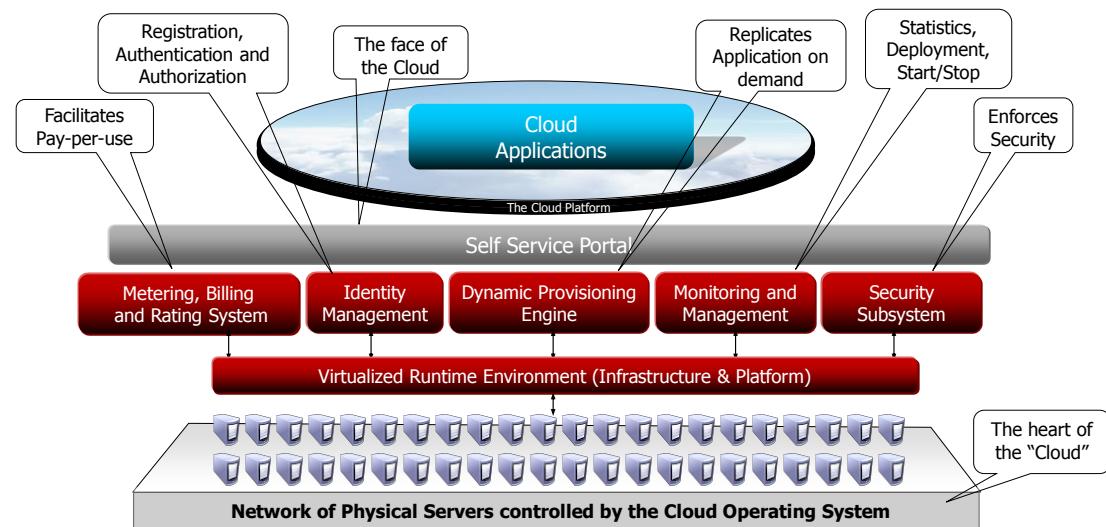


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Inside a Public Cloud



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Cloud Service Providers – A Birds Eye View

Infrastructure
as a Service



Platform
as a Service



Software
as a Service



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Cloud Service Layers - Characteristics

Software as a
Service (SaaS)

- Sometimes free; easy to use; good consumer adoption; proven business models
- You can only use the application as far as what it is designed for

Platform as a
Service (PaaS)

- Developers can upload a configured applications and it “runs” within the platform’s framework;
- Restricted to the platform’s ability only; sometimes dependant on Cloud Infrastructure provider

Infrastructure as
a Service (IaaS)

- Offers full control of a company’s infrastructure; not confined to applications or restrictive instances
- Sometimes comes with a price premium; can be complex to build, manage and maintain

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Cloud Service Layers - Containing

Software as a Service (SaaS)

Collaboration
Business Processes
Industry Applications
CRM/ERP/HR

Platform as a Service (PaaS)

Middleware
Web 2.0 Application Runtime
Development Tooling
Database
Java Runtime

Infrastructure as a Service (IaaS)

Servers
Networking
Storage
Data Center Fabric
Shared virtualized, dynamic provisioning

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Cloud Computing Product Offerings

Amazon EC2 & S3



Google App Engine



Windows Azure



Google App



Panda Cloud



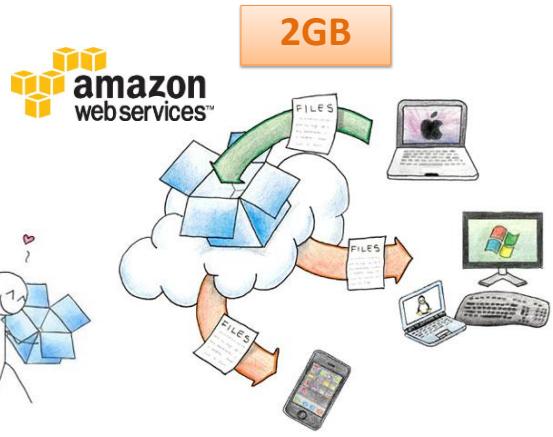
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Amazon Web Service (AWS)

- Amazon is one of the foremost and most reputed Cloud Computing service providers
- Product Offerings include:
Simple Storage Service (S3)
Elastic Compute Cloud (EC2)
SimpleDB



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Amazon Simple Storage Service (S3)

- Object-Based Storage
- 1 B – 5 GB / object
- Fast, Reliable, Scalable
- Redundant, Dispersed
- 99.99% Availability Goal
- Private or Public
- Per-object URLs & ACLs
- US & European Locations

**\$.15 per GB
per month
storage**

**\$.01 for 1000 to
10000 requests**

**\$.10 - .18 per
GB data transfer**

Pay per use



playfish

Dropbox

twitter

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Amazon EC2 – A Detailed Insight



EC2 – Elastic Compute Cloud

- Create a virtual server instance
- Concept of AMI – Amazon Machine Image
- Choose your operating system and/or s/w
- SSH and SFTP to your virtual server
- Web Service interface for admin tasks

S3 – Simple Storage Service

- File System Storage of Arbitrary Data
- Each file can be 5 GB
- Secure storage with ACLs
- Used by SmugMug Photo Service

SQS – Simple Queue Service

- Message Queue Infrastructure
- Reliable delivery

Elastic Map Reduce

- Infrastructure for data-intensive tasks
- Web indexing, data mining, log file analysis

Simple DB

- Core Database Functions
- Fast Indexing, Querying and retrieval

Elastic Cloud Front

- Infrastructure for content delivery
- Based on closest geographical location

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Amazon EC2 - Pricing Details

Light Utilization Reserved Instances

| Region: | US East (Virginia) | 1 yr Term | 3 yr Term | Linux/UNIX Usage | Windows Usage |
|---|--------------------|-----------|------------------|------------------|---------------|
| Standard Reserved Instances | | | | | |
| Small (Default) | \$97.50 | \$150 | \$0.05 per hour | \$0.07 per hour | |
| Large | \$390 | \$600 | \$0.20 per hour | \$0.28 per hour | |
| Extra Large | \$780 | \$1200 | \$0.40 per hour | \$0.56 per hour | |
| Micro Reserved Instances | | | | | |
| Micro | \$23 | \$35 | \$0.012 per hour | \$0.018 per hour | |
| High-Memory Reserved Instances | | | | | |
| Extra Large | \$555 | \$852.50 | \$0.285 per hour | \$0.355 per hour | |
| Double Extra Large | \$1100 | \$1705 | \$0.57 per hour | \$0.71 per hour | |
| Quadruple Extra Large | \$2200 | \$3410 | \$1.14 per hour | \$1.42 per hour | |
| High-CPU Reserved Instances | | | | | |
| Medium | \$195 | \$300 | \$0.10 per hour | \$0.165 per hour | |
| Extra Large | \$780 | \$1200 | \$0.40 per hour | \$0.66 per hour | |
| Cluster Compute Reserved Instances | | | | | |
| Quadruple Extra Large | \$1450 | \$2225 | \$0.742 per hour | \$0.922 per hour | |
| Eight Extra Large | \$1762 | \$2710 | \$0.904 per hour | \$1.114 per hour | |
| Cluster GPU Reserved Instances | | | | | |
| Quadruple Extra Large | \$2410 | \$3700 | \$1.234 per hour | \$1.534 per hour | |

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Google App Engine

Google App Engine (GAE) is a service, offered by Google, that allows developers to build applications that can run on Google's infrastructure.

It is a form of Cloud Computing.



Google App Engine – An Overview

- Cloud computing – Only PaaS & SaaS, No IaaS
- Initially started with Python Runtime
- Recently added support for Java
- Can deploy standard J2EE WAR Files
- Requires a special deployment descriptor
- Provides simple storage as integrated feature
- Storage supports GQL – Google Query Language



| Resource | Unit | Unit cost |
|--------------------|---------------------|-----------|
| Outgoing Bandwidth | gigabytes | \$0.12 |
| Incoming Bandwidth | gigabytes | \$0.10 |
| CPU Time | CPU hours | \$0.10 |
| Stored Data | gigabytes per month | \$0.15 |
| Recipients Emailed | recipients | \$0.0001 |

| Quota | Limit |
|------------------------------|-------------------|
| Emails per day | 2,000 |
| Bandwidth in per day | 1,000 MB |
| Bandwidth out per day | 1,000 MB |
| CPU time per day | 6.5 hours per day |
| HTTP Requests per Day | 1,300,000* |
| Datastore API calls per day | 10,000,000* |
| Data stored | 1 GB |
| URLFetch API calls per day.. | 657,084* |

Windows Azure

“ Windows Azure is an integrated cloud solution, utilizing Microsoft products already familiar with IT professionals ”



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Windows Azure



- **Compute** – auto-provisioning 64-bit application containers in Windows Server VMs; supports a wide range of application models
- **Storage** – highly available distributed table, blob, queue, & cache storage services
- **Languages** – .NET 3.5 (C#, VB.NET, etc.), IronRuby, IronPython, PHP, Java, native Win32 code



- **Data** – massively scalable & highly consistent distributed relational database; geo-replication and geo-location of data
- **Processing** – relational queries, search, reporting, analytics on structured, semi-structured, and unstructured data
- **Integration** – synchronization and replication with on-premise databases, other data sources



- **Service Bus** – connectivity to on-premises applications; secure, federated fire-wall friendly Web services messaging intermediary; durable & discoverable queues
- **Access Control** – rules-driven federated identity; AD federation; claims-based authorization
- **Workflows** – declarative service orchestrations via REST-based activities

| Compute Instance Size | CPU | Memory | Instance Storage | I/O Performance | Cost per hour |
|-----------------------|-------------|---------|------------------|-----------------|---------------|
| Extra Small | 1.0 GHz | 768 MB | 20 GB | Low | \$0.05 |
| Small | 1.6 GHz | 1.75 GB | 225 GB | Moderate | \$0.12 |
| Medium | 2 x 1.6 GHz | 3.5 GB | 490 GB | High | \$0.24 |
| Large | 4 x 1.6 GHz | 7 GB | 1,000 GB | High | \$0.48 |
| Extra large | 8 x 1.6 GHz | 14 GB | 2,040 GB | High | \$0.96 |

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Windows Azure



- **Compute**
 - \$0.12 / CPU hour
- **Storage**
 - \$0.15 / GB / month
 - \$0.01 / 10k transactions / month
- **Bandwidth**
 - \$0.10 in / GB
 - \$0.15 out / GB



- **Web Edition (1GB)**
 - \$9.99 / month
- **Business Edition (10GB)**
 - \$99.99 / month
- **Bandwidth**
 - \$0.10 in / GB
 - \$0.15 out / GB



- **Service Bus**
 - \$0.15 / 100k messages
- **Access Control**
 - \$0.15 / 100k tokens
- **Bandwidth**
 - \$0.10 in / GB
 - \$0.15 out / GB

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Windows Azure



Quincy, WA



Chicago, IL



San Antonio, TX



Dublin, Ireland



Generation 4 DCs



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Cloud Computing - Trends

- Large enterprises are building their own private clouds
- Cloud computing will shift the skills needed by IT workers
- IT departments will shrink as users go directly to the cloud for IT resources
- Professional services will be bundled with commodity cloud services

- Cloud-computing resources will become more customizable
- Large enterprises will become part-time cloud-computing vendors
- Cloud computing will unleash innovation
- The browser will be all the desktop software you need

B. Mobile Software Trends

LIQUID SOFTWARE MANIFESTO

Antero Taivalsaari, Nokia Fellow
COMPSAC – 2014



Antero Taivalsaari



Predictions Back in 2006

- 1) The Web will be *the Application Platform*
- 2) The Web Browser will be the Operating System
(for end user applications)
- 3) JavaScript will be the *de facto*
Programming Language of the Web

Additional Predictions Back in 2006

Web-based software will dramatically change the way people develop, deploy and use software:

- 1) No more software installation or upgrades
 - Applications will simply run off the Web.
 - Always run the latest application version; all updates are transparent.
- 2) Instant worldwide deployment!
- 3) Browser as the OS → whoever owns the dominant browser effectively controls the future of software.

The Impedance Mismatch!

| Web Development | Software Development |
|---|--|
| <ul style="list-style-type: none"> • Documents • Page/form oriented interaction • Managed graphics, static layouts • Source code and text favored • Very limited developer APIs • "Holy trinity" of HTML, CSS, JS • Global tree of attributes (DOM) • Ad hoc development practices • "Web engineering" | <ul style="list-style-type: none"> • Applications • Direct manipulation • Programmer-controlled graphics • Binary representations favored • Rich, mature developer APIs • Well defined interfaces • Data encapsulation/abstraction • Established developer practices • Software engineering |

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The Impedance Mismatch (Continued)

| Web Development | Software Development |
|---|--|
| <ul style="list-style-type: none"> • Instant worldwide deployment • Monetization difficult from developer perspective • Developer ecosystem not controlled by any single vendor (W3C, major browser vendors, major service vendors) • Developers write SW against major <u>browsers</u> – not standards | <ul style="list-style-type: none"> • Conventional binary apps • Well established monetization strategies (e.g., app stores) and developer programs • Controlled developer ecosystem (usually by a single vendor) • Well established SDKs and development tools |

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Chris Anderson, Michael Wolff, Wired, September 2010

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The image shows a screenshot of a Scientific American article. On the left, there's a thumbnail of a magazine cover titled "10 World-Changing Ideas" with various headlines like "Robot Power Plants", "Gas from Garbage", and "DNA Translator". The main article title is "SCIENTIFIC AMERICAN™". Below the title, the permanent address is listed as <http://www.scientificamerican.com/article.cfm?id=long-live-the-web>. The article itself is titled "Long Live the Web: A Call for Continued Open Standards and Neutrality". It includes a subtext: "The Web is critical not merely to the digital revolution but to our continued prosperity—and even our liberty. Like democracy itself, it needs defending". At the bottom, it says "By Tim Berners-Lee | Monday, November 22, 2010 | 35".

"The current trend towards custom-built native web apps is disturbing, because that trend is dividing information into separate content silos that are isolated from each other."

-- Tim Berners-Lee, November 2010

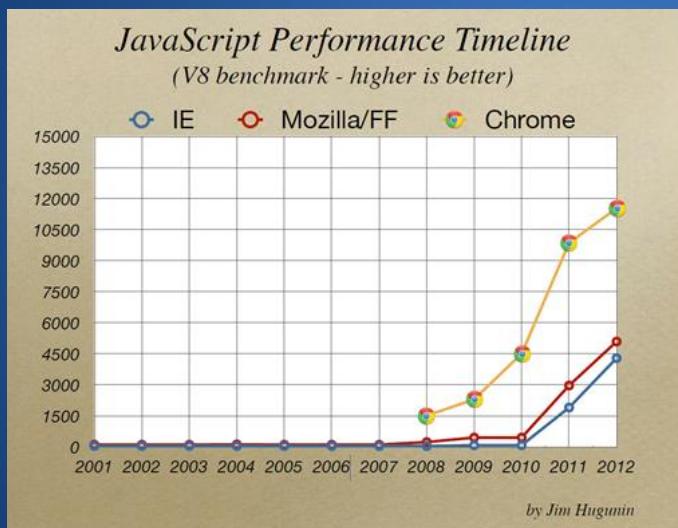
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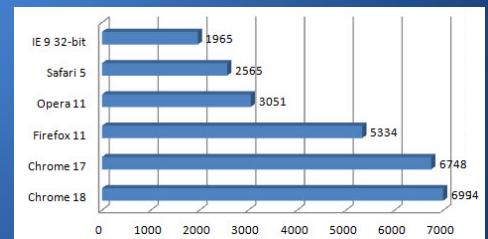
For better or worse, JavaScript has indeed become the programming language of the Web

Caveat: raw JavaScript execution speed does not directly translate into higher web application performance!



<http://whyeye.org/blog/browsers/history-of-javascript-performance/>

JavaScript
Performance
Improvements
Have Exceeded Most
Expectations



However...

The basic challenges have not changed much –
the impedance mismatch is still mostly there

API incompleteness & fragmentation are major
concerns – just like with Java ME ten years ago

Interesting Trends in the Mobile Web Area

Backend as a Service (BaaS)

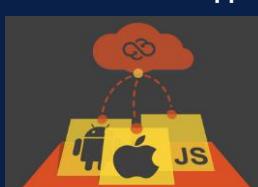
Motivation and Background

- The landscape of mobile software development has changed considerably in the past ten years.
- Today's mobile applications are rarely standalone; rather, applications must commonly
 1. talk with various third party data services,
 2. work on a number of different platforms, and
 3. stay in sync across a number of devices that the user has.
- The dependence on various backend features has led to the emergence of *Backend as a Service (BaaS)* systems.
 - Goal: abstract away all the complexity related to the cloud

Backend as a Service (BaaS)

- **Backend as a Service:** *a model for providing web and mobile app developers with a way to link their applications to hosted backend cloud storage while also providing features such as user management, push notifications, and integration with social networking services, all as an integrated offering.*
- Key goal is to **abstract away all the complexity related to cloud and cloud management**, and provide simple APIs that can be used across all popular mobile platforms.
 - “Don’t worry about the server side, we’ll take care of it for you.”
- This is a very popular area these days; 40+ startup companies in this area have sprung up recently.

BaaS – Commonly Provided Features

Data Storage**Push Notifications****3rd Party Data Integration****User Management****Cross-Platform Support****Versioning, analytics, etc.**

(differentiators)

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Example Feature Set: Parse.com

Parse was recently acquired by Facebook

**Parse Data**

Store your app's data in the cloud.
No servers necessary.

Parse Hosting

A powerful web presence without all the
hassle.

**Parse Push**

Creating, scheduling, and segmenting push
notifications just got a whole lot easier.

**Parse Social**

Make your app social. Instantly.

**Cloud Code**

Run custom app code in the Parse Cloud.
Say goodbye to servers.

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Partial List of BaaS Systems / Companies

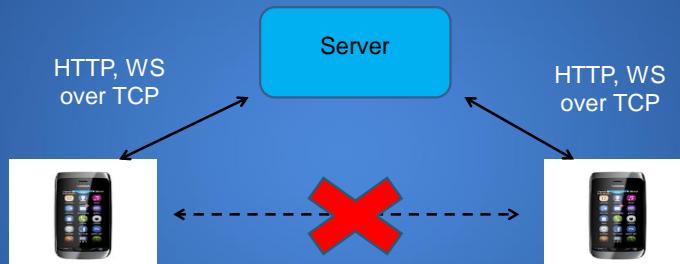
- <http://www.anypresence.com/>
- <http://www.apiomat.com/>
- <http://www.appcelerator.com/>
- <http://www.appy.io/>
- <http://www.aplicasa.com/>
- <http://www.applicationcraft.com/>
- <http://www.apstrata.com/>
- <http://www.baasbox.com/>
- <http://www.backendless.com/>
- <http://www.catavolt.com/>
- <http://www.cloudmine.me/>
- <http://www.convertigo.com/>
- <http://www.dreamfactory.com/>
- <http://www.fatfractal.com/>
- <http://www.feedhenry.com/>
- <http://www.icenium.com/>
- <http://www.innoquant.com/>
- <http://www.instanext.com/>
- <http://www.jaystack.com/>
- <http://www.kii.com/>
- <http://www.kinvey.com/>
- <http://www.kumulos.com/>
- <http://www.mobdb.net/>
- <http://www.netmera.com/>
- <http://www.openmobster.com/>
- <http://www.parse.com/>
- <http://www.proxomo.com/>
- <http://www.quickblox.com/>
- <http://www.shephertz.com/>
- <http://www.sencha.com/products/space/>
- <http://www.stackmob.com/>
- ...

WebRTC – Browser as the Universal Communication Platform

WebRTC in a Nutshell

- WebRTC will enable universal voice calling, video calls, and P2P file/data sharing in a generic web browser without any plugins or add-on components.
- Forthcoming W3C standard (see www.webrtc.org) – already supported by Google Chrome and Mozilla Firefox.
- At the implementation level, WebRTC consists of three fairly simple APIs:
 - `getUserMedia` – camera + audio access
 - `RTCPeerConnection` – set up audio/video calls
 - `RTCDataChannel` – P2P data transfer
- <http://www.webtutorials.com/content/2013/05/eleven-answers-webrtc-explained.html>, <http://apprtc.appspot.com/>

Some Background – Traditional Web

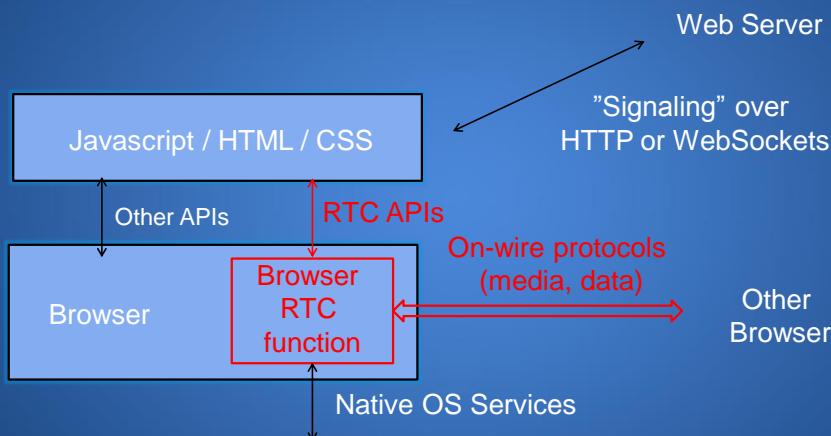


Pure client-server interactions, no peer-to-peer transfer
Only TCP (reliable, in order), no UDP transport

WebRTC

- WebRTC adds APIs and protocols that allow web applications to do peer-to-peer and real-time communication without platform-specific or service-specific plugins
- Joint effort by W3C and IETF
 - Builds upon W3C's HTML5 and IETF's real-time and security protocols

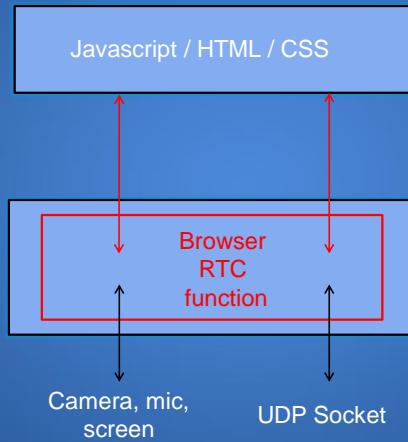
Architecture Overview



APIs (defined by W3C)

getUserMedia

- Capture media stream from a (video)camera, microphone or screen
- Subject to user consent
- Other usages than just WebRTC



RTCPeerConnection

- Establish a secure P2P transport connection to another browser/peer
- Attach local media streams to it to be sent
- Receive remote media streams
- Control aspects such as media types, codecs, bitrates, synch, ...
- In addition, **RTCDataChannel** for P2P "data"

Protocols (defined by IETF)

Browser
RTC
function

- **Secure RTP/RTCP** to carry audio and video
 - DTLS-SRTP key exchange
- **SCTP/DTLS** for data channel
 - Both reliable and unreliable modes
- **ICE** with **STUN** and **TURN** for NAT traversal
 - Establish the optimal path
- These are generally the same protocols e.g. SIP, XMPP/Jingle (GoogleTalk) and FaceTime clients use

WebRTC is a free, open project that enables web browsers with Real-Time Communications (RTC) capabilities via simple JavaScript.

Our mission: To bring the power of real-time communication to the Web. We believe that the Web is the best platform for real-time communication, and that it should be easy for anyone to build real-time communication into their web application.

WebRTC

APIs and tools for building real-time communication into the Web.

The WebRTC team.

Supported browsers

The WebRTC API is now available in:

-  [Chrome's stable version](#) [Chrome WebRTC Release Notes](#)
-  [Firefox's stable version](#)
-  [Opera's stable version](#) New!

Chrome, Firefox and Opera [can now "talk"](#).

Developers, learn more here:

- The [Intro to WebRTC](#) video
- The [Getting Started](#) guide
- The [W3C WebRTC API](#) draft
- The [HTML5 Rocks](#) guide to WebRTC
- The [webplatform.org](#) documentation
- The [W3C WebRTC](#) workgroup list
- The [IETF Rtcweb](#) workgroup list
- The [WebRTC Google+](#) page.
- The [WebRTC email list](#).

“Imagine a world where your phone, TV and computer all communicate on a common platform. Imagine it was easy to add video chat to your web application. That's the vision of WebRTC.”

“WebRTC is a new front in the long war for an open and unencumbered Web.”

-- Brendan Eich (Mozilla CTO; inventor of the JavaScript language)

Give it a try @ <http://apprtc.appspot.com/>

New Languages to Replace/Complement JavaScript?

- Web development can be far too dynamic and error-prone for many software developers.
- There are numerous language proposals to make web programming simpler and safer:
 - **CoffeeScript** (<http://coffeescript.org/>)
 - **Dart** (<http://www.dartlang.org/>)
 - **JSX** (<http://jsx.github.io/>)
 - **TypeScript** (<http://www.typescriptlang.org/>)
- A new version of JavaScript (ECMAScript 6) is also being standardized, with similar improvements/abstractions.

11/20/2014 (J.P. Shen)

CMU 18-640 - Lecture 21

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Tectonic Shifts:
how the mobile industry keeps reinventing itself

The fundamental business model changes behind the apps phenomenon, the evolution of mobile ecosystems, and the future of HTML5 vs. native

WWW.VISIONMOBILE.COM/MEGATRENDS14

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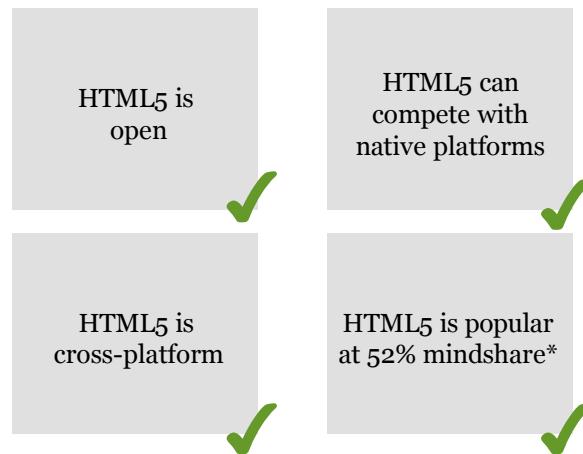
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The future of HTML5 mobile is bright



*source: VisionMobile Developer Economics Q1 2014 & Q3 2013

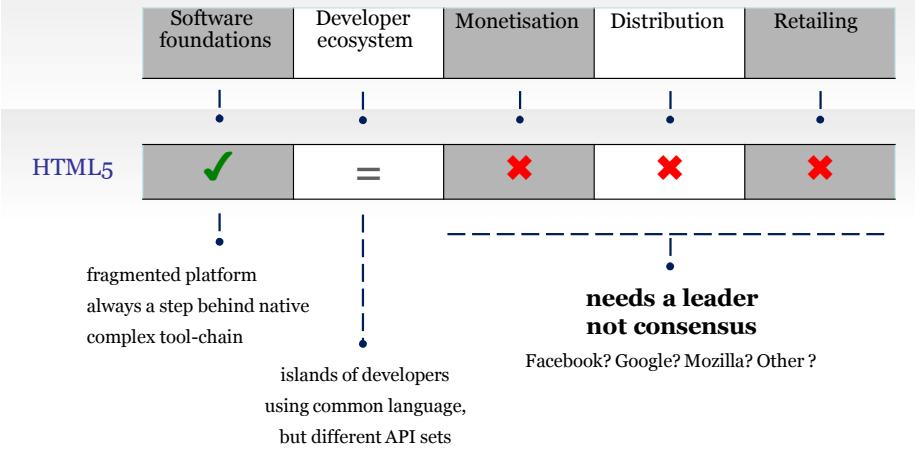
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HTML5 is a technology, IT won't replace mobile platforms

lacks key ingredients to compete with leading mobile platforms

Key ingredients



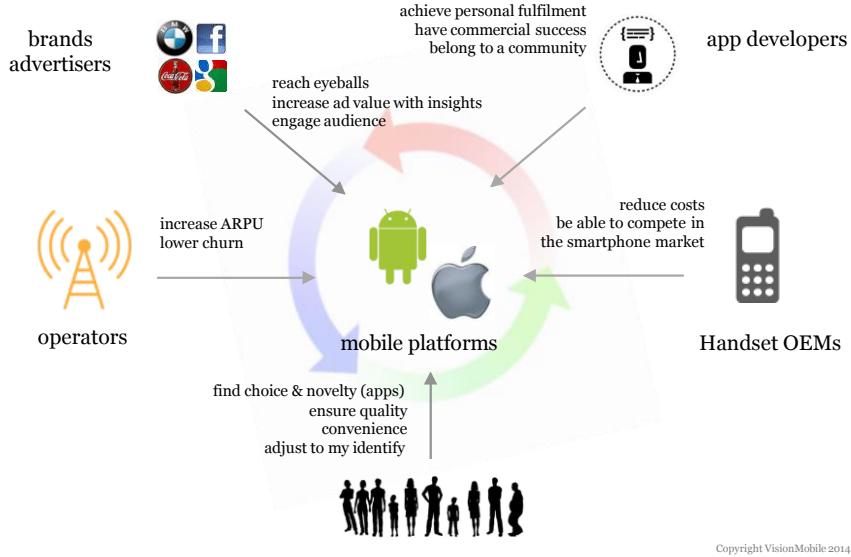
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Openness is not within primary audience needs

The open nature of HTML5 doesn't intrinsically help anybody do their job better



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Google & Facebook are creating new web walled gardens

adding missing ingredients on top of HTML5 enabling technology

| Key ingredients | Software foundations | Developer ecosystem | Monetisation | Distribution | Retailing |
|-----------------|--|--|---|---|---|
| | application runtime, developer tool-chain, & platform APIs | Developers building and publishing apps around the software foundation | micropayments, ad networks and settlement | app distribution to end users through SaaS or devices | app discovery, promotion, placement, search & recommendations |
| | HTML5 browsers (fragmentation) | web developers | ? | ? | ? |
| | HTML5 with Chrome API | web developers | Google Wallet | PC, Mac, Android, iOS, Chrome OS | Chrome Web Store |
| | HTML5 with Facebook APIs | web, Flash and mobile developers | Facebook Credits | 1B+ Facebook users | Facebook app recommendations |

HTML5 may end up a yet another walled garden despite the promise of openness

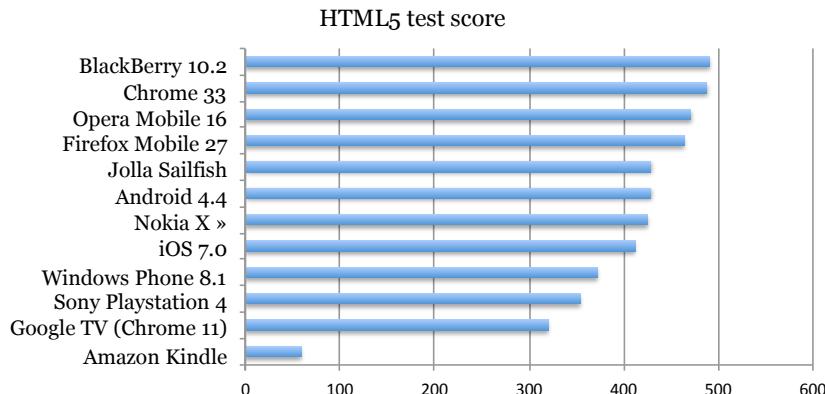


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Browsers are heavily fragmented across platforms

HTML5 features and APIs vary widely across browsers



Source: html5test.com, April 2014.

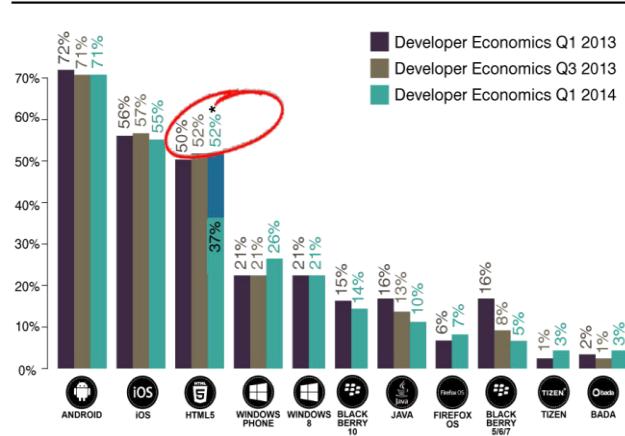
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HTML5 Is the 3rd choice among mobile developers

MOBILE DEVELOPER MINDSHARE, Q1 2014
% of developers using each mobile platform (n=6,311)



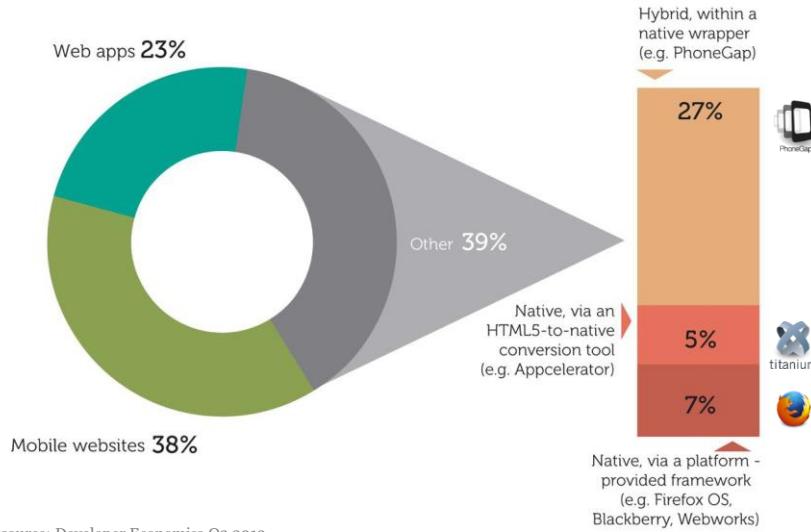
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39% of HTML5 Mobile devs are going beyond the browser

Overall five HTML5 technology routes to market to choose from



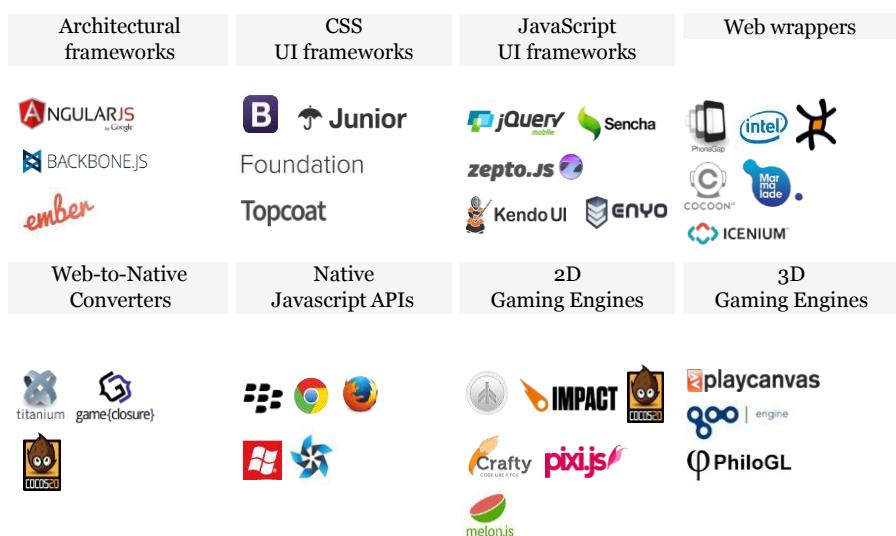
*source: Developer Economics Q3 2013

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A flurry of tools to support off-browser web apps

Hundreds of tools to make that possible



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