Extending the Capabilities of the Internet to the Rural Developing World

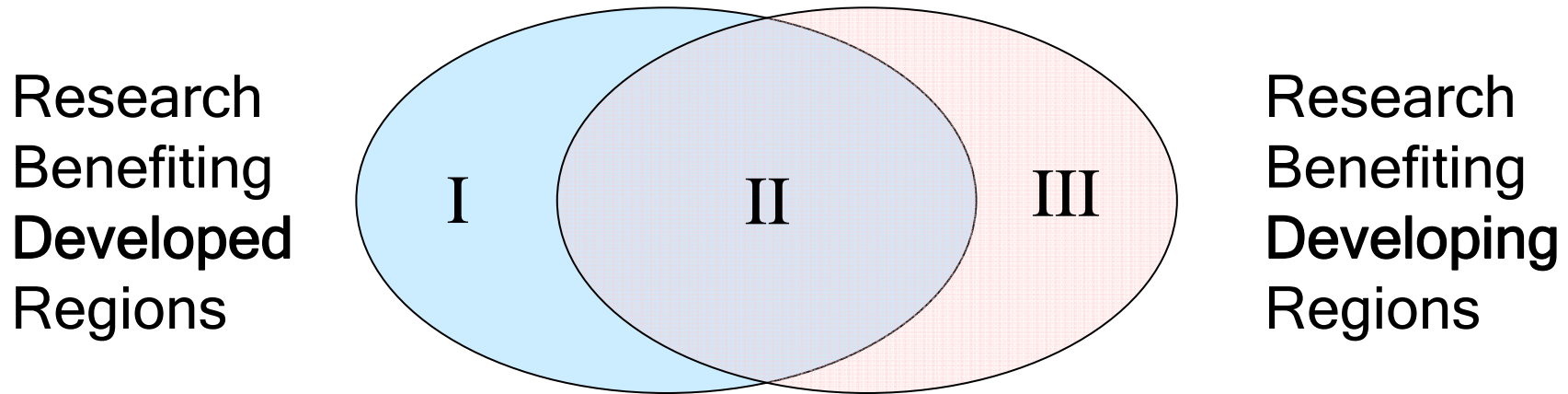## Bill Thies

Computer Science and Artificial Intelligence Laboratory

Massachusetts Institute of Technology

Carnegie Mellon University

April 25, 2008

Technology *Research* for Developing Regions

Research Benefiting **Developed** Regions

I   II   III

Research Benefiting **Developing** Regions

- Most research falls in intersection (II)
  - Invented for developed areas, later applied in developing areas
  - Examples: computers, cell phones, Internet, …
  - Many people are working in this area

Technology *Research* for Developing Regions

Research Benefiting **Developed** Regions

Research Benefiting **Developing** Regions

I   II   III
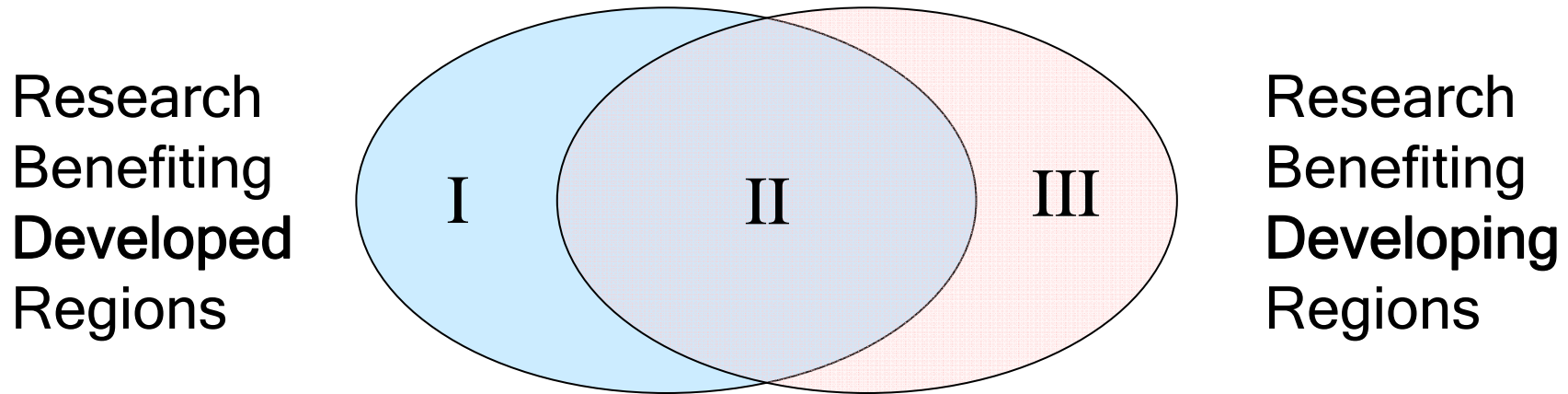
- How to target developing regions (III)?
    1. Identify trend, constraint or opportunity that is present in developing world, but not in developed world
    2. Invent technology to exploit or compensate for the trend
    3. Result would not have been invented in developed world

- Strive for deep, novel, long-term research innovations
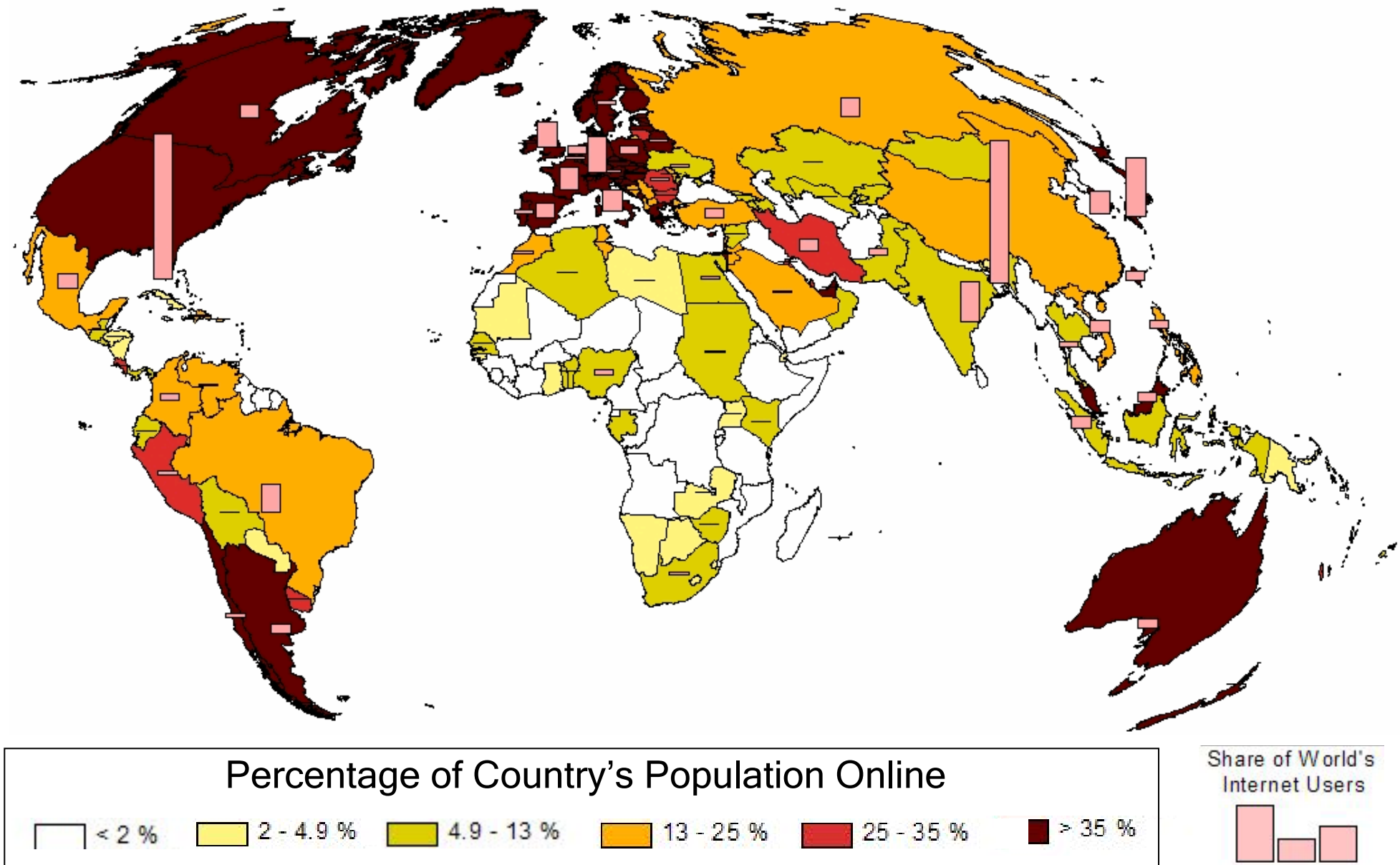   - Fewer people working in this area → large potential impact

In This Talk: Three Directions

1. Retrieving information

2. Publishing information

3. Collecting medical data

In This Talk: Three Directions

1. Retrieving information

2. Publishing information
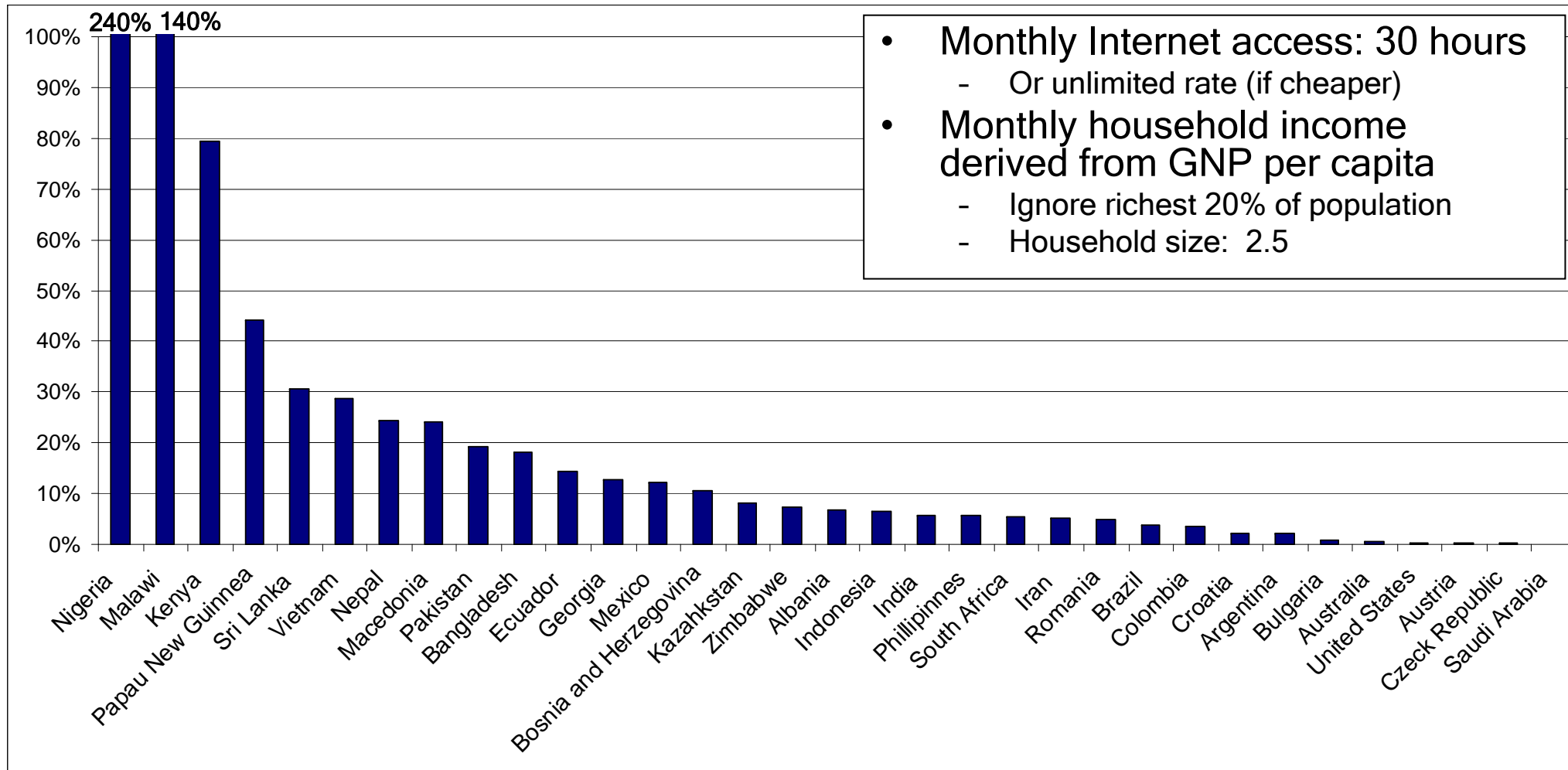
3. Collecting medical data

Internet Users Worldwide

Percentage of Country's Population Online

☐ < 2 %   ☐ 2 - 4.9 %   ☐ 4.9 - 13 %   ☐ 13 - 25 %   ☐ 25 - 35 %   ■ > 35 %

Share of World's Internet Users
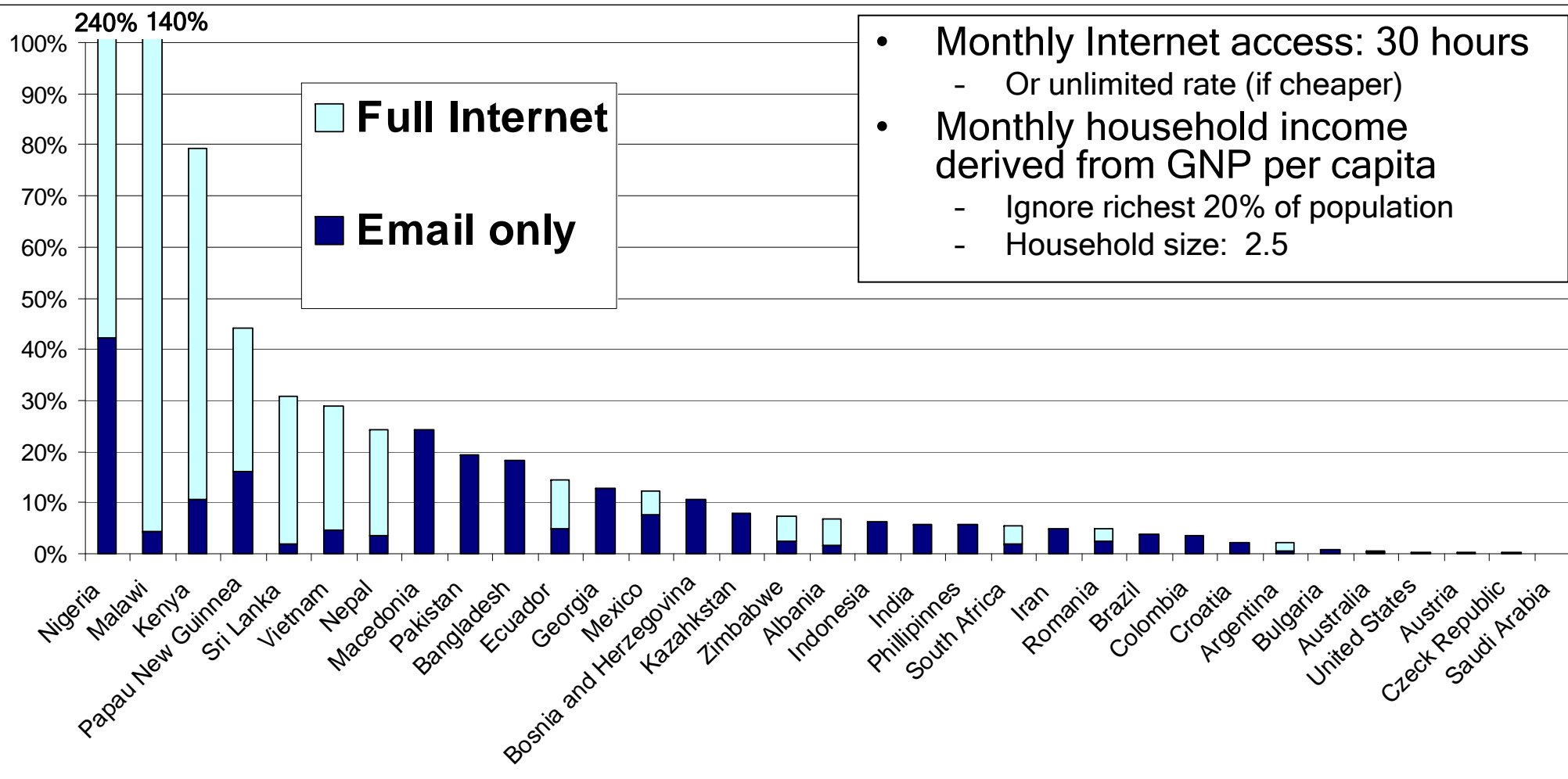
Barriers to Internet Access

- Infrastructure
  - Limited phone lines
  - Low-bandwidth international links
  - Unreliable power supplies

- High costs
  - Computer unaffordable or unavailable
  - ISP, telephone costs can exceed local wage
  - Exacerbated by slow connections

- Social barriers
  - Illiterate or non-technical users
  - Lack of local content

Cost of Dial-up Internet Access
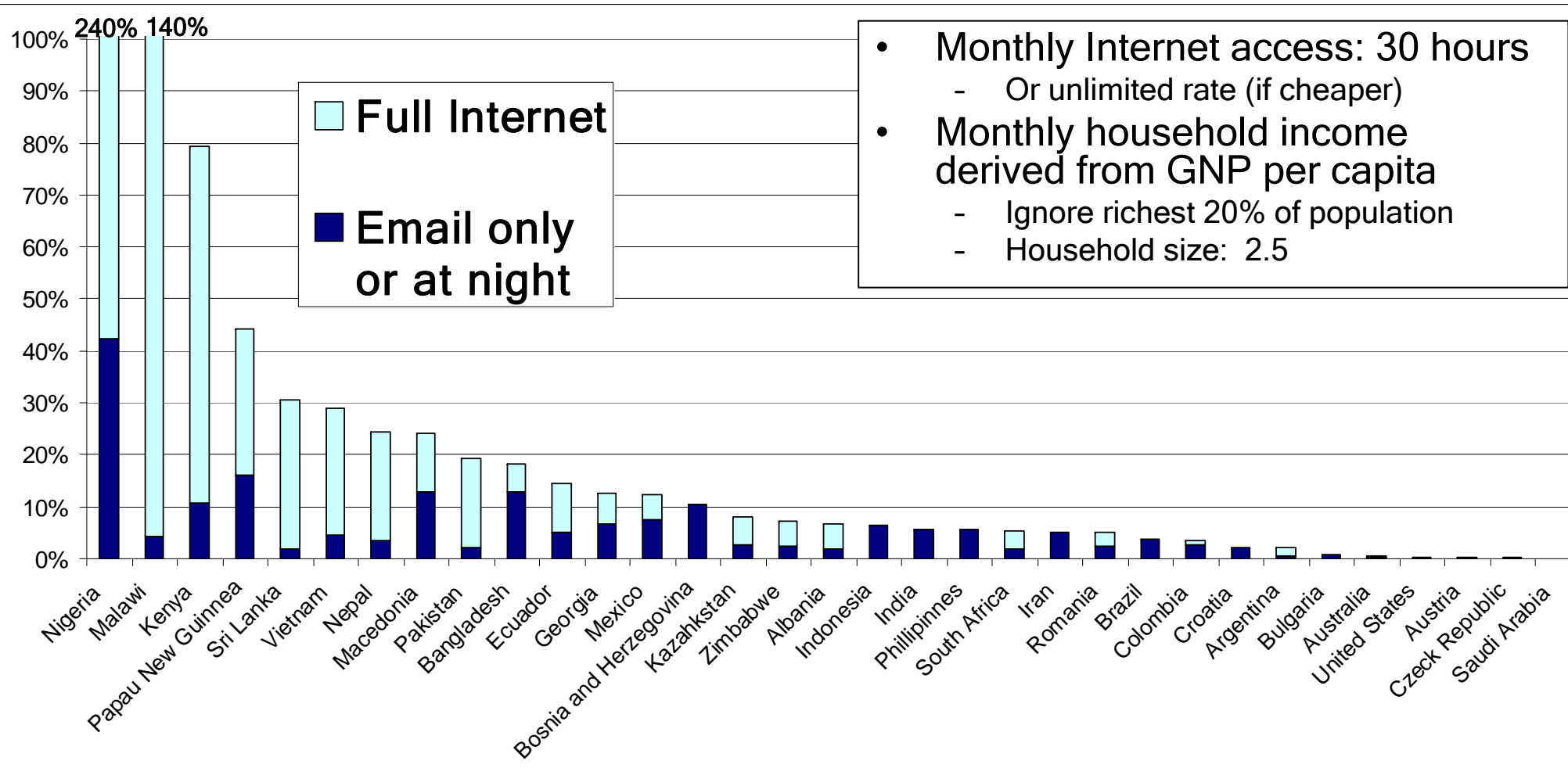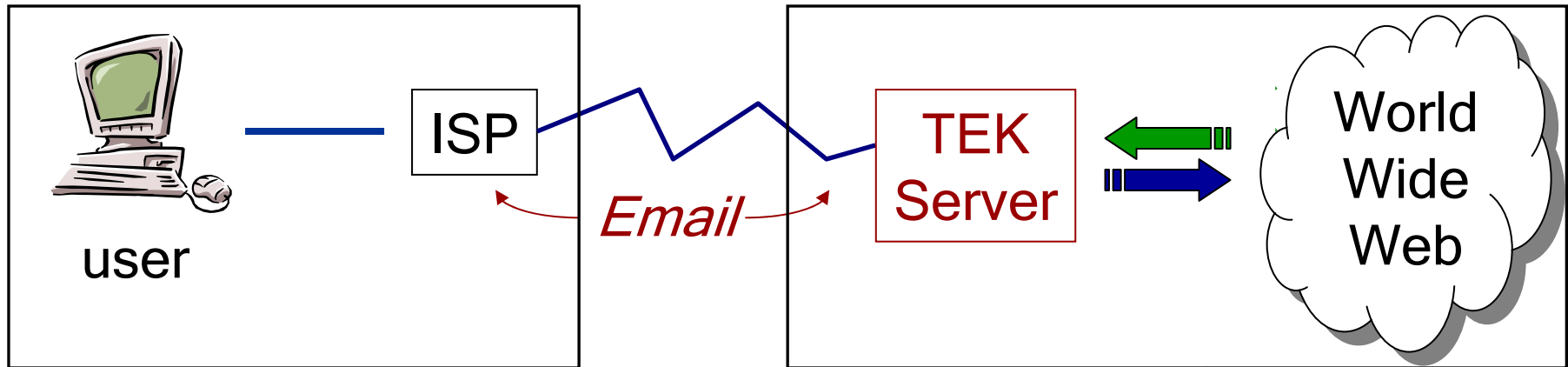# as a Fraction of Household Income

240% 140%

Chart data (left to right):
- Nigeria: 240% (bar capped at 100%)
- Malawi: 140% (bar capped at 100%)
- Kenya: ~80%
- Papau New Guinnea: ~44%
- Sri Lanka: ~31%
- Vietnam: ~29%
- Nepal: ~24%
- Macedonia: ~24%
- Pakistan: ~19%
- Bangladesh: ~18%
- Ecuador: ~14%
- Georgia: ~13%
- Mexico: ~12%
- Bosnia and Herzegovina: ~11%
- Kazahkstan: ~8%
- Zimbabwe: ~7%
- Albania: ~7%
- Indonesia: ~7%
- India: ~6%
- Phillipinnes: ~6%
- South Africa: ~5%
- Iran: ~5%
- Romania: ~5%
- Brazil: ~4%
- Colombia: ~4%
- Croatia: ~2%
- Argentina: ~2%
- Bulgaria: ~1%
- Australia: ~1%
- United States: ~0%
- Austria: ~0%
- Czech Republic: ~0%
- Saudi Arabia: ~0%

Y-axis: 0% to 100% in 10% increments

- Monthly Internet access: 30 hours
  - Or unlimited rate (if cheaper)
- Monthly household income derived from GNP per capita
  - Ignore richest 20% of population
  - Household size: 2.5

Sources: ISP Websites 2005, UNDP Development Report 2004, WorldBank 2003

Cost of Dial-up Internet Access as a Fraction of Household Income

240% 140%

Legend:
- **Full Internet** (light blue)
- **Email only** (dark blue)

- Monthly Internet access: 30 hours
  - Or unlimited rate (if cheaper)
- Monthly household income derived from GNP per capita
  - Ignore richest 20% of population
  - Household size: 2.5

Y-axis: 0% to 100%

Countries (left to right): Nigeria, Malawi, Kenya, Papau New Guinnea, Sri Lanka, Vietnam, Nepal, Macedonia, Pakistan, Bangladesh, Ecuador, Georgia, Mexico, Bosnia and Herzegovina, Kazahkstan, Zimbabwe, Albania, Indonesia, India, Phillipinnes, South Africa, Iran, Romania, Brazil, Colombia, Croatia, Argentina, Bulgaria, Australia, United States, Austria, Czech Republic, Saudi Arabia

Sources: ISP Websites 2005, UNDP Development Report 2004, WorldBank 2003

Cost of Dial-up Internet Access
as a Fraction of Household Income

Legend:
- **Full Internet**
- **Email only or at night**

Text box:
- Monthly Internet access: 30 hours
  - Or unlimited rate (if cheaper)
- Monthly household income derived from GNP per capita
  - Ignore richest 20% of population
  - Household size: 2.5

240% 140%

Countries (left to right): Nigeria, Malawi, Kenya, Papau New Guinnea, Sri Lanka, Vietnam, Nepal, Macedonia, Pakistan, Bangladesh, Ecuador, Georgia, Mexico, Bosnia and Herzegovina, Kazahkstan, Zimbabwe, Albania, Indonesia, India, Phillipinnes, South Africa, Iran, Romania, Brazil, Colombia, Croatia, Argentina, Bulgaria, Australia, United States, Austria, Czech Republic, Saudi Arabia

Sources: ISP Websites 2005, UNDP Development Report 2004, WorldBank 2003

TEK: Email-Based Search

Solution has two components:

1. Transfer all data through email, not http
   - Connect only to send/receive email, not to browse web

2. TEK Server optimizes for bandwidth requirements

TEK: "Time Equals Knowledge"

TEK Client

- Implemented as an HTTP Proxy Server bundled with a custom version of Firefox

- When offline, users can:
  - Search and browse old results as if connected
  - Enqueue queries for new results or missing pages

- When online, users can:
  - Send pending queries
  - Receive new results (attached to standard emails)

TEK Server
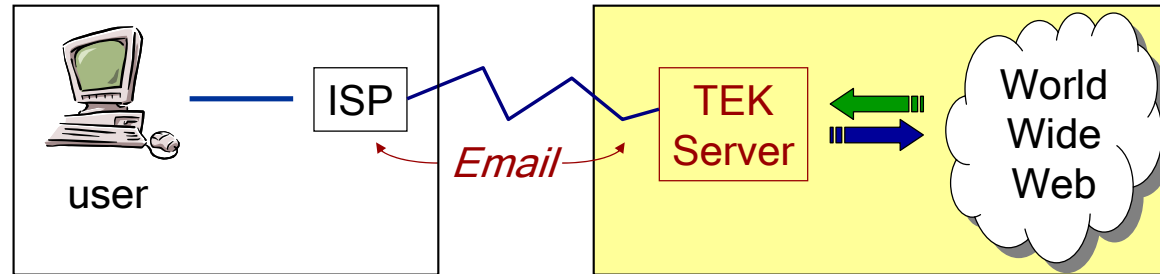
- Queries Google or Scirus for relevant pages

- Returns filtered content of ˜20 pages to user
  - Remove images
  - Remove junk HTML (JavaScript, colors, meta tags, etc.)
  - Convert PDF, PS to HTML

- Compress pages, send as single attachment
  - Overall size reduction: 5-10X on HTML, 10X on PDF

- Maintain server image of client page cache
  - Avoid sending duplicate pages

File   Edit   View   Go   Bookmarks   Tools   Help

http://tek/search2.html

TEK Home

TEK
TIME EQUALS KNOWLEDGE

Private Account of Bill Thies

Logout

| Search | Queries | Results | | Help |

Search for: | | Not: | | Add to list

E.g. "heart attack" AND stress

Get this URL: | | Add to list

tsunami aid   Edit   Delete   Previous results(4)

united nations g8 summit   Edit   Delete   Previous results(30)

Submit list to TEK

© MIT TEK & Scirus 2005

Find: g8   ⊙ Find Next ⊘ Find Previous ▣ Highlight ☐ Match case ⚠ Phrase not found

Done

http://tek/queries.html?status=1   Go

TEK Home

TΞK
TIME EQUALS KNOWLEDGE

Private Account of Bill Thies

Logout

| **Search** | **Queries** | **Results** | | **Help** |

Pending queries (2)

| "global warming" | Refine | | No results yet |
| penicillin allergy | Refine | | No results yet |

Returned queries (6)   Show all returned queries

taro disease	Refine	Delete	59 results	New!
aids symptoms	Refine	Delete	39 results	New!
seaweed farming	Refine	Delete	20 results	Jul 9
hiv diagnosis	Refine	Delete	34 results	Jul 8
aids prevention	Refine	Delete	40 results	Jul 8

© MIT TEK & Scirus 2005

Find: g8   ⊙ Find Next ⊙ Find Previous ▤ Highlight ☐ Match case ⚠ Phrase not found

Done

File   Edit   View   Go   Bookmarks   Tools   Help

http://tek/results2.html?term=aids+treatment&tnot=&main=relevance&page=1   Go   G

TEK Home

TEK
TIME EQUALS KNOWLEDGE

Private Account of Bill Thies

Logout

Search   **Queries**   Results   **Help**

Search for: aids treatment   Not: Local search

Get this URL: Local Search

60 Results

Sort by: best results | newest results

1. HIV symptoms and information on treatment and s...
   http://www.managinghiv.com/

2. HIV/AIDS Prevention
   http://www.avert.org/hivprevention.htm

3. HIV/AIDS - aids, hiv, aids symptoms, hiv testin...
   http://bc.us.yahoo.com/b?P=Si2FO9htdWIn0BF962aNV...

4. Newly Diagnosed: HIV/AIDS Symptoms
   http://my.webmd.com/content/pages/11/1624_50945...

Find: g8   Find Next   Find Previous   Highlight   Match case   Phrase not found

Done

Testing Positive for Aids/HIV

Your Guide, Tracee Cornforth[i-Your Guide, Tracee Cornforth]

From Tracee Cornforth, Your Guide to Women's Health. **FREE** Newsletter. Sign Up Now!

What does testing positive for HIV mean? What is meant by the window period? How does a false positive relate to it?

About.com[i-About.com]
Health & Fitness
Women's Health
Essentials
What Do My Symptoms Mean?Women's
Health TreamentsFrequently Asked Female
Health QuestionsWhat You Need to Know
About Your HealthMost Requested Women's
Health Articles
Articles & Resources
Heart Health for WomenMenopause -
PerimenopauseSexual HealthBirth

A window period is a recommended waiting period to receive an accurate HIV test result. Generally, it is a six-week to six-month period from the moment of your last unsafe sex encounter to the moment that you receive a HIV screening. This is the time your body uses to create antibodies in the blood stream, which signify exposure to HIV. This process is known as seroconversion.

It is important when receiving an HIV test to ask what kind of test is being used. Whenever someone is screened for HIV, two types of tests are used. They are, 1) a reactive test, and 2) a confirmatory test. A reactive HIV test indicates if HIV antibodies are in the blood (such as the Elisa Test). A reactive test may give a false positive reading to

TEK Users

- TEK available on SourceForge and via free CD
- Most active users in partner organizations
  - People's First Network   - United Villages

People's First Network

- Solomon Islands served by HF Radio Network
- Email only
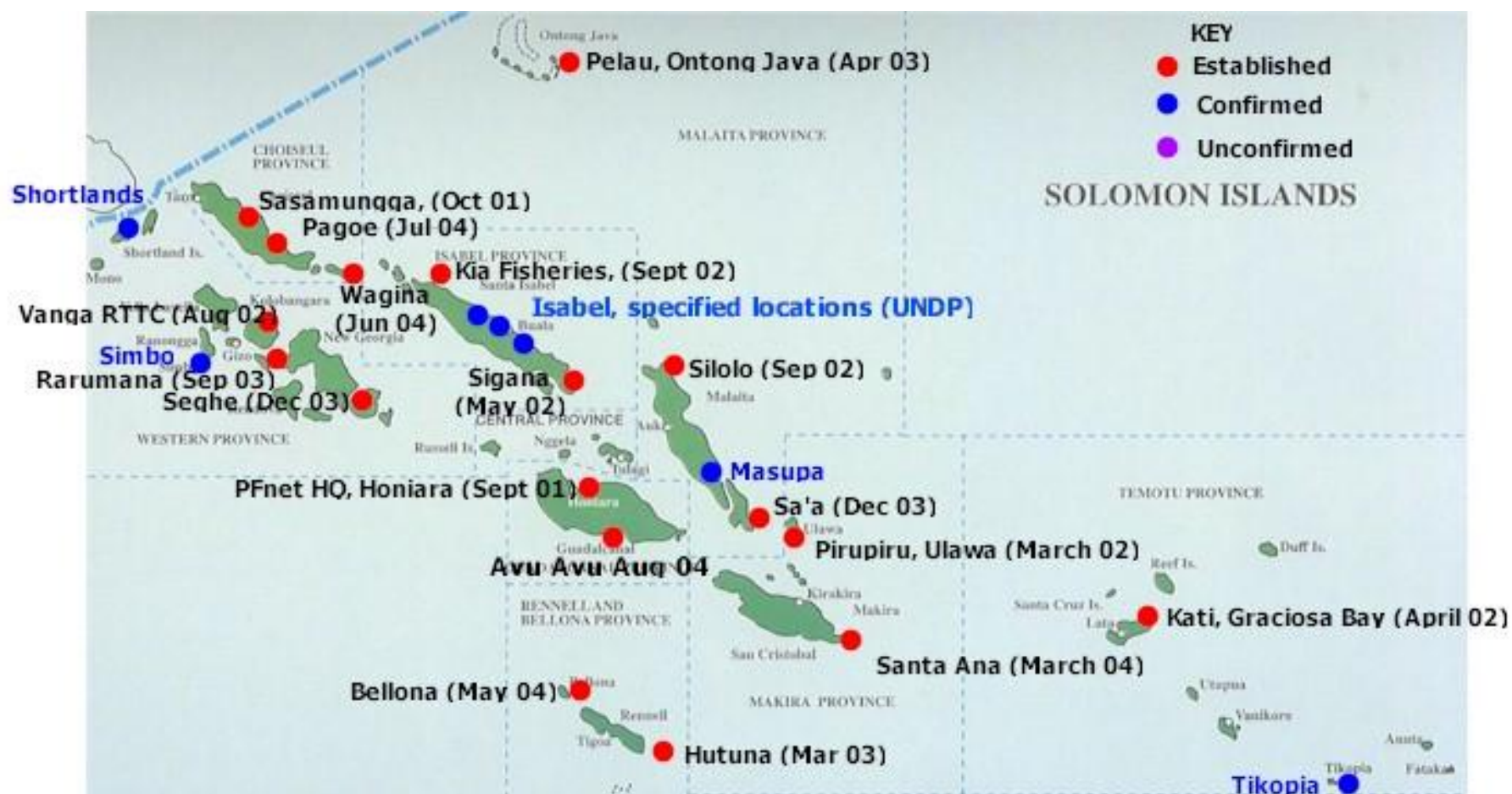
People's First Network

- TEK installed: $0.65 per query from kiosk
    - Compare to $0.25 per email, $0.65 to type one page
    - $1.30 / hour for operator assistance browsing results
    - Contributes to kiosk sustainability

- Many applications reported
    - 1. Farmers – information on diseases; networking

    Subsistence farmers on Rennell have obtained advice concerning taro diseases affecting their crop. Via the **'TEK-websearch'** facility, one group of farmers was able to access detailed technical information about vanilla farming and to communicate with a specialist from the *Kastom Gaden Association.   -- Chand et al., PFNet Case Study, 2005*

    - 2. Teachers – environmental impact of local logging
    - 3. Pastors – downloading sermons
    - 4. Entrepreneurs – download / sell lyrics
    - 5. General – health, education, sports, entertainment

United Villages

- Store-and-forward connectivity via Mobile Access Point

United Villages

- Store-and-forward connectivity via Mobile Access Point

United Villages

- Store-and-forward connectivity via Mobile Access Point
  - India, Costa Rica, Cambodia, Rwanda, Paraguay
- TEK provides only Web access

Source: www.firstmilesolutions.com
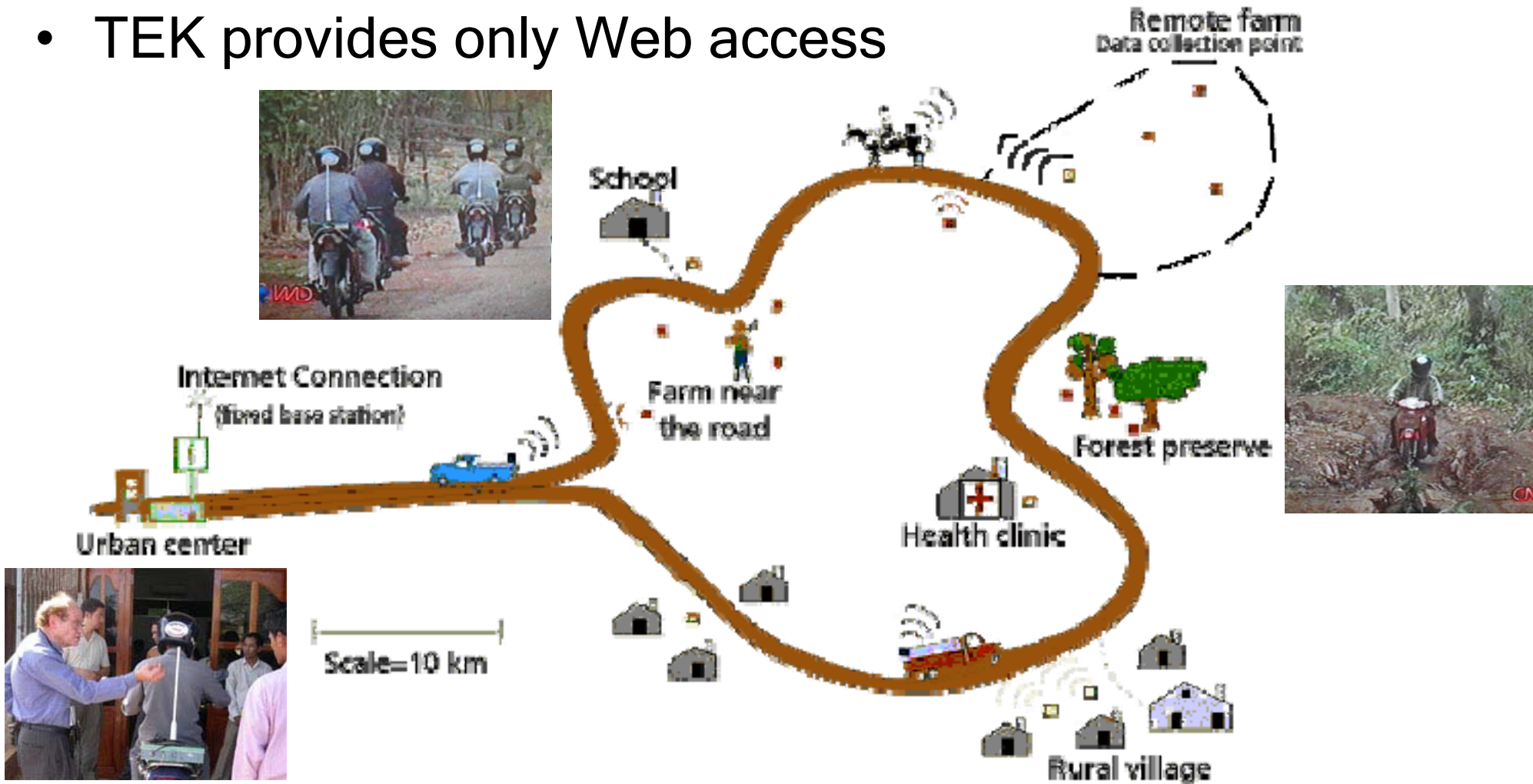
Applications in Developed Countries

- Airplanes
  - Tenzing supplies email-only connection ($10-$20)
    - Continental Airlines, United Airlines, US Airways
  - ~2.4kbs satellite link for entire plane[1]

- Mobile phones
- ISPs charge for bandwidth (Australia)
- Conservative religious sects[2]
- Anxiety about browser security[2]

[1] *http://www.pcworld.com/news/article/0,aid,114216,00.asp*
[2] *anecdotes from EmailWeb users*
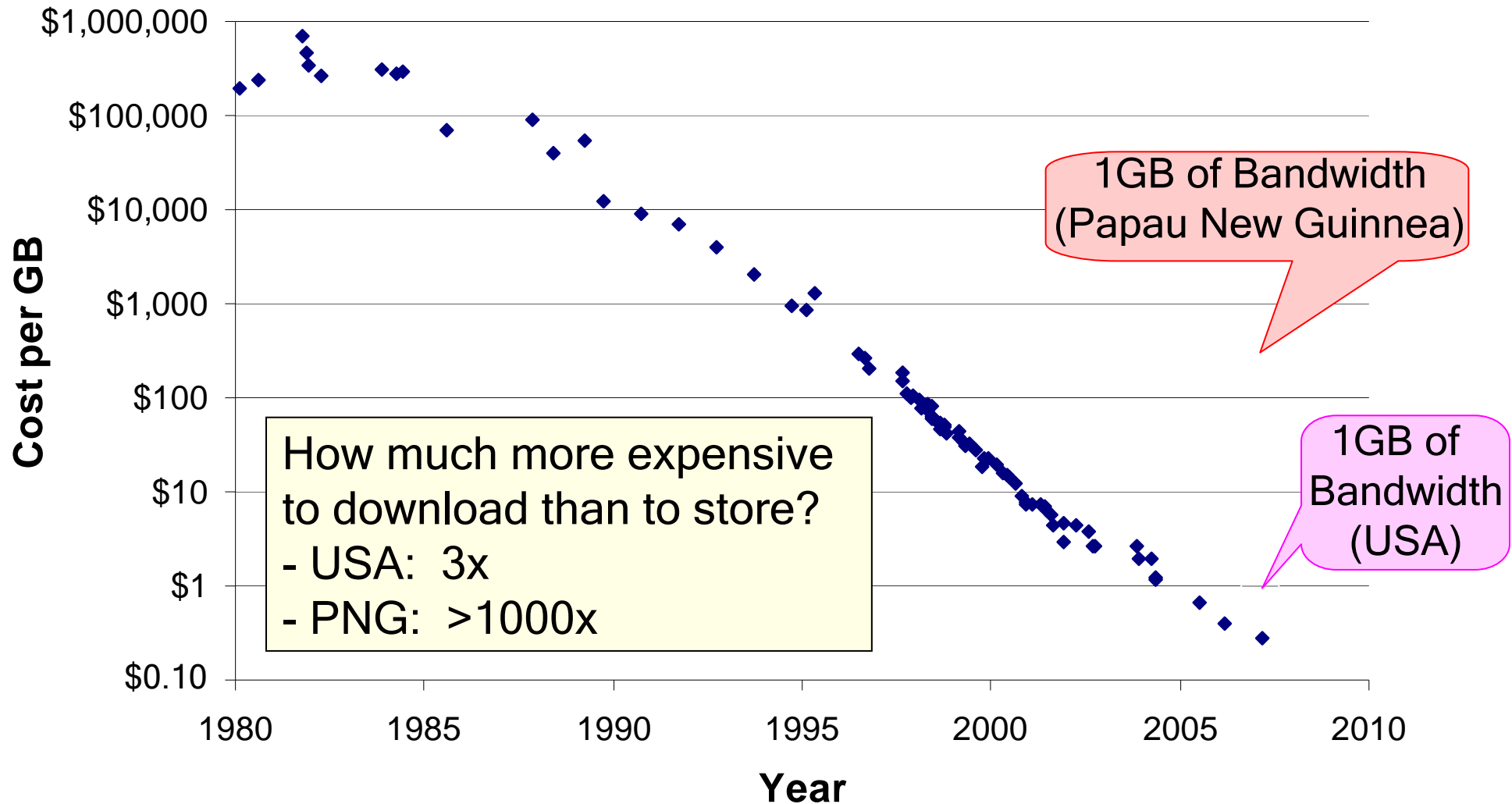
State-Based Compression

- Idea: use client-side storage reduce bandwidth requirements

- If server knows everything stored on client, can it improve compression of search results?

http://www.aidsinfo.nih.gov/

TEK Server

http://www.hivnetnordic.org/index.shtm
http://www.acnl.net/Basic_HIV_&_AIDS_Info.htm
http://www.info.gov.hk/health/aids/
http://www.cdc.gov/hiv/graphics/women.htm
http://www.med.unsw.edu.au/nchecr/
http://www.utopia-asia.com/aids.htm
http://www.sfaf.org/aids101/hiv_testing.html
http://www.gaytoronto.com/casey/

http://www.hivnetnordic.org/index.shtm
http://www.acnl.net/Basic_HIV_&_AIDS_Info.htm
http://www.info.gov.hk/health/aids/
http://www.cdc.gov/hiv/graphics/women.htm
http://www.med.unsw.edu.au/nchecr/
http://www.utopia-asia.com/aids.htm
http://www.sfaf.org/aids101/hiv_testing.html
http://www.gaytoronto.com/casey/

State-Based Compression

- General problem:
  If two parties share a large dictionary, can they reduce communication bandwidth?

- In general: no
  - info content (index) = info content (entry)

- In practice: maybe
  - Space of inputs is not uniformly populated
    - E.g., many images are text, bullets, smileys, patterns
  - Lossy: send index of closest match in dictionary
  - Lossless: send exact diff from dictionary entry

Photo Mosaics

- Mosaic: picture made of other pictures
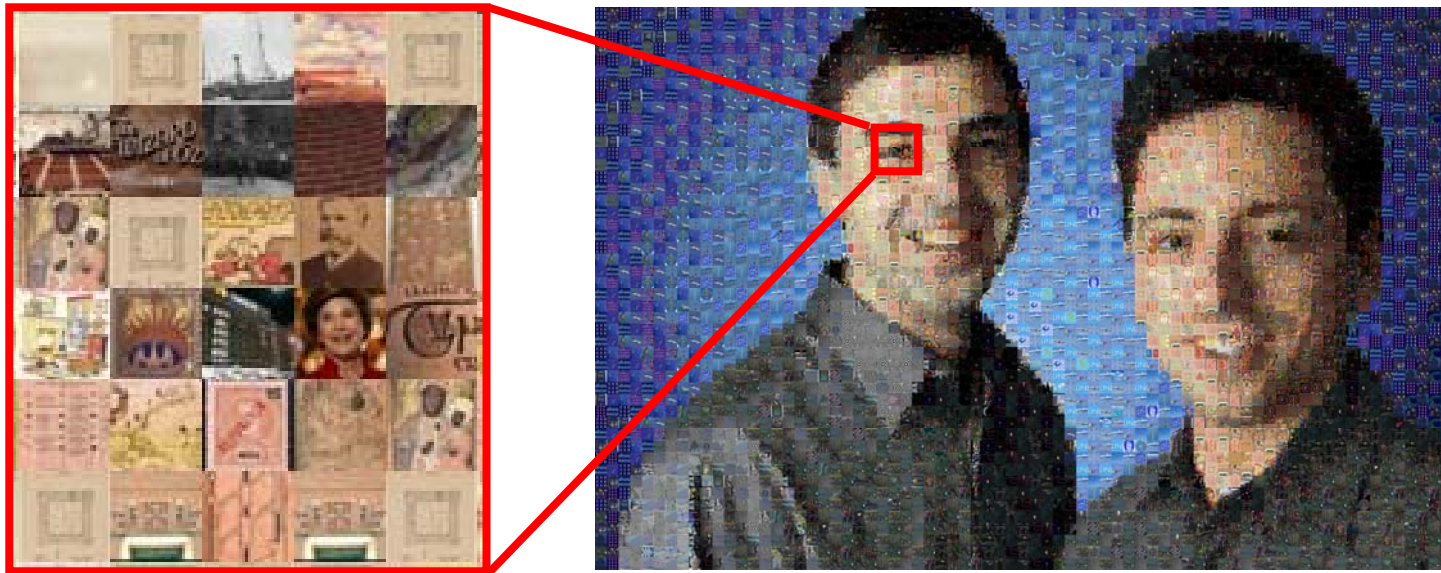
1. Break image into cells
2. Match each cell against image library
   - Use wavelet decomposition for perceptual match

Mosaic Compression
(Samidh Chakrabarti)

- Idea: server constructs mosaic from client images
  - Send pointers to image components, not image data
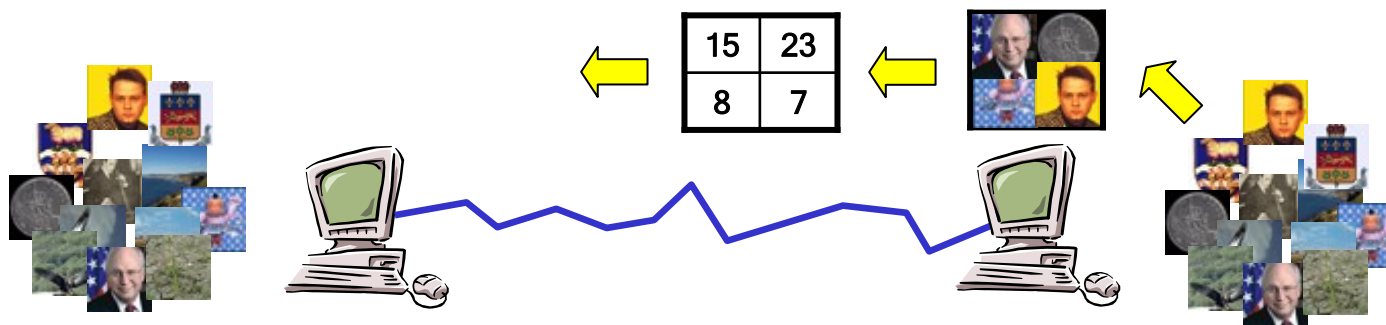
- Experiments
  - Image library: 4096 images from Wikipedia
  - Use shareware PhotoMosaic software (BlackDog)

Wikipedia JPEG: 46 Kb
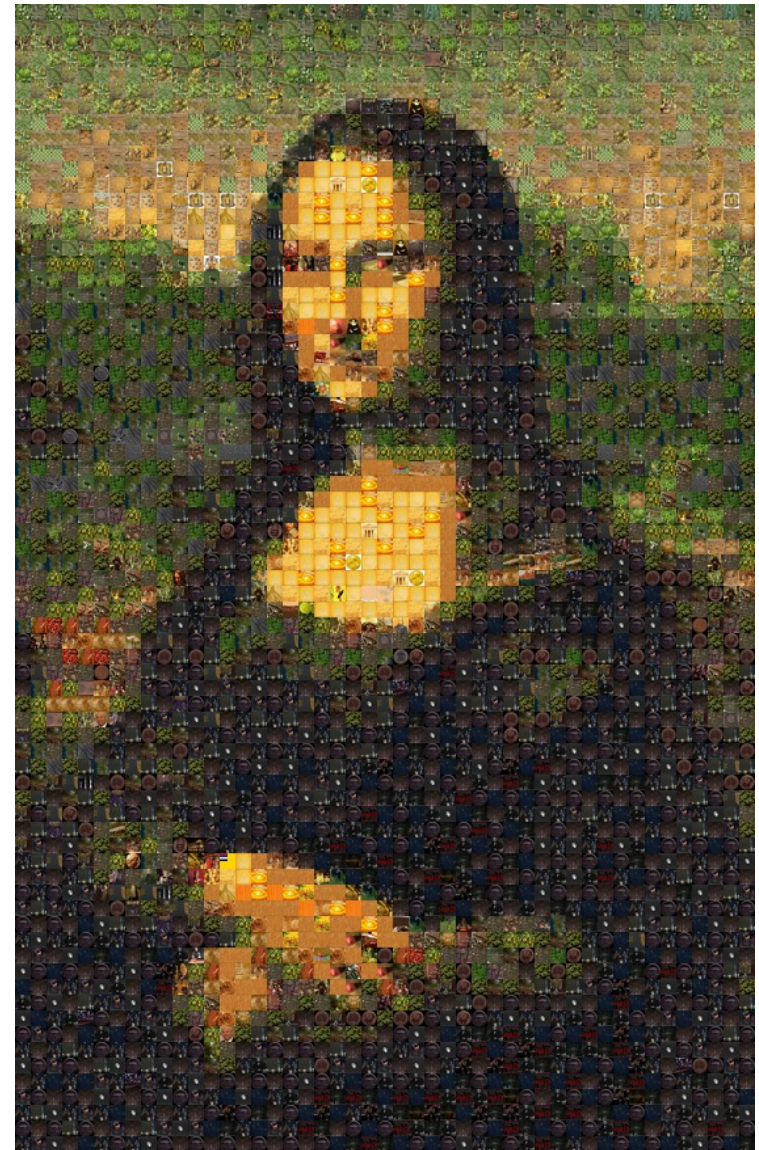
Mosaic: 2.0 Kb
(22X smaller)

2.0 Kb JPEG
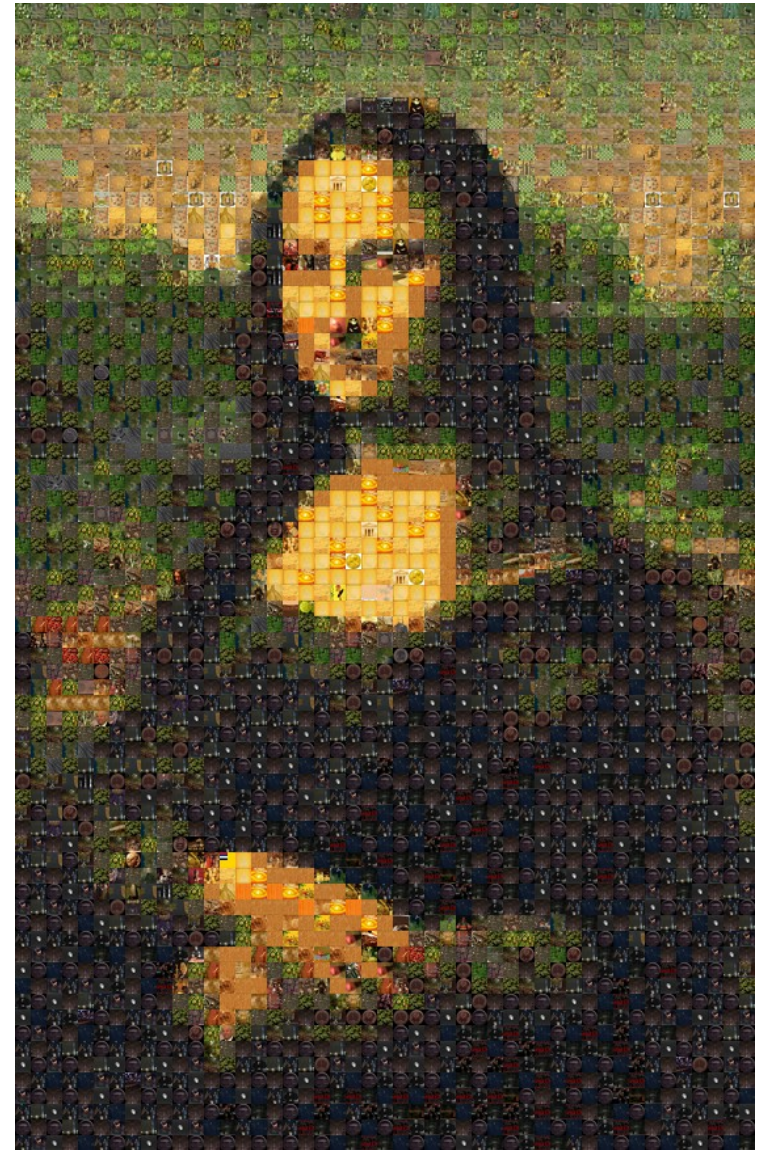
Mosaic: 2.0 Kb
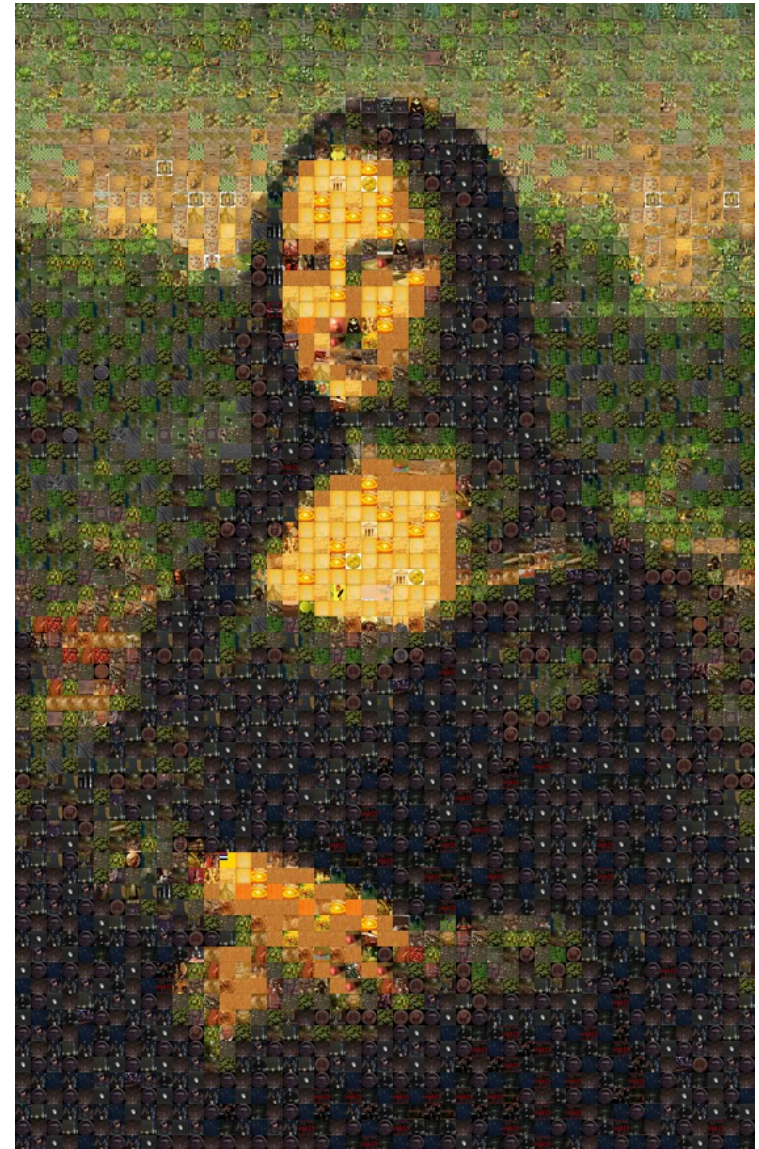
2.0 Kb GIF   Mosaic: 2.0 Kb

Compressing Landscapes

JPEG Image: 52 Kb
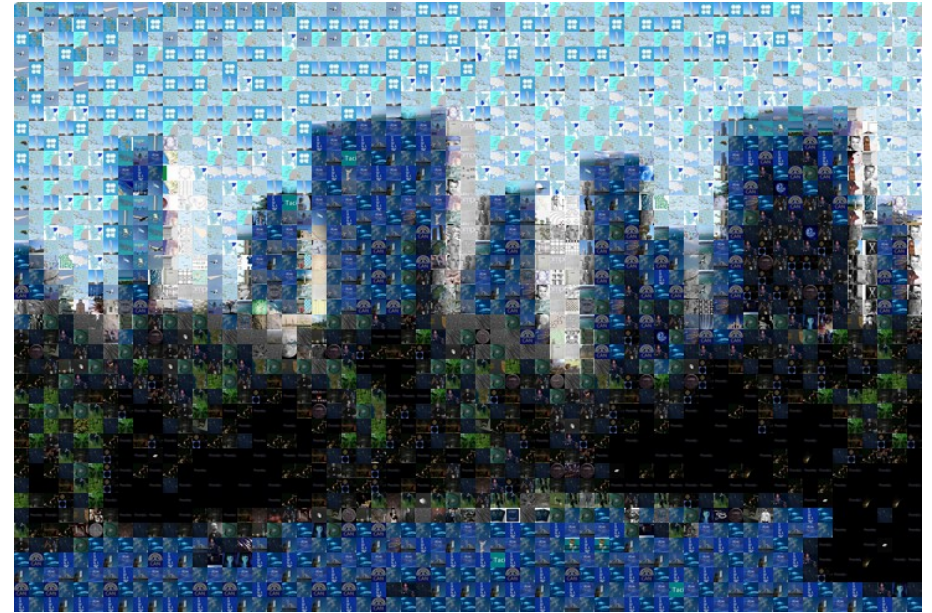
Mosaic: 1.6 Kb
(33X smaller)

Compressing Landscapes
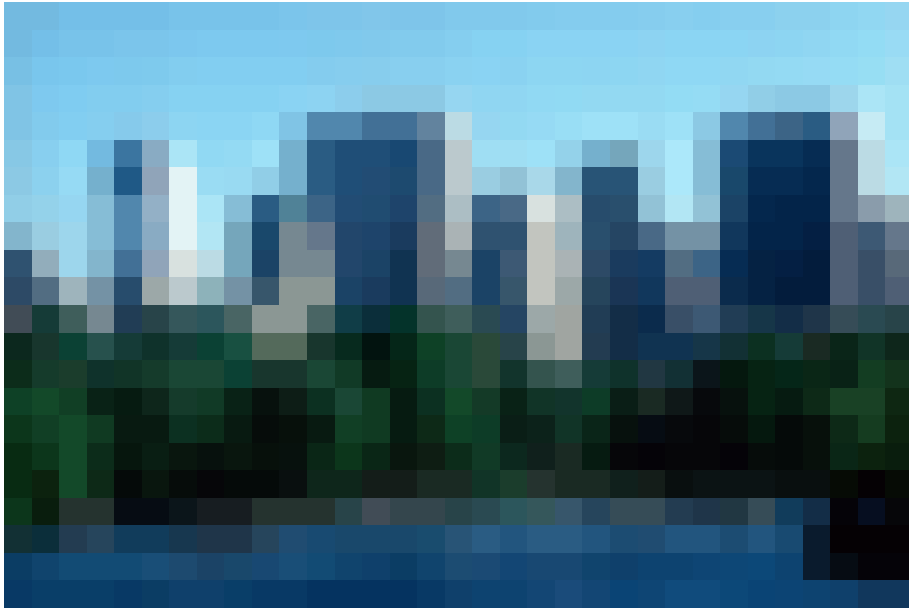
1.6 Kb GIF
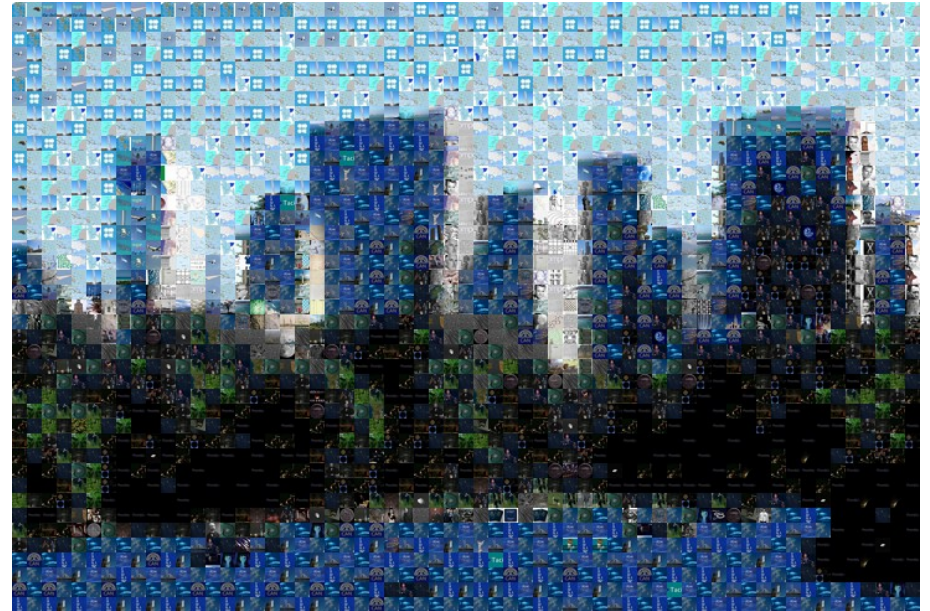
Mosaic: 1.6 Kb

Importance of Small Images

- Most bandwidth spent on small images!
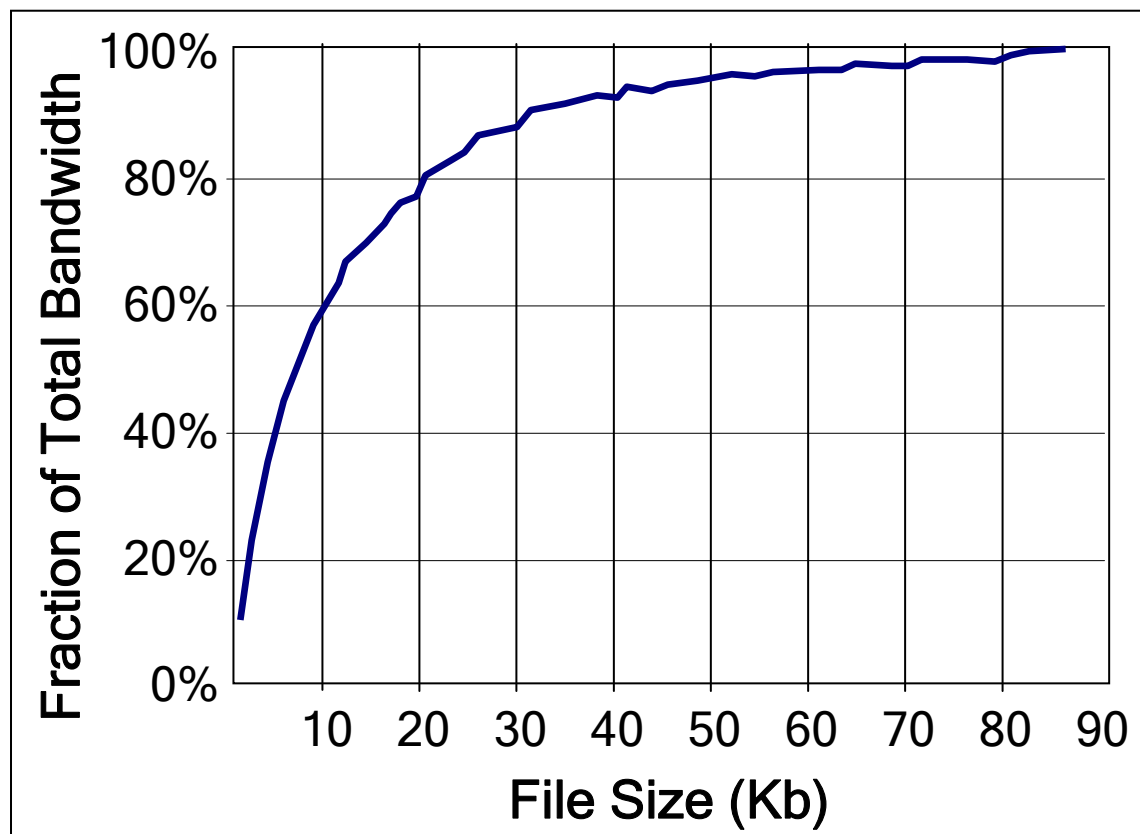
60% of bandwidth on images < 10Kb

→ Text recognition?
→ Icon substitution?

- Source: Chakrabarti'02
- 42,684 images from sites in Google programming contest
- 5,540 images from 1,000 most popular sites (ZDNet)

Compressing Logos

Original GIF: 4 Kb
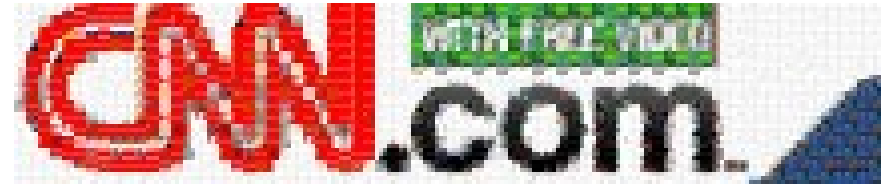
Mosaic: 0.8 Kb
(5X Smaller)

Compressing Logos
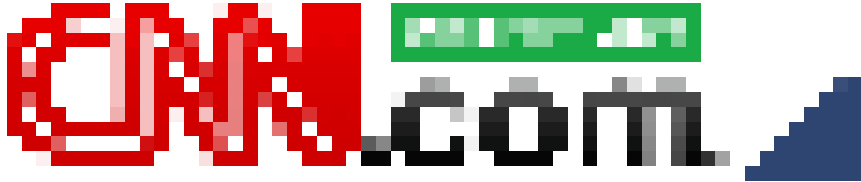
3.7X Smaller GIF: 0.8Kb
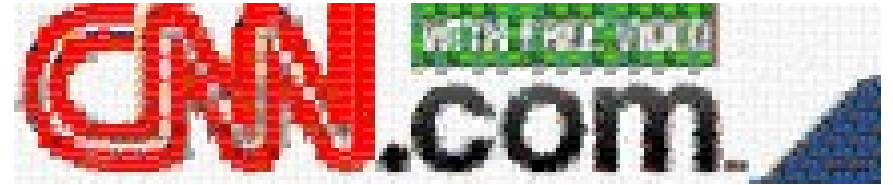
Mosaic: 0.8 Kb
(5X Smaller)

What's the Verdict?

- Many avenues for improvement
  - What is the best image library?
  - Impact of smoothing, rotation, diffs?
  - Edge detection + texture mapping
    - Lossy compression of edges
    - Random noise for realism

- In current form, perhaps useful as a preview
  - 5-33X smaller than JPEG
  - More entertaining than ALT tag or blurry picture

In This Talk

1. Retrieving information
2. **Publishing information**
3. Collecting medical data

The Power of Publishing

- **User-Generated Content has come to define the Web**
  - Original attraction of the Web….everyone can be a publisher
  - Now…Blogs, review sites, digital video, forums, news comments, …
  - Empowers ordinary citizens with a voice + a global audience

> **"75% of all content on the Web is user-generated."**
> — *Reggie Bradford, CEO of Vitrue*

> **"35% of U.S. Internet users have posted some sort of user-generated content online."**
> — *Home Broadband Adoption 2006, Pew Internet & American Life Project*

- **However, the ability to publish and share content remains out-of-reach for most people around the world**
  1. Lack of personal computers, Internet access
  2. Language/literacy barriers
  → Can we use cell phones + voice to enable content sharing?

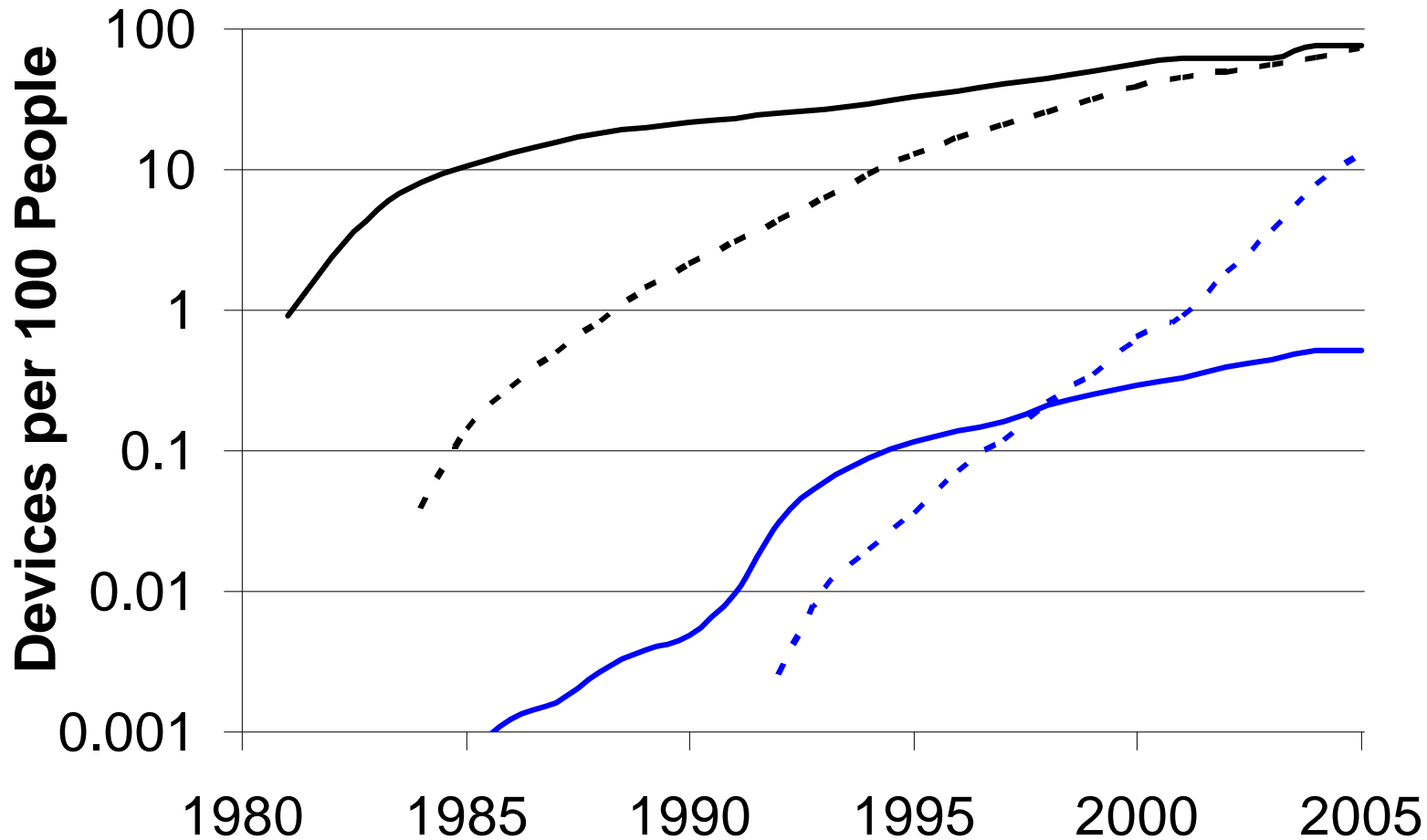# 1. Overcoming the Lack of Computers
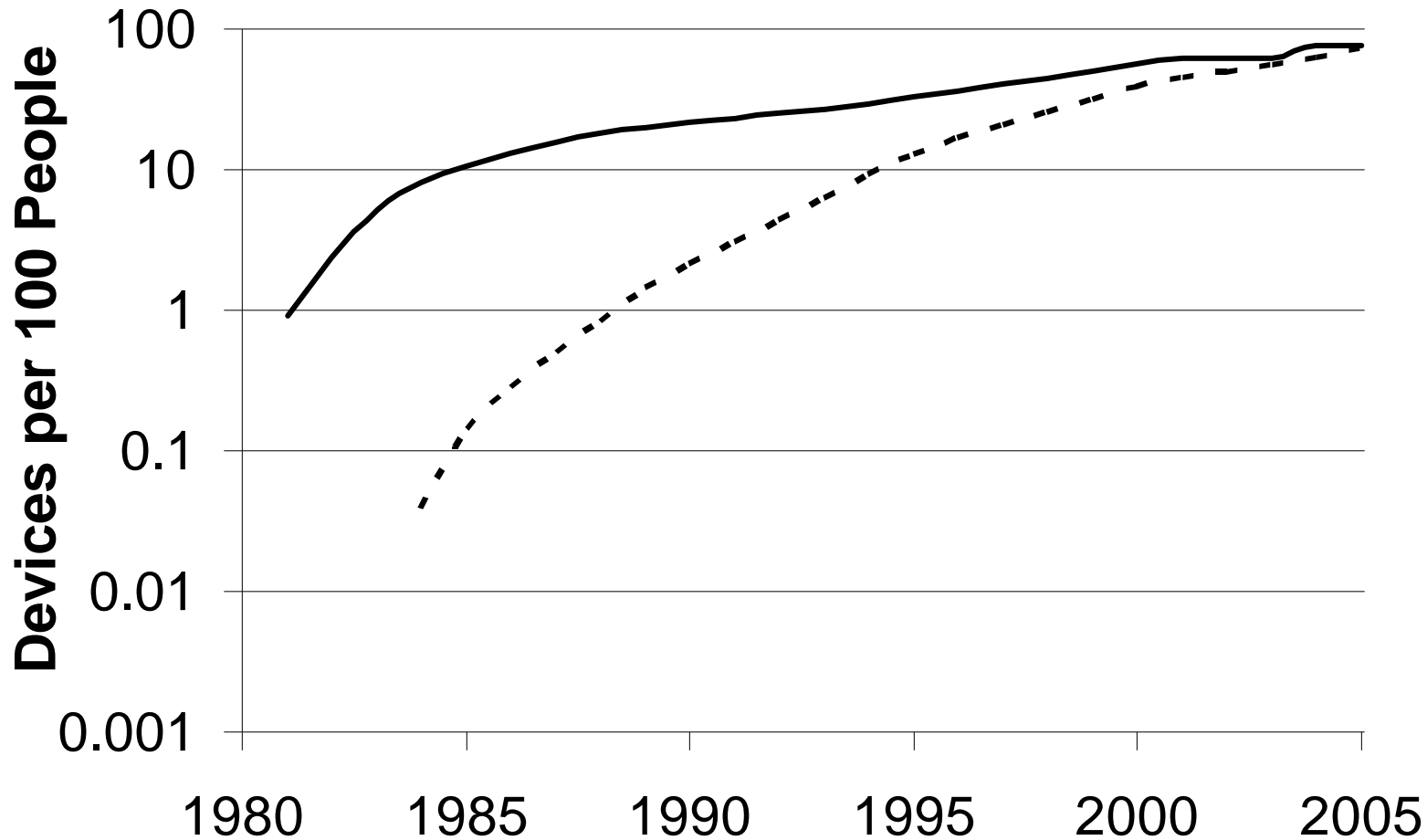
Source: International Telecommunications Union

1. Overcoming the Lack of Computers
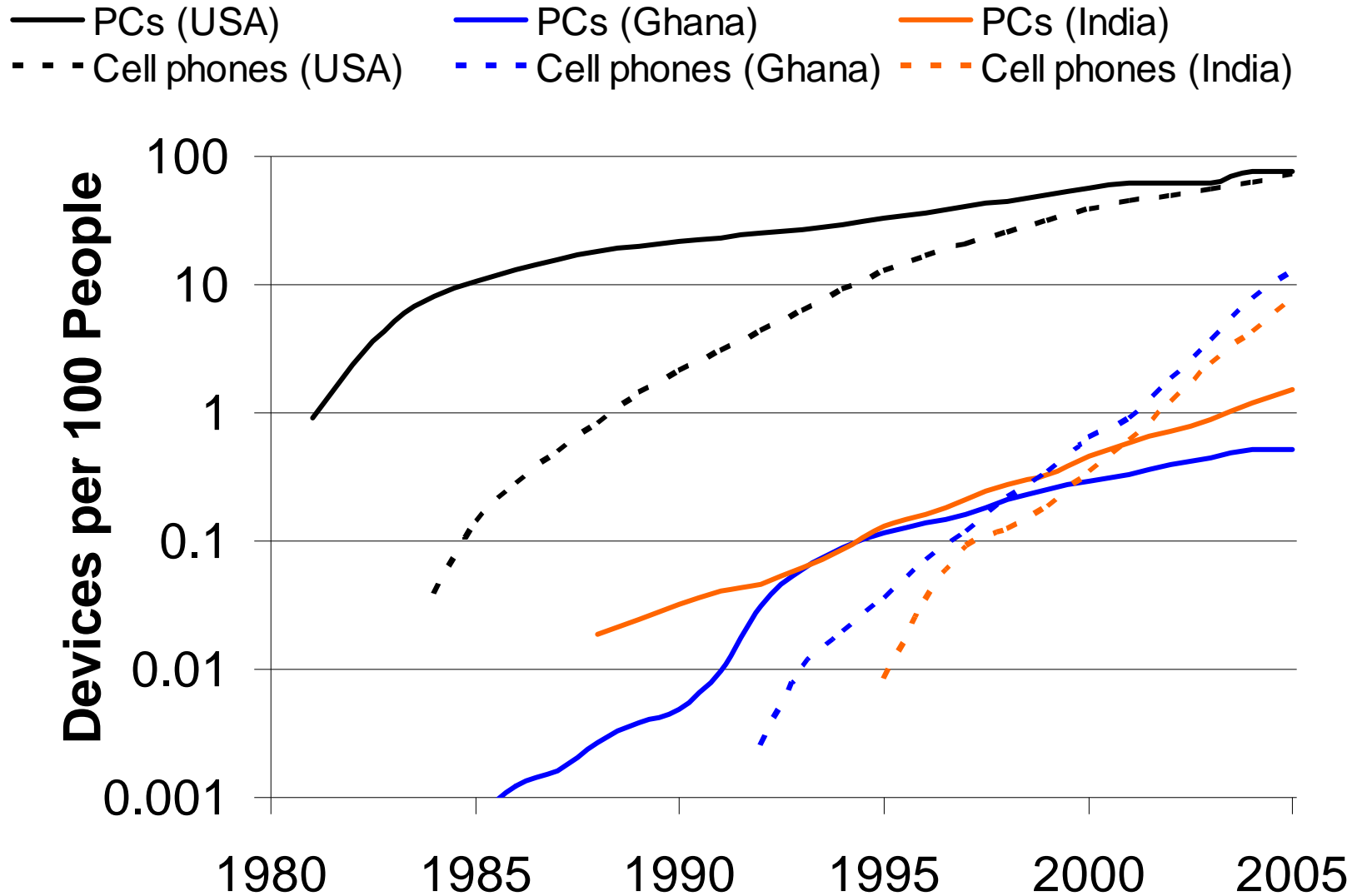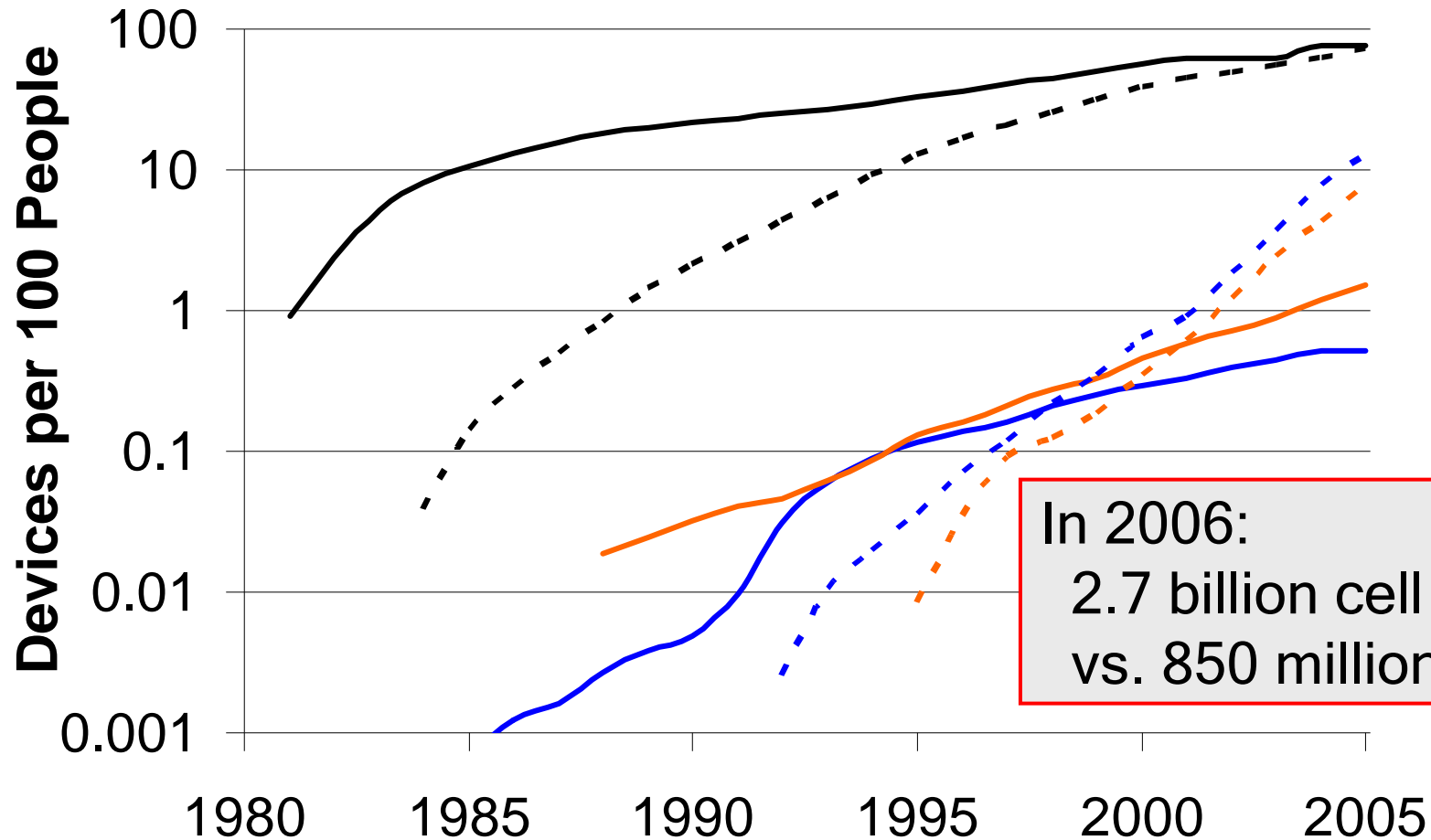

Source: International Telecommunications Union

# 1. Overcoming the Lack of Computers

Legend: PCs (USA), PCs (Ghana), PCs (India), Cell phones (USA), Cell phones (Ghana), Cell phones (India). Y-axis: Devices per 100 People (100, 10, 1, 0.1, 0.01, 0.001). X-axis: 1980, 1985, 1990, 1995, 2000, 2005.

Source: International Telecommunications Union

1. Overcoming the Lack of Computers

—— PCs (USA) —— PCs (Ghana) —— PCs (India)
- - - Cell phones (USA) - - - Cell phones (Ghana) - - - Cell phones (India)

Devices per 100 People (y-axis: 100, 10, 1, 0.1, 0.01, 0.001)

x-axis: 1980, 1985, 1990, 1995, 2000, 2005

In 2006:
2.7 billion cell phones
vs. 850 million PCs

Source: International Telecommunications Union

1. Overcoming the Lack of Computers

—— PCs (USA)	—— PCs (Ghana)	—— PCs (India)
- - - Cell phones (USA)	- - - Cell phones (Ghana)	- - - Cell phones (India)

In 2010:
4 billion cell phones
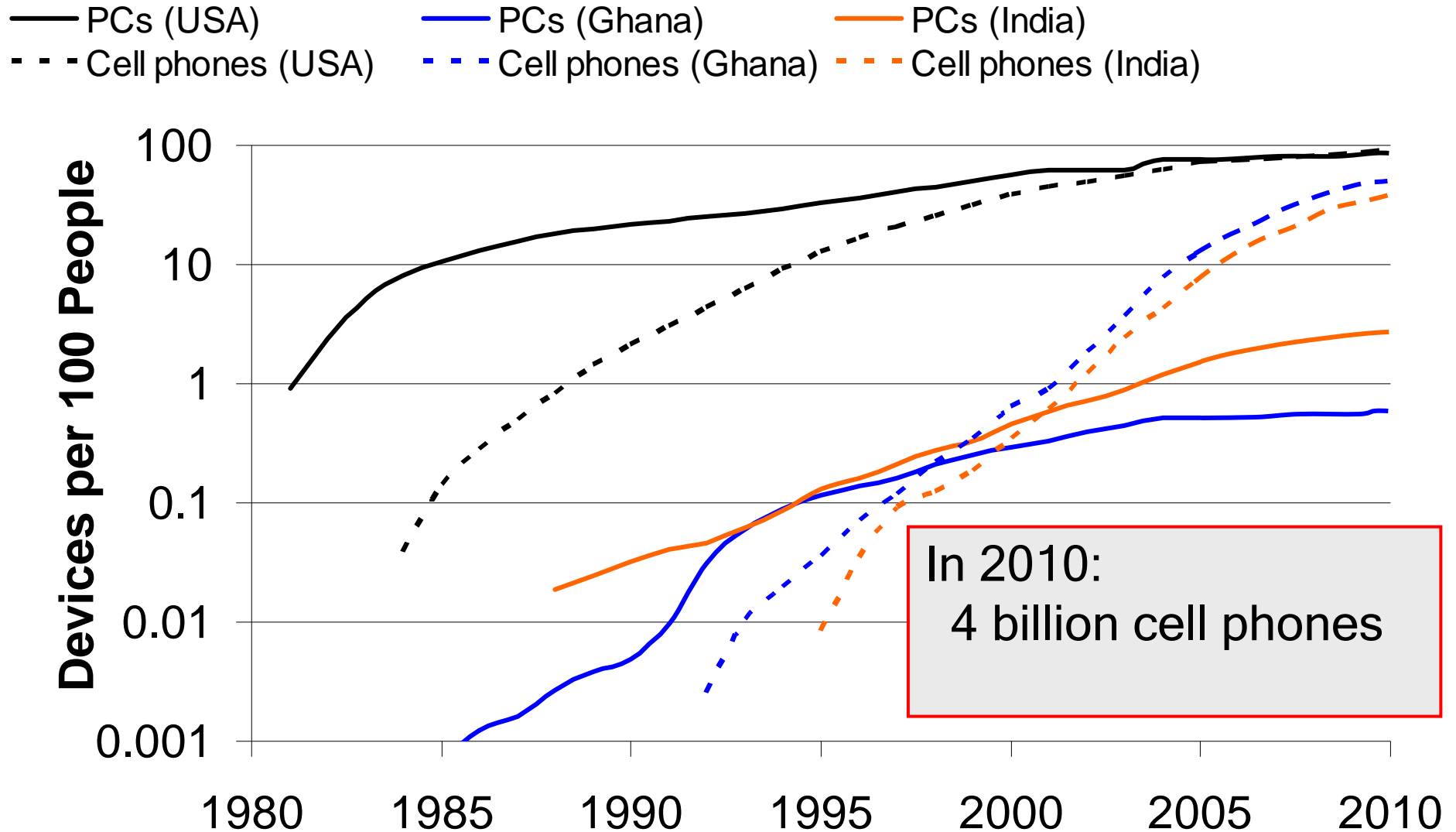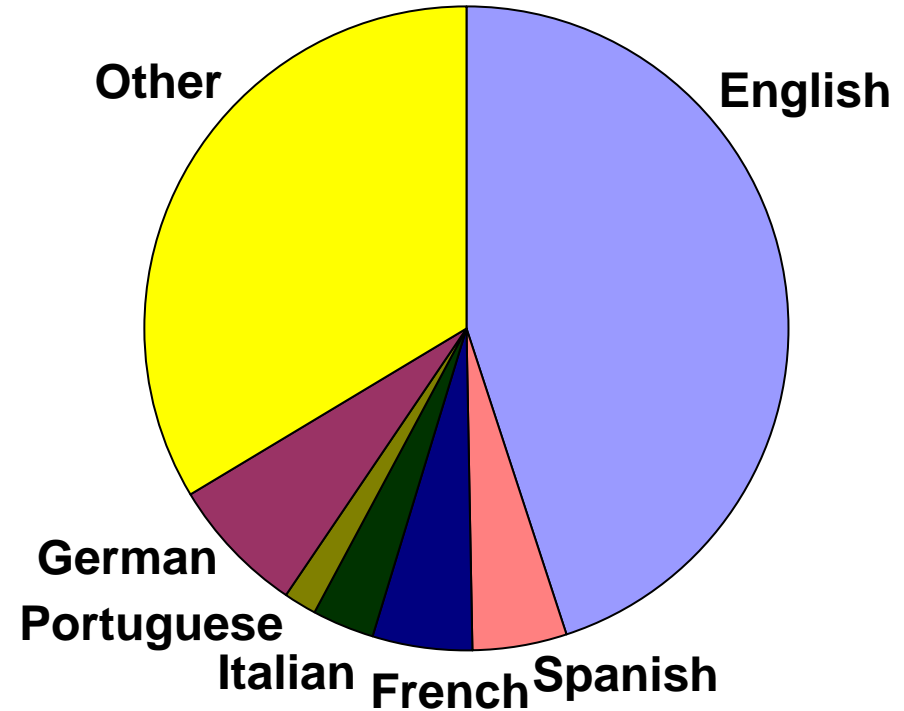
Source: International Telecommunications Union

2. Overcoming Language Barriers

- **Top languages:**
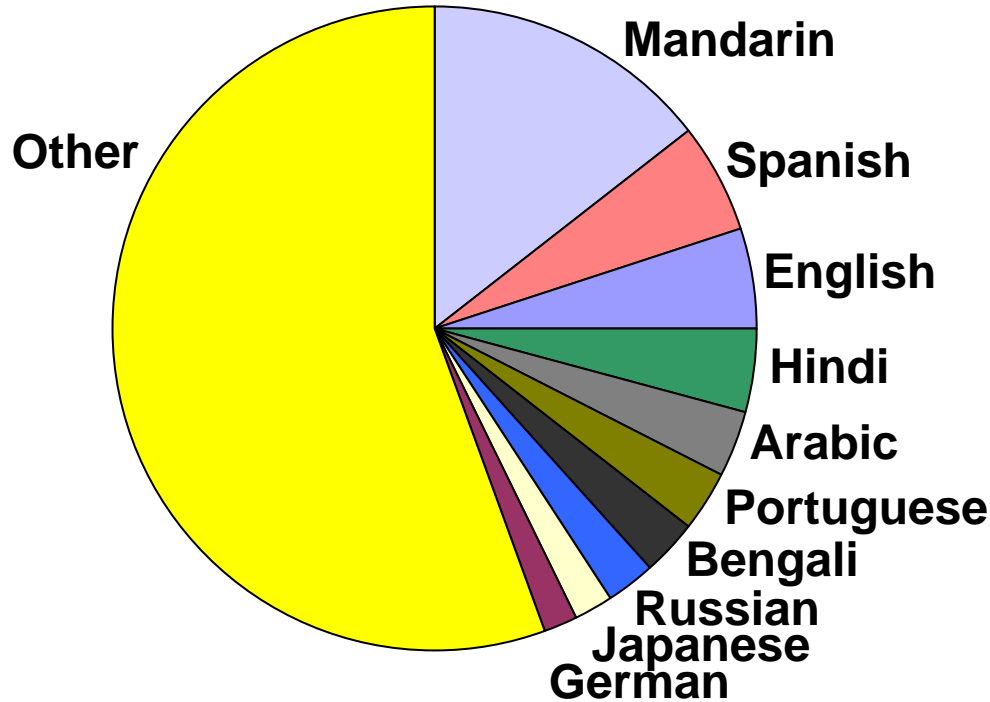
By native speakers
(Source: Wikipedia, 2008)

By Internet Web Pages
(Source: Networks & Development Foundation, 2005)

- **Existing interfaces heighten language barriers:**
  - Text displays require literacy
  - Text input requires complex font encoding

Solution: An Audio Wiki

- **Allow users to publish information:**
  - Using a phone rather than a computer
  - Using voice rather than text

- **Audio recording and playback, but keypad-driven navigation**
  - Not attempting a dialogue-based system

recording, playback   *navigation*

- **Research challenge: making it usable**
  - Interactive voice response (IVR) typically frustrating
  - Research: adaptive interfaces, audio linking, flexible playback

- **Two prototypes in development:**
  - Structured forum on a given topic (ala Yahoo! Answers)
  - Completely flexible Wiki (ala Wikipedia)

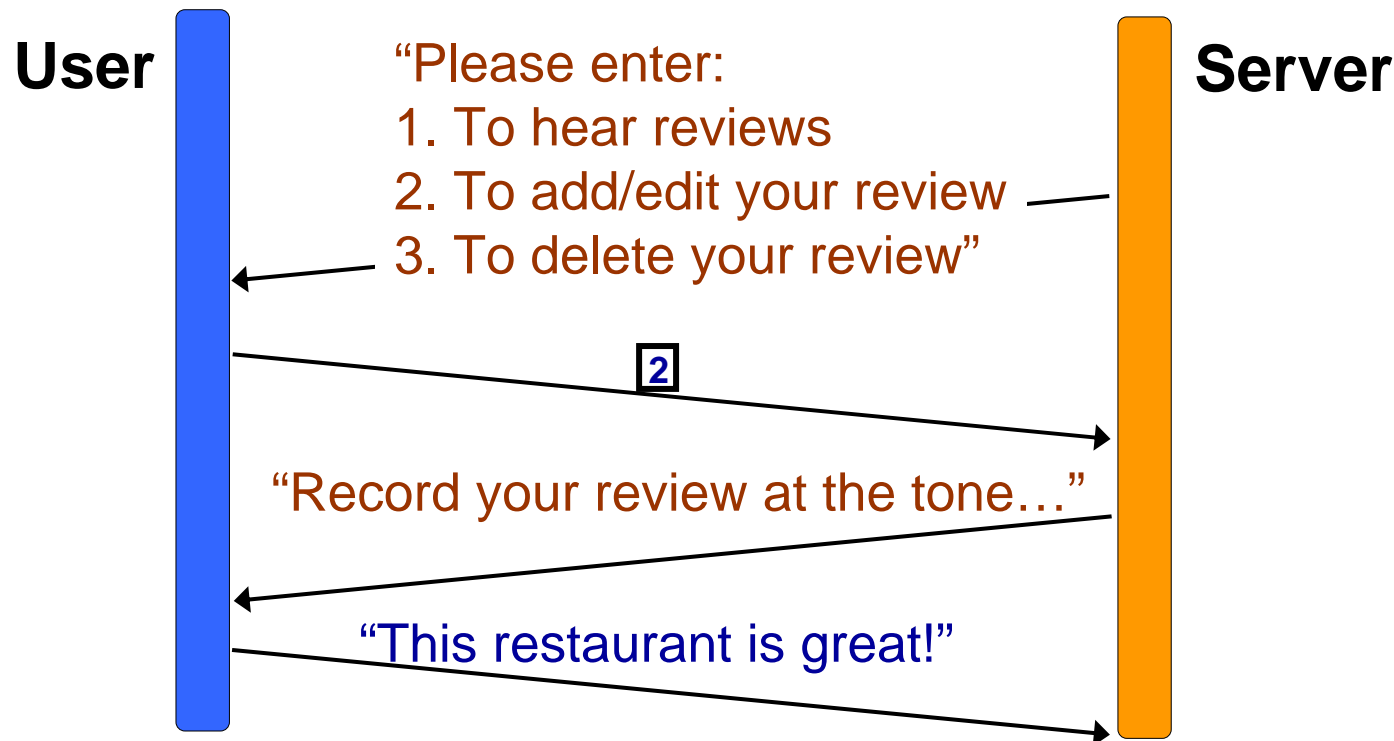# Prototype 1: Structured Forums

- **Organized as set of topics with user comments**
  - Users can:
    - Add topics, search for topics (using keypad)
    - Add, edit, or listen to comments (using keypad+voice)

- **Initial testbed: restaurant reviews**

User → Call server → **Server**

"Please spell restaurant name."

B E R T U C C I S
2 3 7 8 8 2 2 4 7

"Please enter:
1. To hear reviews
2. To add/edit your review
3. To delete your review"

Prototype 1: Structured Forums

- **Organized as set of topics with user comments**
  - Users can:
    - Add topics, search for topics (using keypad)
    - Add, edit, or listen to comments (using keypad+voice)

- **Initial testbed: restaurant reviews**

User

"Please enter:
1. To hear reviews
2. To add/edit your review
3. To delete your review"

2

"Record your review at the tone…"

"This restaurant is great!"

Server

Ranking and Improving Content

- **User-generated content sites rely on ratings and incentives to improve the quality of content**
  - Article of the month (Wikipedia)
  - Featured reviewers (Amazon, Yelp, etc.)
  - Highest-rated contributors (YouTube, Photo.net, etc.)
  - Financial compensation (Metacafe, Revver, etc.)

- **Mechanisms for evaluation / ranking on an audio wiki:**
  1. *Track most popular content*
     - Users can press key to skip remainder of entry
     - Least-skipped entries are played first
     - Such tracking is more difficult to perform on the Web

  2. *Leverage user profiles*
     - Users may create profiles, send/receive voicemail
     - All content is linked to author's profile with press of key
     - Provides incentive to create good online persona

Prototype 2: Flexible Wiki

- **Unlike the structured forums,
  allow all users to edit the same audio snippets**
  - Insert, edit, delete, and link
  - Create and delete audio pages

- **How to lookup content?**
  - Spell with keypad
  - Ask 20 questions
  - Language-agnostic search of keywords

- **New user interface abstraction: *the audio cursor***
  - During editing, can advance cursor to point of interest
  - Iterative playback ensures cursor is at intended position
  - Cursor used to mark insertion point, and to select text for deletion or linking

Implementation Status

- **Prototype implementations complete**
  - Implemented using Asterisk, Summer 2007 – Spring 2008

- **Three deployments underway:**
  - IIT Guwahati: course reviews
  - Boston: restaurant and product reviews
  - Boston: flexible Wiki service

- **Using experienced gained, will transition to developing regions**
  - Agriculture
  - Government
  - Entrepreneurship
  - Health

Agenda for Future Research

- **New interfaces for linking content**
  - Background tone, accented speech, separate section?
  - Need to adapt audio links to unique constraints of Audio Wiki:
    - Limited fidelity   - Need to edit content   - Unpredictable user voices

- **Adapting the interface to suite the user**
  - Recognize caller, keep track of preferences, favorites, etc.
  - Allow users to create shortcuts across the user interface

- **Multimodal interfaces**
  - Voice + SMS + local app
  - Voice + web

- **Language independence**
  - Index and search with universal phonemes

- **Improving playback quality**
  - Speed / volume adjustment
  - Noise elimination / equalization

- **Universalization of local content**
  - Find correlations between distant geographies
  - "Content Networking"

In This Talk

1. Retrieving information
2. Publishing information
3. Collecting medical data

Innovators In Health:
Improving Rural Healthcare Delivery via Data-Driven Intervention

- Tuberculosis remains major challenge in India
  - 4.5 million existing cases
 - 1.7 million new cases per year
  - 300,000 deaths per year

- Logistically challenging to run treatment programs
  - Prajnopaya Foundation's program starting May 2008: 1600 patients, 45 villages, 80 health workers

➡ How can we ensure that pills are reaching the patients, and that patients are taking their medication?

uBox: A Low-Cost Electronic Pillbox

- Features:
  - Records when pills are dispensed
  - Reminds patient to take pills
  - Locks to prevent overdose

- Benefits:
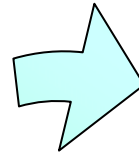 - Records of medication adherence can be analyzed in depth
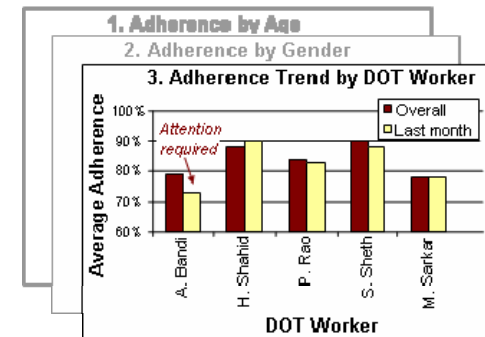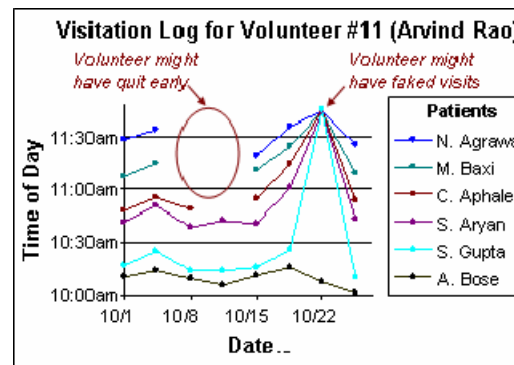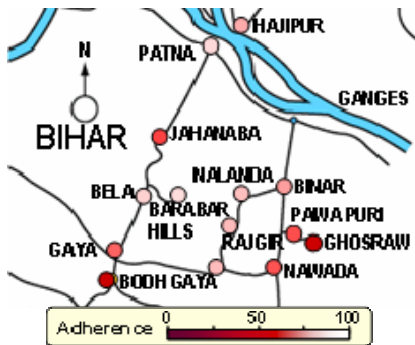
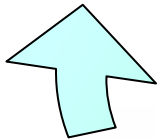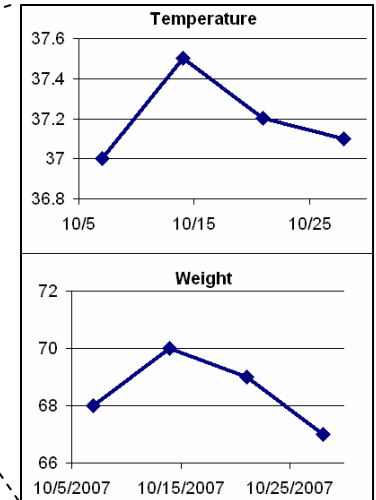

  - Enables new incentives, interventions

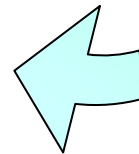# uPhone: Using Cell Phones to Monitor and Improve Patient Health

Health worker
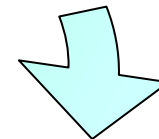enters vital patient health indicators into cell phone

Nurse
analyzes data, identifies problems

Patient
lives in a remote area

Physician
sends advice to patients, schedules field visits

ICTD in the MIT Curriculum

- **Fall 2007: Reading group on ICTD (co-organized with Emma Brunskill)**
  - **Readings:**
    - Brewer et al., *The Case for Technology for Developing Regions*
    - Bailur et al., *Review of Resarch on Rural PC Kiosks*
    - Banerjee & Duflo, *The Economic Lives of the Poor*
    - Jensen, *The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector*
    - Kam et al., *Localized Iterative Design for Language Learning in Underdeveloped Regions: The PACE Framework*
    - Kumar & Best, *Impact and Sustainability of E-Government Services in Developing Countries: Lessons Learned from Tamil Nadu, India*
    - Pawar at al., *Multiple Mice for Retention Tasks in Disadvantaged Schools*
  - **Speakers:**
    - Rich Fletcher (United Villages)
    - Hamish Fraser (Partners In Health)
    - Jonathan Jackson (Dimagi, Inc.)
    - Daniel Kayiwa (Makerere University, Uganda)
    - Kieran Sharpey-Schafer (Cell-Life, South Africa)
- **Spring 2008: 9-unit design class on ICTD**
  - Instructors: Gari Clifford, Rich Fletcher, Jhonatan Rotberg, Luis Sarmenta
  - Cross-listed in EECS, Media Arts & Sciences, Health Sciences Technology

MIT ICT4D Projects (Spring '08)

(Instructors: Gari Clifford, Rich Fletcher, Jhonatan Rotberg, Luis Sarmenta)

- *Economic Empowerment*
  - **Mosoko Mobile Marketplace** (Nokia, Kenya)
  - **Assured Labor** (Brazil)
  - **Smart MicroLoans** (India)
- *Health*
  - **Pediatric care for Urban Poor** (Johns Hopkins & IRD, Pakistan)
  - **Cervical Cancer Prevention** (Dimagi, Zambia)
- *Education*
  - **Knowledge Box "Virtual Internet"** (Beehive School, Malawi)
- *Community Action*
  - **Disaster Management** (CRS India)
  - **FreePress** (Hanantek, Bolivia)

Slide courtesy of Luis Sarmenta

Related Work

- Delay-tolerant networking
  - TierStore (Demmer, Brewer et al.)   - SeNDT (Geraghty et al.)
  - ZebraNet (Martonosi et al.)   - EmailWeb (Griswold)
  - Postmanet, Digital Study Hall (Wang et al.)   - Interplanetary Internet
- Extreme compression
  - Space-optimized texture maps (Balmelli et al.)
- Audio wiki
  - HealthLine (Sherwani et al.)
  - MobileED (Leionen et al.)
  - World Wide Telecom Web (Kumar et al.)
- uBox / uPhone
  - Pillboxes: e-Pill Dispenser, MedReady Plus, SimPill, AARDEX MEMS, …
  - Phone programs: Voxiva HealthNet, Cell-Life, Jiva Teledoc, Pesinet, DataDyne EpiSurveyor, MIT MDSS

Conclusions

- Technology research for the developing world:
    1. Identify unique trends and opportunities
    2. Address with new and appropriate technology

Trend / Opportunity	Research Direction
Email cheaper than Web access	Email-based search
Storage cheaper than bandwidth	State-based compression
Cell phone penetration + Illiterate users	Audio wiki

- Growing community of researchers and educators at MIT

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  - Samidh Chakrabarti

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  - Pratik Kotkar

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  - Jessica Leon
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