



Physical-Digital Ensembles

integrated interactions for capturing, retrieving, and sharing information

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23 April 2006

CHI 2006 DOCTORAL CONSORTIUM



Computers Everywhere

Five C.S. challenges for 2006

- Each challenge is for a specific subfield
- Each challenge also applies to *all* of Computer Science

The Computer Science Challenges

Visibility	experimental systems and visualization	See
Complexity	theory, economics, gaming	Know
Abstraction	nanotechnology, parallel systems	Build
Connection	internet, channels	Tie
Invisibility	human factors and user interface	Fit

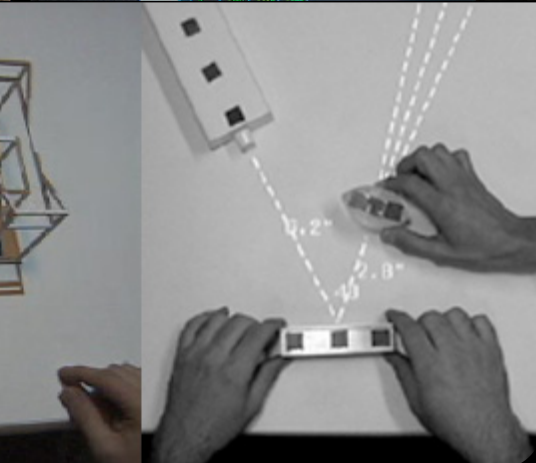
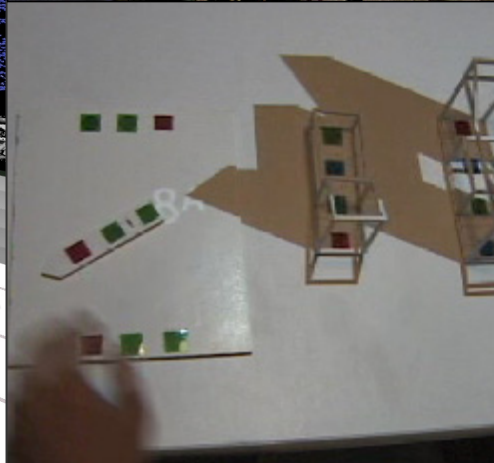
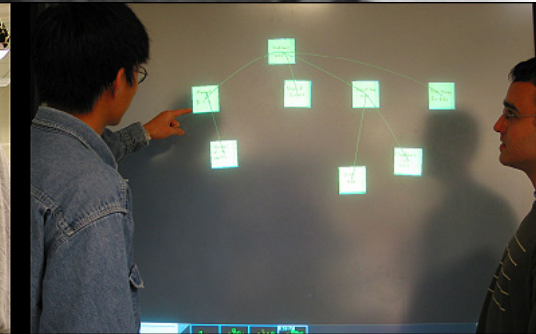
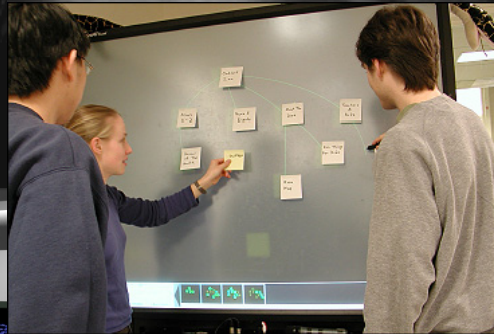
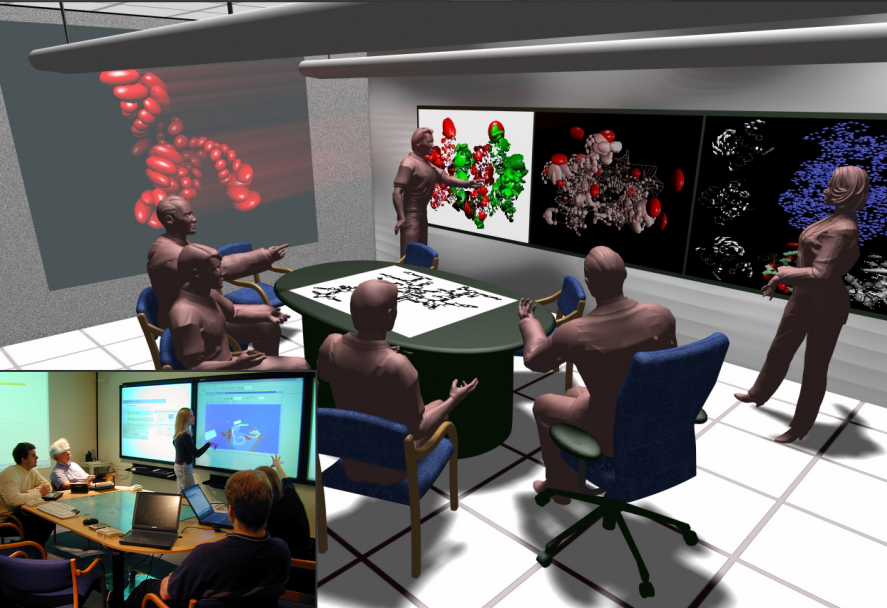
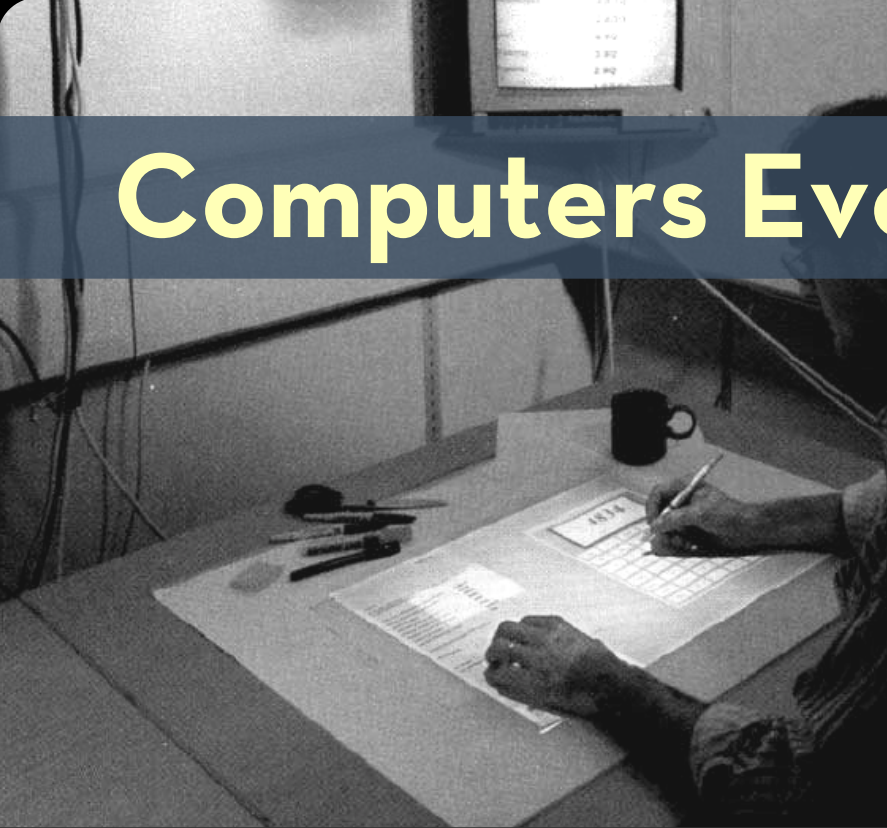
Scenario 2 “augmented reality”

existing physical devices +
cheap and easy-to-use electronic add-ons

- Wallet + ... digital cash and digital ID
- Paper Notebook + ... facts at your fingers
- Automobile + ... directions and identity
- Kitchen Cabinet + ... contents tracking

Mark Weiser

Computers Everywhere



No Computers



Bridging the Physical and the Digital

“...imagine if we did not have to choose, and we had a space where documents could be both paper and electronic at the same time.”

Pierre Wellner, 1993

“Choosing between books and computers makes as much sense as choosing between breathing and eating... the bits and the atoms belong together.”

Neil Gershenfeld, 1999

Device Ensembles

“In the future...digital devices will work in concert, like an ensemble of musicians that achieves a total effect greater than the individual performers.”

Schilit & Sengupta, 2004

Ensemble Interaction

A **physical-digital ensemble interaction** is a human-computer dialogue that takes place across multiple tools (physical and digital), possibly leveraging multiple input modalities and output media.



Ensemble Interaction

A user employs a **sender** device to initiate an action that is executed on the **receiver** device.





Background

motivation, inspiration, investigation



Projects

ButterflyNet, Interactive Gigapixel Prints, Sensing Notebook



Prior and Future Work

taxonomies, physical-digital primitives, ensembles toolkit

Interviews and Observations



seeing
 trap-lin
 birds wh
 I heard
crowned Kinglet repeating
 etc. — its note of a
 up and located it



Cent...
 ...marks on hypost. (f-shaped
 in 2/3) - Pear-shaped abdomen, slaty,
 mostly hairless bodies. Head flat
 @ bottom

Hylaeus (comp.)
 ...ocypods - all ♂ have yellow mark on the
 face. ♀ don't have corbicula (unlike
 Bombus). Bombus is hairier than

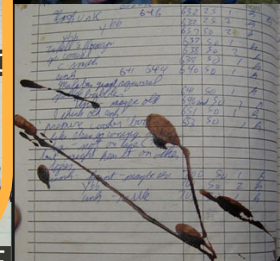
...already collected to separate the/No
 of different dimensions (length, width)
 the values by changing keep
 monitor set-up. Several not distinguish
 ed speeds were all same for all trials
 the wind speed. Effectively wind is
 a motor and wind speed is controlled

Prob. N of Cases Max Diff Probability (2 tail)
 GBOCVL 148.000 0.000 0.178

9/26 area layout 3rd or 4th section lanes and pieces the space to
 to calibrate physical models w/ range of larval body
 models used the ♂ is firm w/ Aug 15th - 1st lab of includes w

#104 I51 I11-3 I3-X82

F	3	Gambon Alto	OTF	1	
F	21	Edilca	F	1	(2.0)
T	22	Lorica bimol	FD	2	
F	23	Gambon So	FD	2	
T	24	Gambon So	TOF	1	
T	46	Antonia Rojas	TO	2	
O	50	Petra Brava	O	2	
O	51	Cambe de Gonda	FD	1	
O	57	Rovano Alto	O	1	
Edge					
E	5	LC Edge 1	E	Z	
E	55	Colombol	E	M	
E	63	Gambon Alto	E	N	



Los Tuxtlas Tropical Rainforest



Jasper Ridge Biological Preserve



We observed that...



Capture is (relatively) easy, but...

Transformation



Access



Sharing



...are not.

Current tools

Pens & Paper Notebooks

Cameras

Spreadsheets

Coin Envelopes

Laptop & Desktop Computers

Sensors

GPS Devices

GIS Software

Printers

Physical/Tangible

Pens & Paper Notebooks

Coin Envelopes

Digital

Cameras

Spreadsheets

Laptop & Desktop Computers

Sensors

GPS Devices

GIS Software

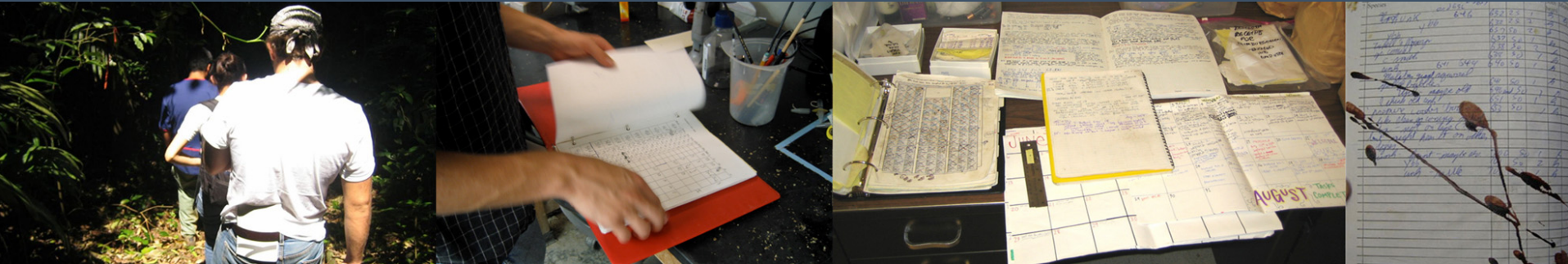
Printers

Different Advantages



Paper Notebooks

[Robust, ∞ “Battery”, ...]



Computers

[Search, Storage, Sharing, ...]



Paper Notebooks

[Robust, ∞ Battery, ...]



Computers

[Search, Storage, Sharing, ...]

**1) Augment paper with digital affordances
(and vice versa).**

**2) Use both digital and physical devices in
concert.**

Digitizing Pen Technology

JAS
11/12/04
CER RMBL
2004
STANFORD

GEL I:	PAI	PAM	GGPD
1A	3/4	3/3	2/2
1B	3/3	3/3	1/1
1C	4/4	3/4	1/2
1D	3/4	4/4	2/2
1E	4/4	3/4	1/2

PROCEDURAL NOTES: ONLY
ZIGZAGS

1F	4/4	3/3	2/2
1G	4/4	3/4	2/2
1H	3/4	3/4	2/2 1/2
1IA	3/4	3/3	1/2

correction - re-read gel

1IC	3/4	3/4	2/2
1ID	3/4	3/4	1/2
27A	3/3	3/3	1/2

STAINING NOTES FROM
W.B. USHTT:
PAI - 3 on ferritin
PAM - acts as 2 monomer
GGPD - tetramer

STAINING NOTES cont:

PAI/PAM:

PAI: 3/4 3/4	PAM: 3/4 3/4
--------------------	--------------------

ferritin
unimpound
white box

heterozygote banding
1:4:6:4:1
only visible part.

Subject / Keywords
RMBL_2004-CER-NOV-12-04

To

JAS
11/12/04
CER RMBL
2004
STANFORD

GEL I:	PAI	PAM	GGPD
1A	3/4	3/3	2/2
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STAINING NOTES cont:

PAI/PAM:

PAI: 3/4 3/4	PAM: 3/4 3/4
--------------------	--------------------

ferritin
unimpound
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1:4:6:4:1
only visible part.

Subject / Keywords
RMBL_2004-CER-NOV-12-04

To

The Ensemble Interactions

Ensemble Interaction

A user employs a **sender** device to initiate an action that is executed on the **receiver** device.



Ensemble Interactions



Select



Manipulate



Associate



Transport

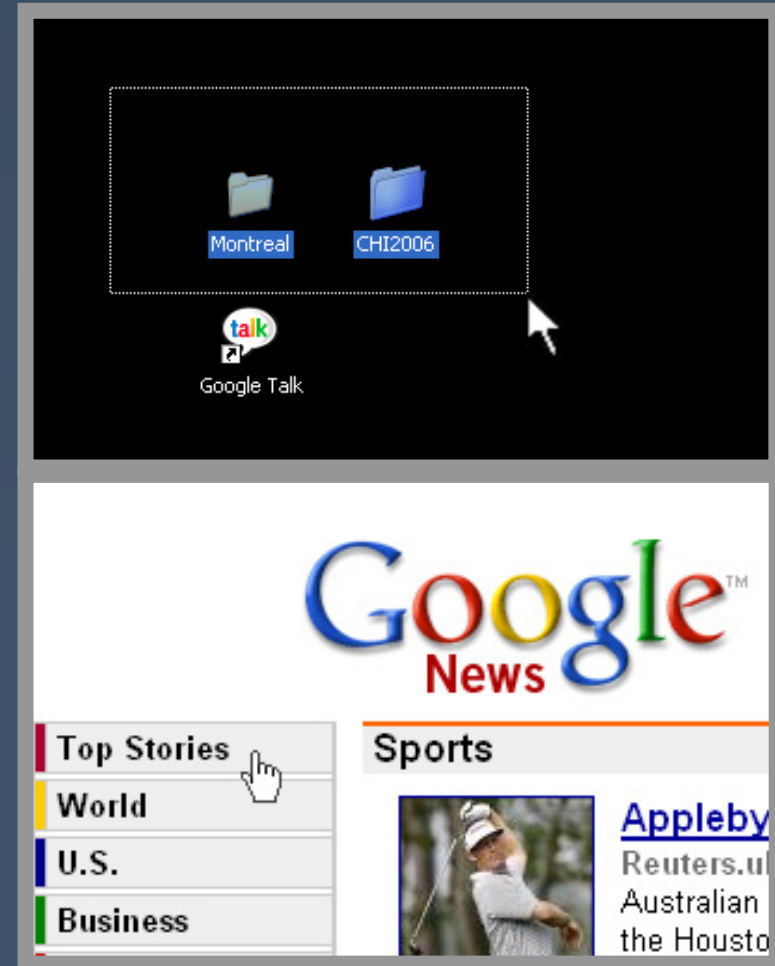
Select



Graphical UI Select...
[Foley & Wallace 1974]

Ensemble Select

- Subsumes F&W's Pick & Button
- choose item(s)
- constrain movement
- query for results



Manipulate

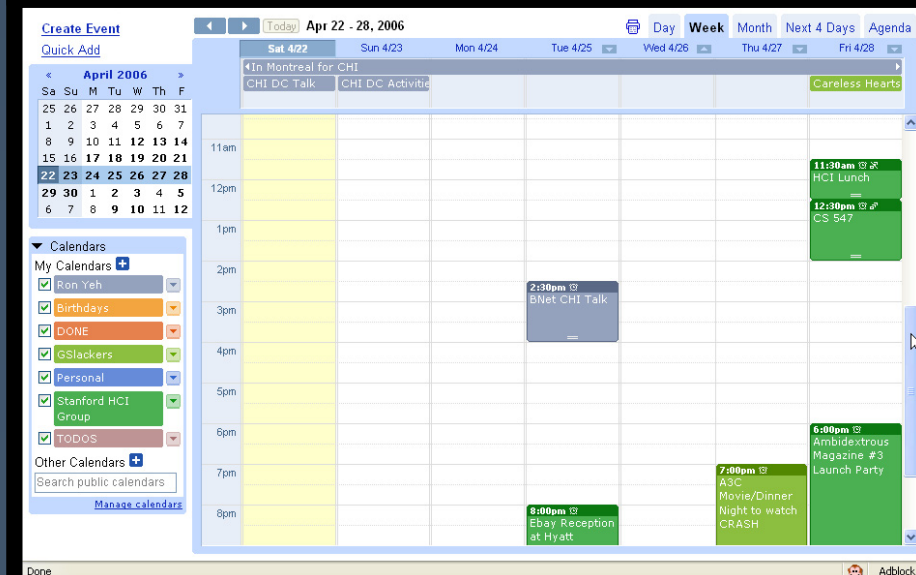
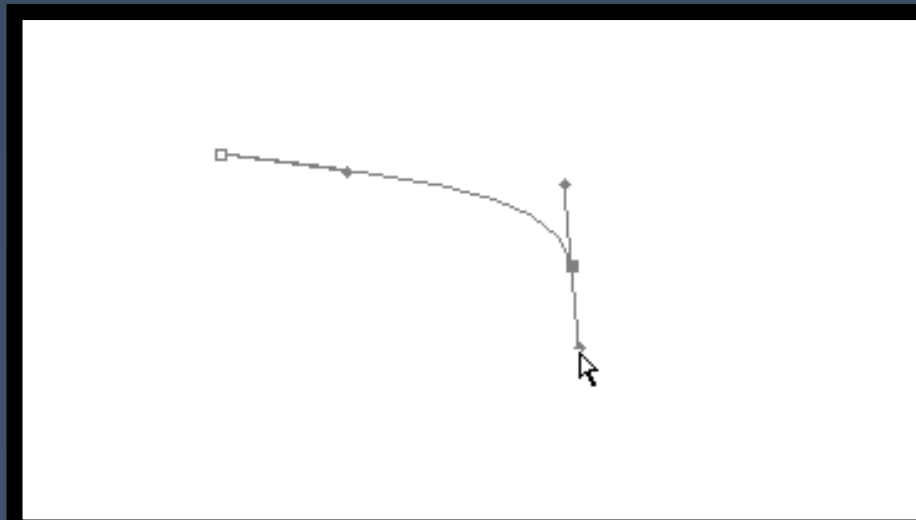


Graphical Manipulate Subsumes F&W's

- Locate
(Manipulate X,Y,Z,...)
- Valuate
(Manipulate Values)

Ensemble Manipulate

- Move/Flick/Drag
- Navigate



Associate



Hyperlink

Stitch

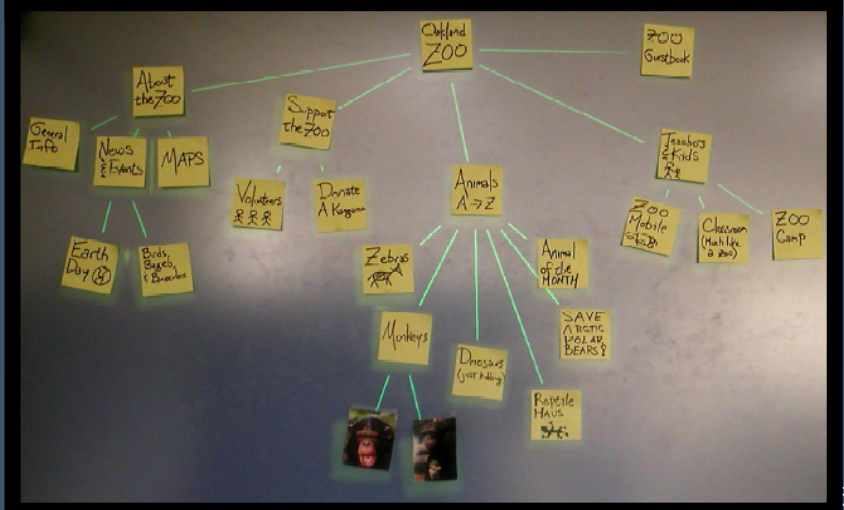
Connect

Concatenate

Attach Behavior

...

africa amsterdam animal animals april **architecture** art australia autumn baby barcelona
beach berlin **birthday** black blackandwhite blue boston building bw california
cameraphone camping canada canon car cat cats chicago china
christmas church city clouds color concert day dc december dog dogs england
europe fall **family** festival florida flower flowers food france
friends fun garden geotagged germany girl graffiti green halloween hawaii
hiking holiday home honeymoon hongkong house india ireland italy **japan** july kids
lake landscape light london losangeles macro march me mexico moblog mountain
mountains museum music nature new newyork newyorkcity newzealand night
nikon **nyc** ocean paris park party people photo portrait red river roadtrip rock
rome san sanfrancisco school scotland sea seattle show sky snow spain spring
street summer sun sunset sydney taiwan texas thailand tokyo toronto travel
tree trees trip uk urban usa vacation vancouver washington water
wedding white winter yellow york zoo



Transport



Capture

Print

Send

Retrieve

Copy

Move

...





Background

motivation, inspiration, investigation



Projects

ButterflyNet, Interactive Gigapixel Prints, Sensing Notebook



Prior and Future Work

taxonomies, physical-digital primitives, ensembles toolkit



BUTTERFLY NET



Left Page:

• be sure to note the treatment, response, and type
 • 200m separation for replicates in CO₂

idea for JP

3 or 4 species of poplar but 10 mixing
 found only in 1 or 2
 → do bees w/ 10 mixes have more
 treatment → can measure mixing w/ string
 → focus has pupas in his computer
 about nursing
 → feed to caterpillars?
 → maybe have diff. defenses?

Costus
 2 species - 1 grows in open light,
 in shade - one has bugs under
 by other doesn't

Right Page:

→ can test herbivory related genes
 → simple or complex
 → maybe in defense, maybe
 the leaves & top
 → many diff. populations - one has
 like red

→ many in open field, in within
 forest

(some) - temp, humidity, flexibility of getting roots
 tradeoff: allocation & transpiration

→ Median - yellow latex
 - rates of herbivory like red & green leaves
 tradeoff: defense vs photosynthesis
 (some) - understanding the role of young/red

induced defenses - intraspecific
 induction with a plant - some for what is spread
 by lar. butterflies (some) - that induction (mostly)
 in response parts
 (some) - rbc, apical

some leafy plants
 that are not visible
 immediately

Send 

Bottom Left:

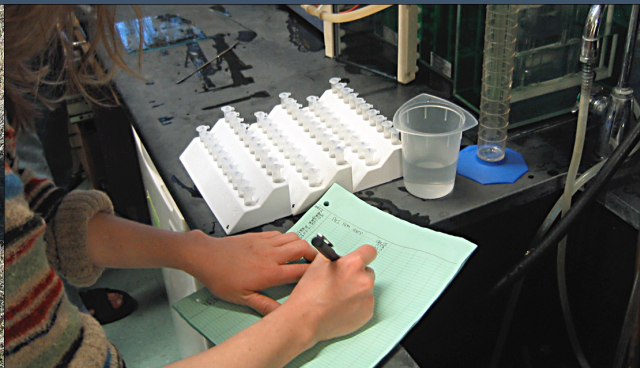
2123102
 Sample
 Lilius - mixed bag
 05-18-11

Bottom Right:

Olympus
 PEN EPL2
 12MP
 4.3" LCD
 10.1mm lens



Tools and techniques to help field biologists **collect, organize, and share** their research content.



ButterflyNet System



Capture



Structure



Access



Transform

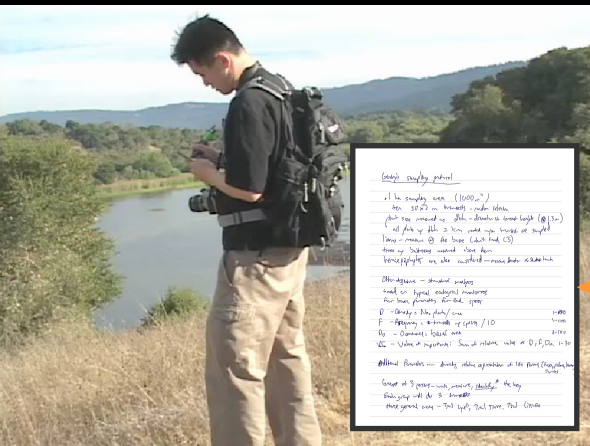


Share

Ensemble Interaction 1



Associate



notes @ 4:43pm



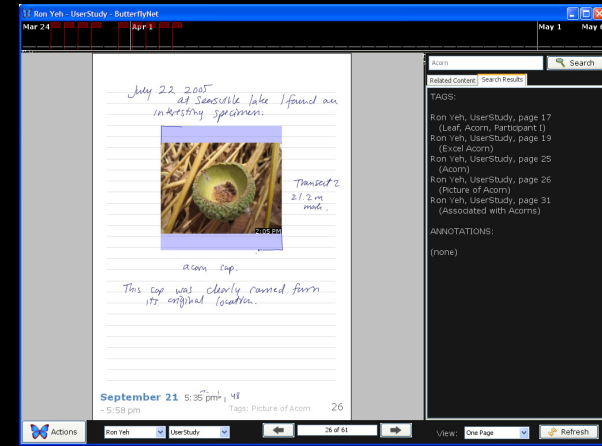
photo @ 4:44pm

Automatic Association
Notes + Photos associated by **Time**

Ensemble Interaction 2



Associate



Manual “Hotspot” Association

Notes + Photos associated by **Inked Gesture**

Ensemble Interaction 3



Associate



Manual “Visual Specimen Tag” Association

Notes + Photos + Specimens associated by **2D BARCODE**

ButterflyNet Browser

Zhen Kan - My Field Notes - ButterflyNet



araceae anthurium (also dieffenbachia, which does not climb)
• vines - herbaceous, (vs. lianas, which climbs but has woody)
• striking variation in leaf morphology w/in an indiv.
• pollinated by beetles

piper acritum

- V. light-demanding piper
- strong spicy smell, used for cooking
- striking inflorescence

araceae monstera

- geminate on forest floor, stick itself to something & eventually reach light
 - invented skoto tropism - directs plant to source of darkness i.e. trunk that's already established in forest
- capture runoff nutrients that come down the tree
- will change its morphology to reach more light

legume - ings → has compound leaves (only 1 bud)
family → common tree in trop rainforests
• rachis often winged



a gland that acts as a
• extrafloral nectary - produces nectar separate from the flowers
 ↳ distinguishing feature of an inga
 → mutualism w/ ants which defends the leaves
• young leaves a lot more hairy than old leaves

Cordia

- wood is v. high quality
- leaves in layers

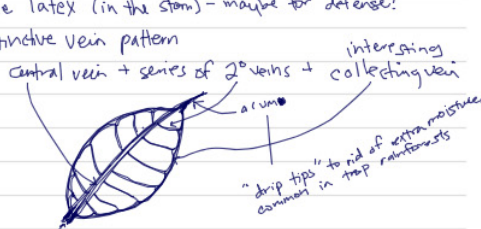
Eurostachyaceae bursera - dioecious

- bark peels off (its reddish) - "exfoliating" bark to expose a green stem

moraceae family - widespread

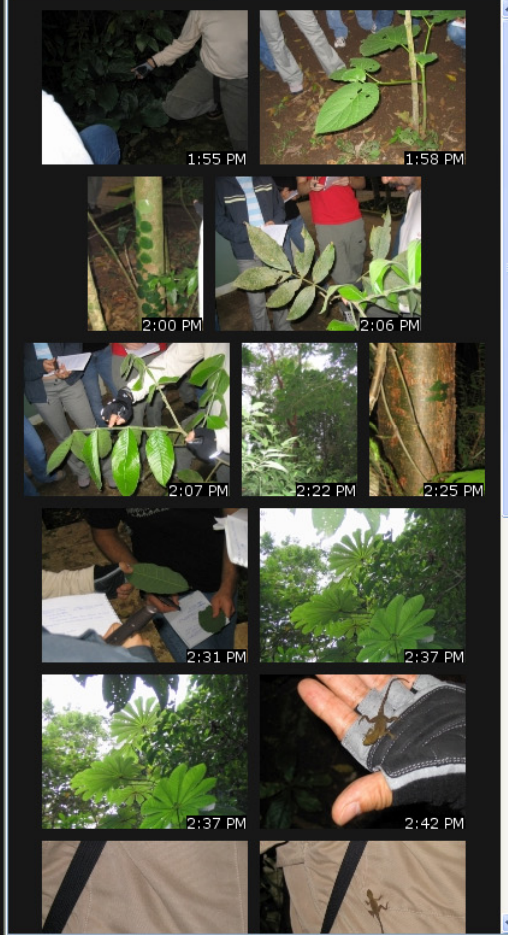
- white latex (in the stem) - maybe for defense?

- distinctive vein pattern



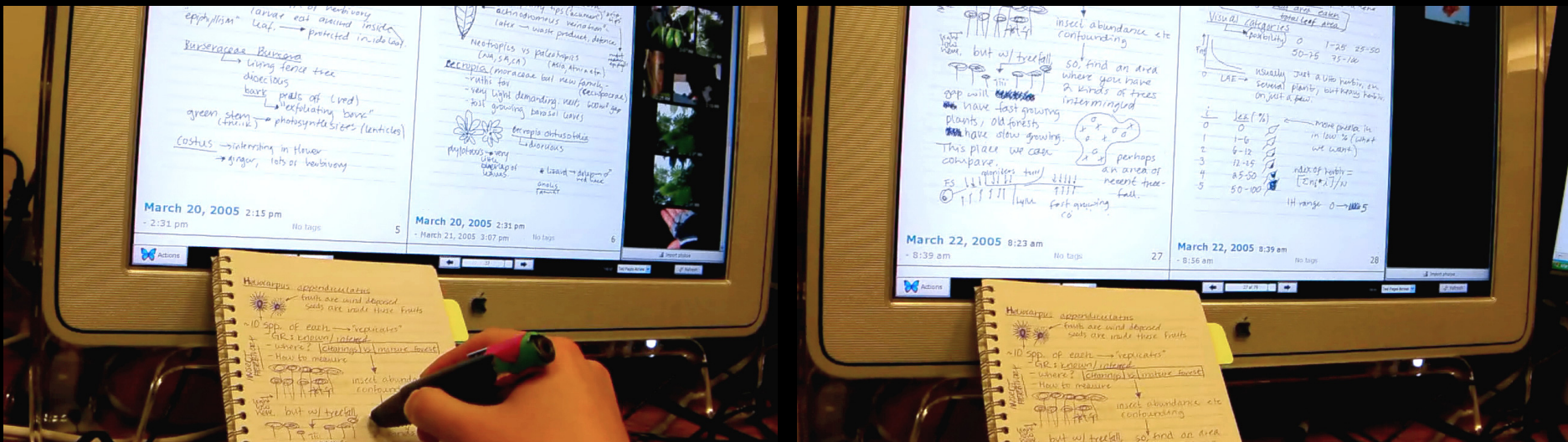
Search

Related Content Search Results



Import photos

Ensemble Interaction 4

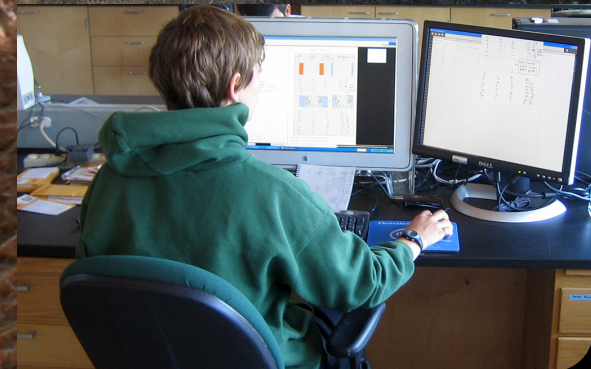


Navigate by Pen & Paper Notebook

A First-Use Study

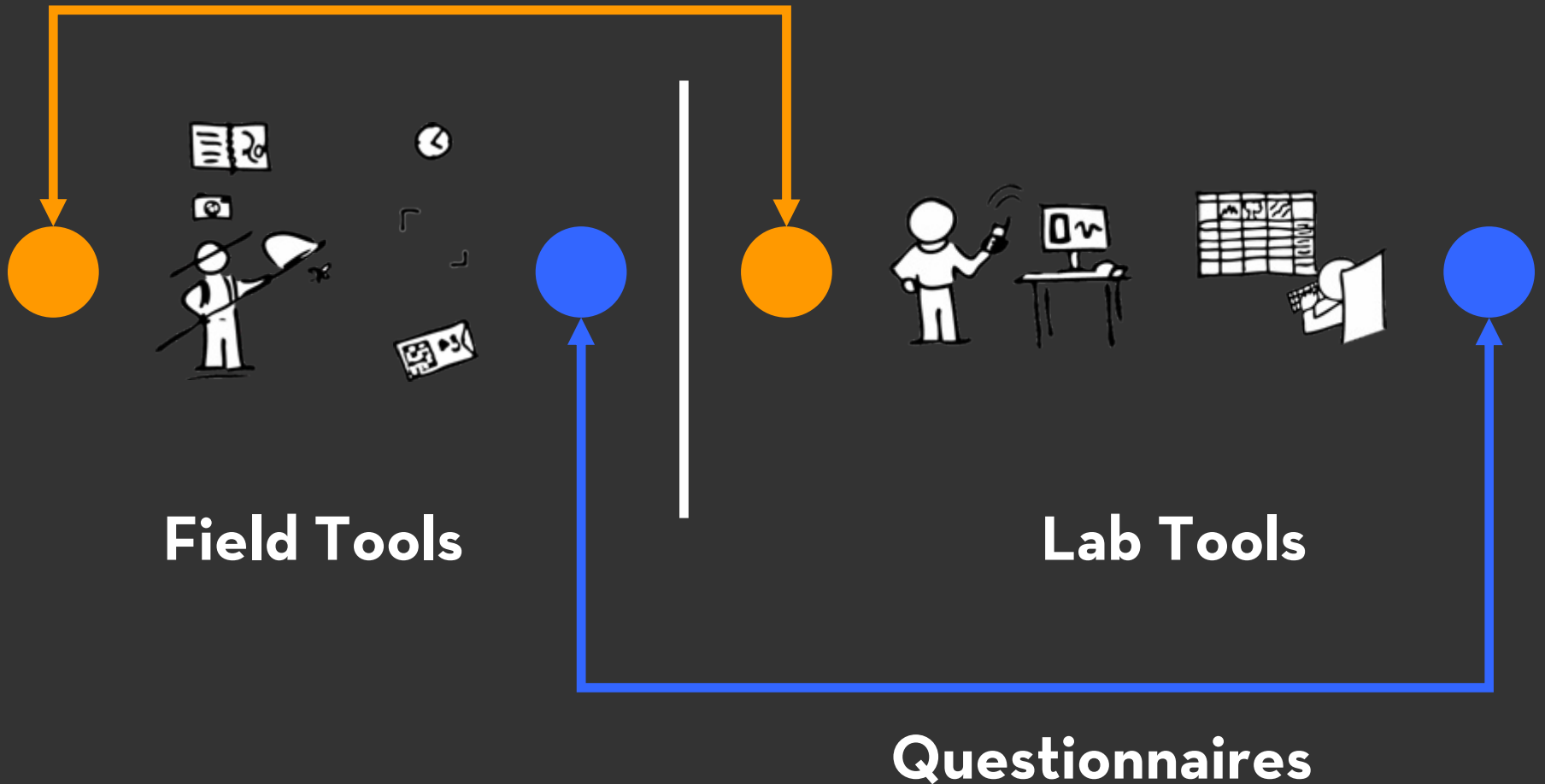
14 Field Biologists

2.5-hours each



Experimental Design

10-min Tutorial



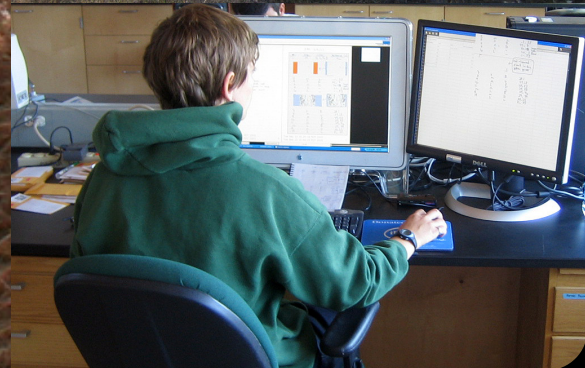
Likes

Dislikes

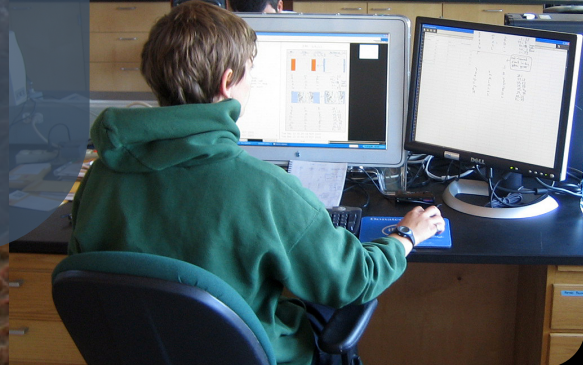
Automatic Capture and Classification Bulky Pen,  adds to field time

Requests

Handwriting Recognition
GPS Integration
Support for audio &
other content types



Longitudinal Evaluation



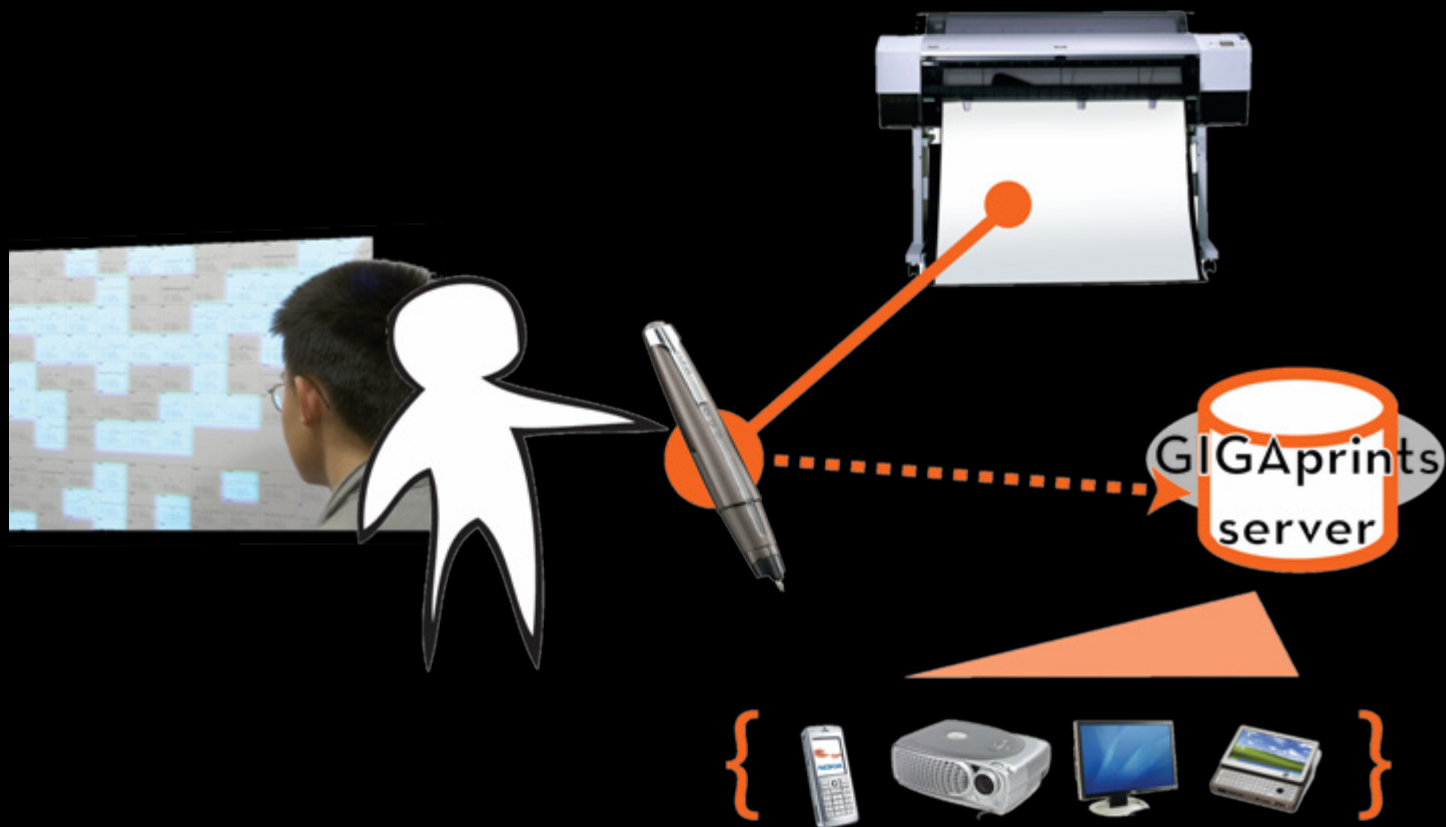
Used By:
Field Biologists at JRBP/Stanford
Anthropologists at Intel Digital Home Group

Will Soon Be Used By:
Cancer Researchers at Stanford
NASA Researchers
and more...

ButterflyNet contribution

Leverages ensemble interactions to provide **rich browsing** of notes with automatically and manually associated research content

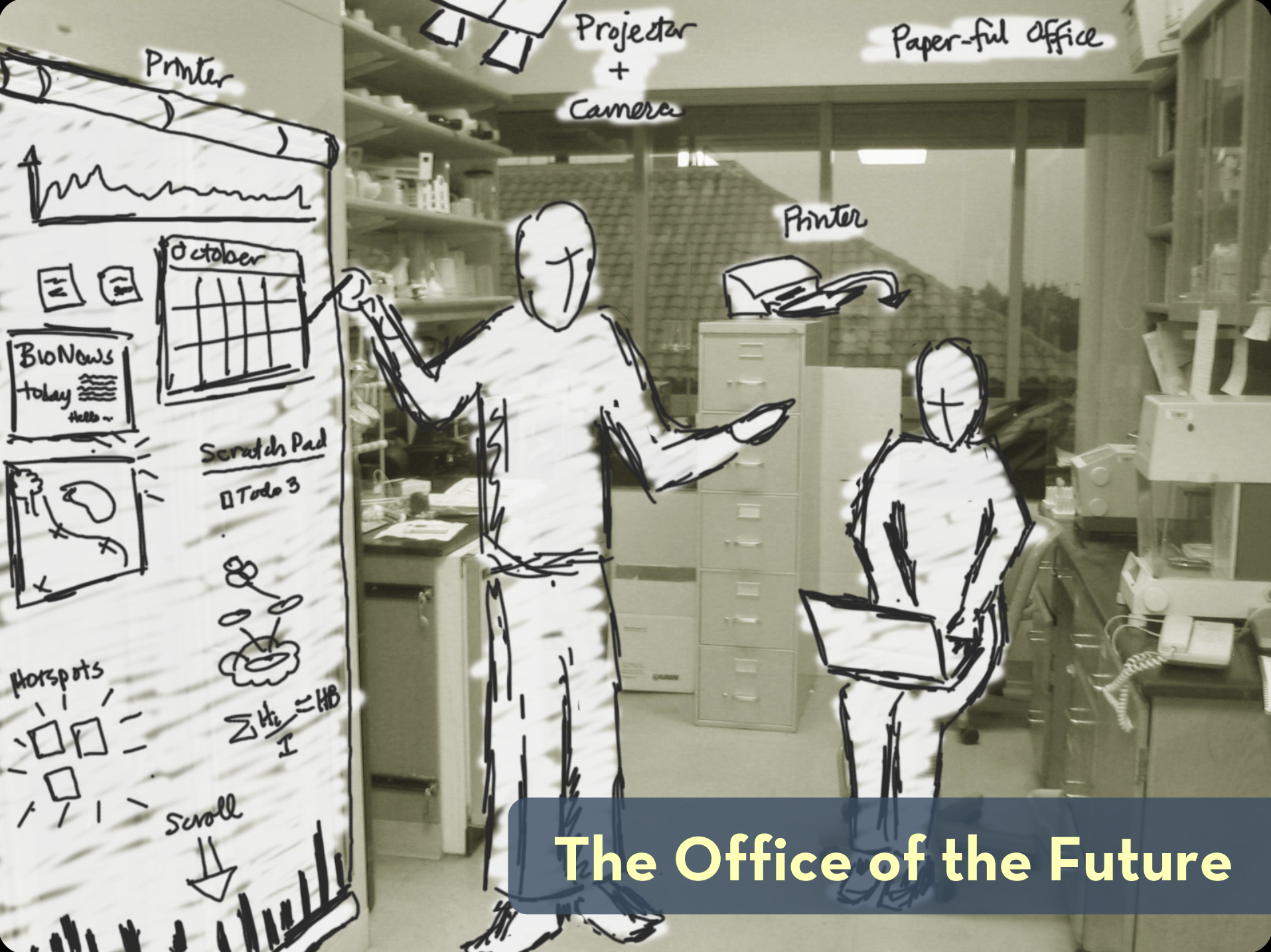
GIGAprints



Mission Statement

Design and Develop...

- 1) visualizations for large, paper-based displays
- 2) techniques for interacting with them.



Printer

Projector
+
Camera

Paper-ful office

Printer

Scratch Pad

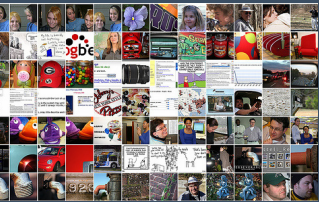
□ Todo 3

$$\sum \frac{H_i}{I} = HB$$

Scroll

The Office of the Future

Paper + Digital Affordances!



Intermittent Output

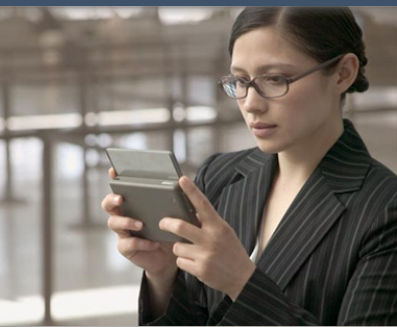
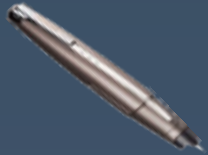
- Print a Visualization on a Wide-format Printer

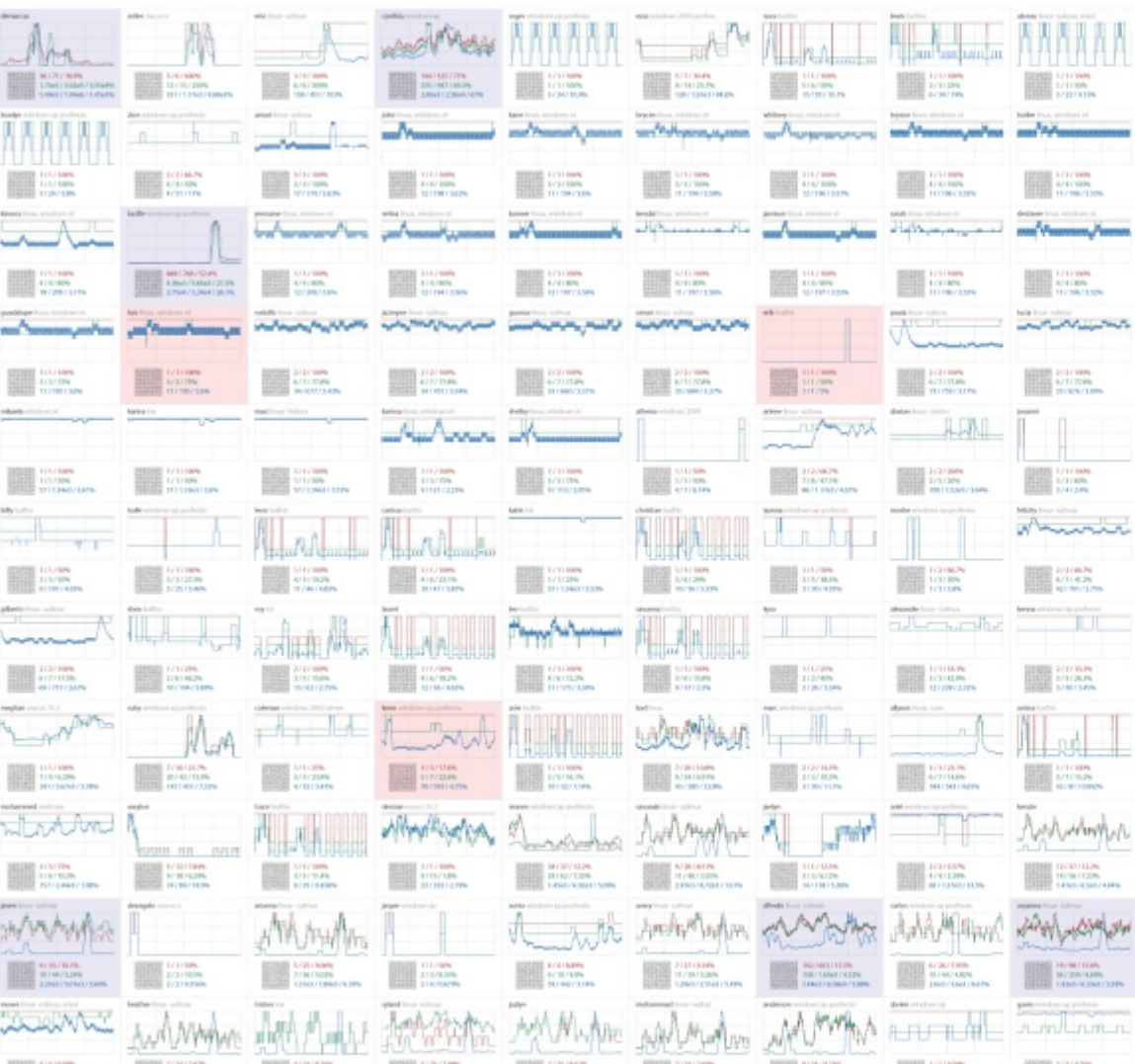
Input

- Digital Pen Technology

Real-Time Output

- Mobile Device
- Nearby Display (LCD or Laptop)
- Projected Overlay





Saturday

Explore Tag

demarcus

36 / 71 / 16.9%
1.73e5 / 3.92e5 / 3.55e4%
5.49e5 / 1.49e6 / 1.45e3%

miles macos x

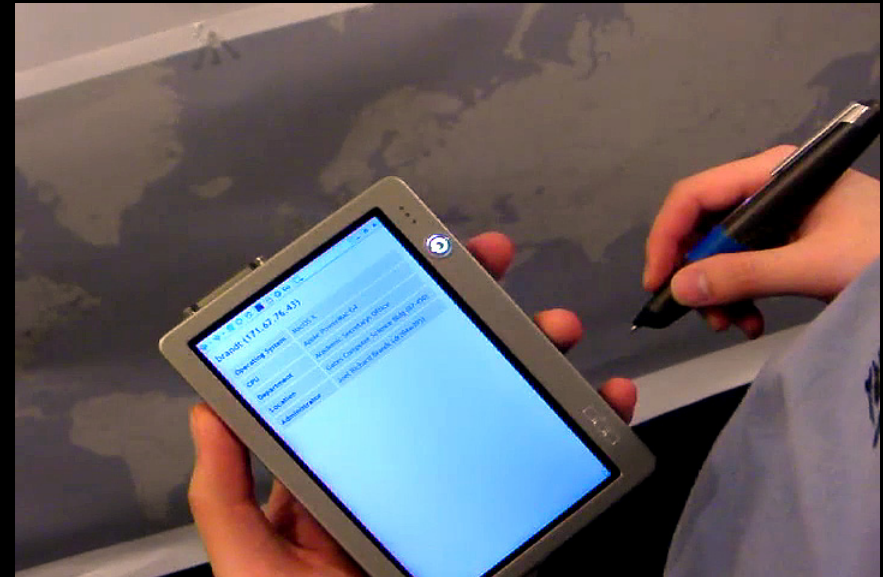
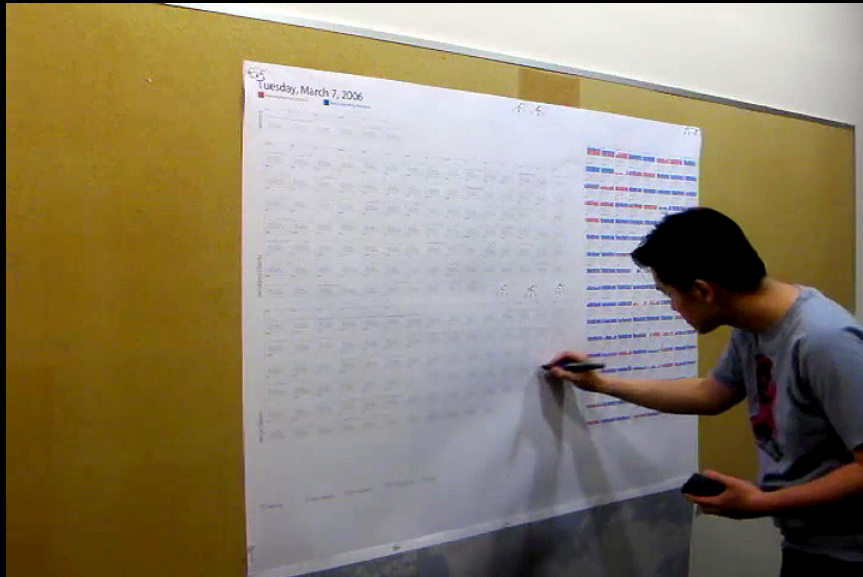
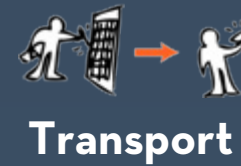
5 / 6 / 600%
12 / 15 / 25%
351 / 1.17e6

bradyn windows xp profesio

zion windows xp profesio

Network Monitoring Tool

Ensemble Interaction 5



Progressive Information Disclosure

Ensemble Interaction 6



Photo Browsing and Tagging

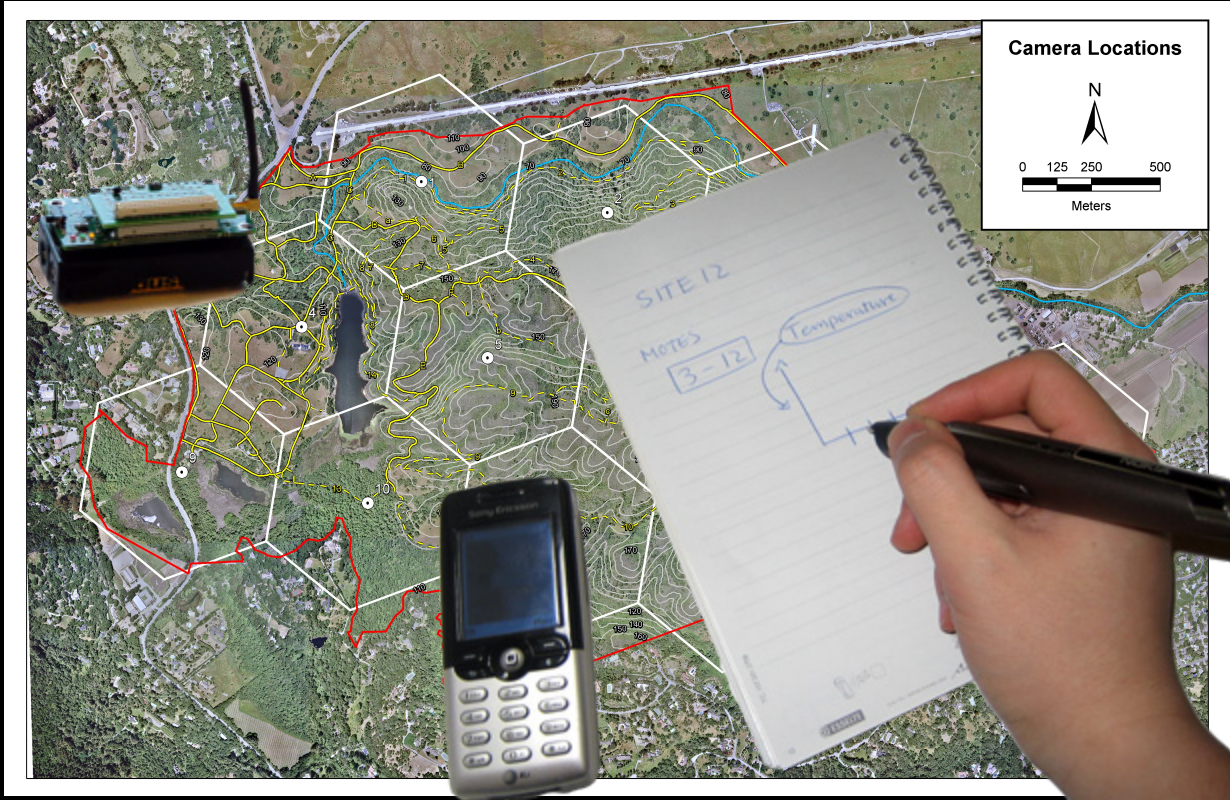
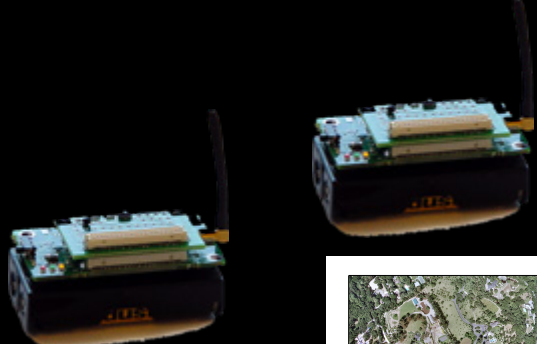
Ensemble Interaction 7



Architect Navigates a 3D View for Client

GIGAprints contribution

Augment large paper surfaces with digital content (on mobile device, projector...), to provide **visual context**, **collaboration**, and **mobility**.



The Sensing Notebook

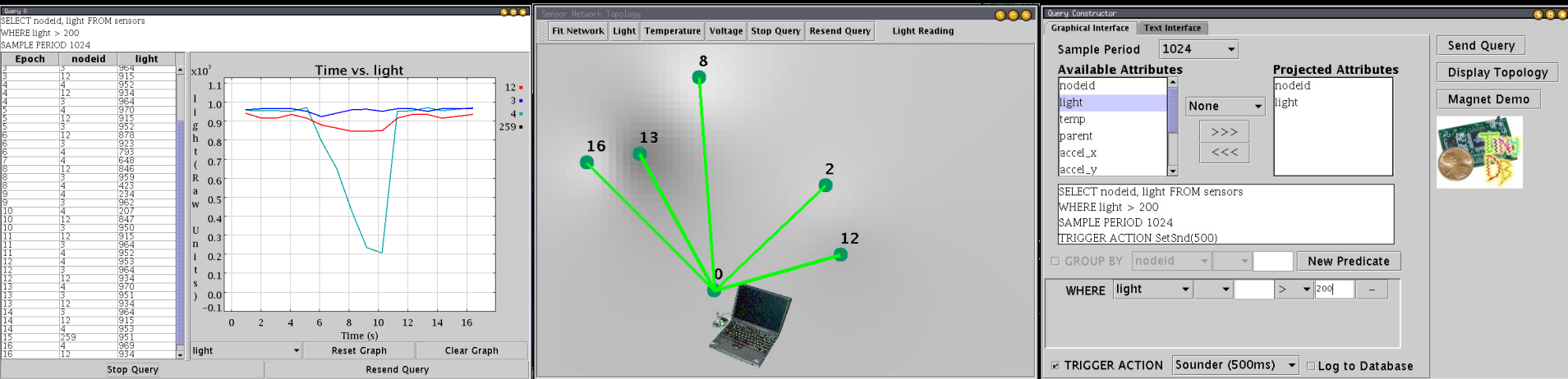
Configure and Manipulate Sensor Networks

Field Sciences
Industrial Monitoring
Digital Home
...and more



Photos from
[Crossbow, USC, VATech, UCLA]

A Desktop Interface (Tiny DB)



A Programmer's Interface (Maté)

```
buffer data;  
data[0] = light();  
send(data);
```

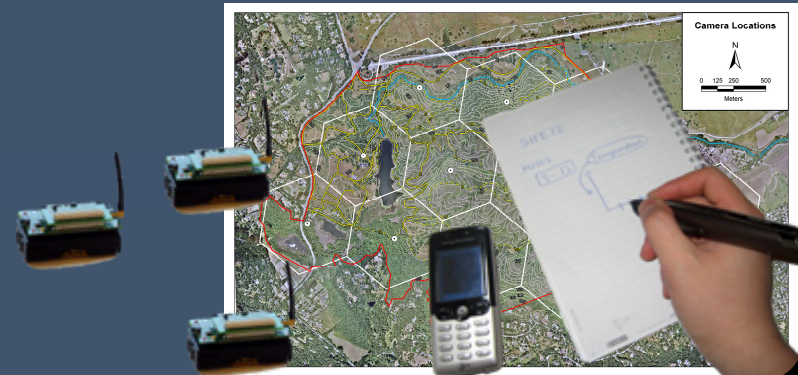
! Route the data to a collection point

Our Goal

Provide a **learnable** yet **efficient** interface for configuring and querying sensor networks.

As these wireless sensors tend to be deployed outside, use an ensemble of a mobile device (e.g., phone) and a portable paper surface (e.g., notebook) to communicate with the sensors.

This is work-in-progress! 😊



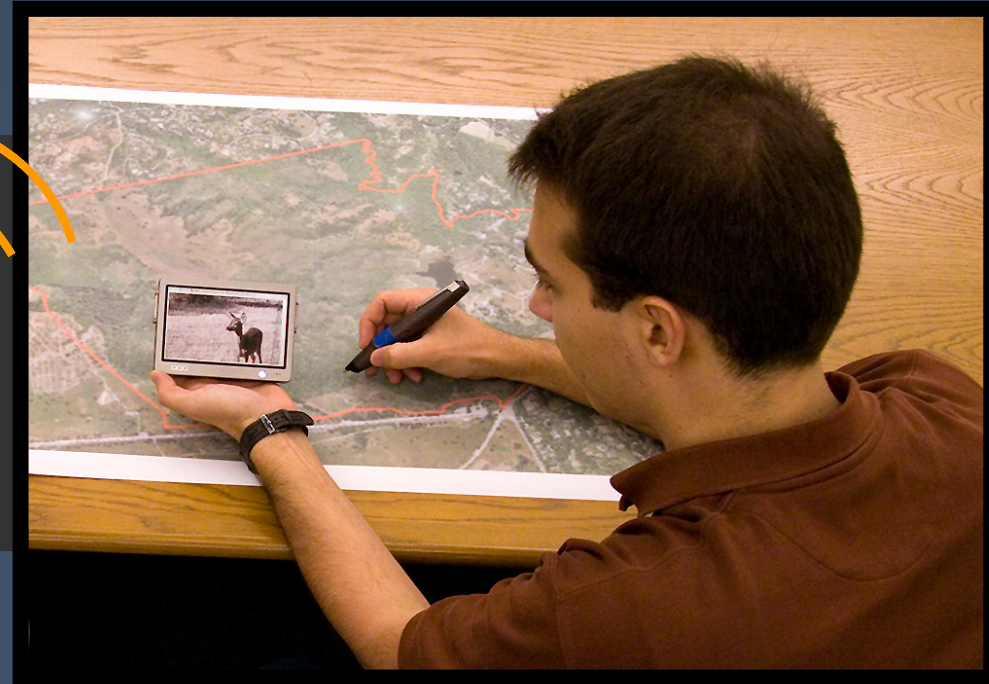
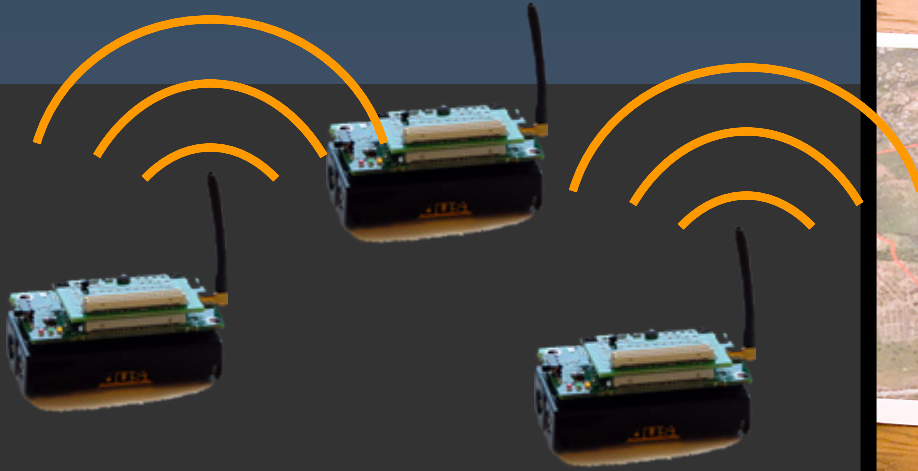
Ensemble Interaction 8



Select



Transport



Select and Transport Live Field Data

Ensemble Interaction 9



Configure Sensor Networks via Gestures



Background

motivation, inspiration, investigation



Projects

ButterflyNet, Interactive Gigapixel Prints, Sensing Notebook



Prior and Future Work

taxonomies, physical-digital primitives, ensembles toolkit

Graphical User Interface Primitives

[Foley and Wallace 1974]

- Pick
- Button
- Locator
- Valuator

[Myers 1990]

- Menu
- Move-grow
- New-point
- Angle
- Text
- Trace

Tangible User Interfaces

Framework from Ullmer, Ishii, and Jacobs
MCRit (MCRpd)

Like Model-View-Controller, except
Controller split between
Intangible (**P**hysical) and **T**angible (**D**igital)
Representations

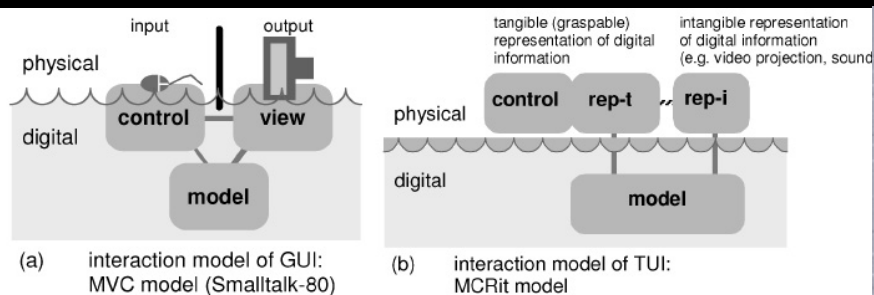
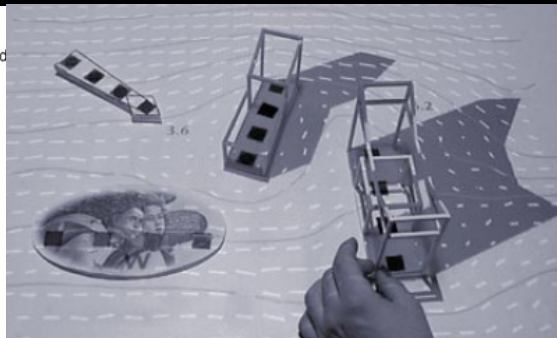


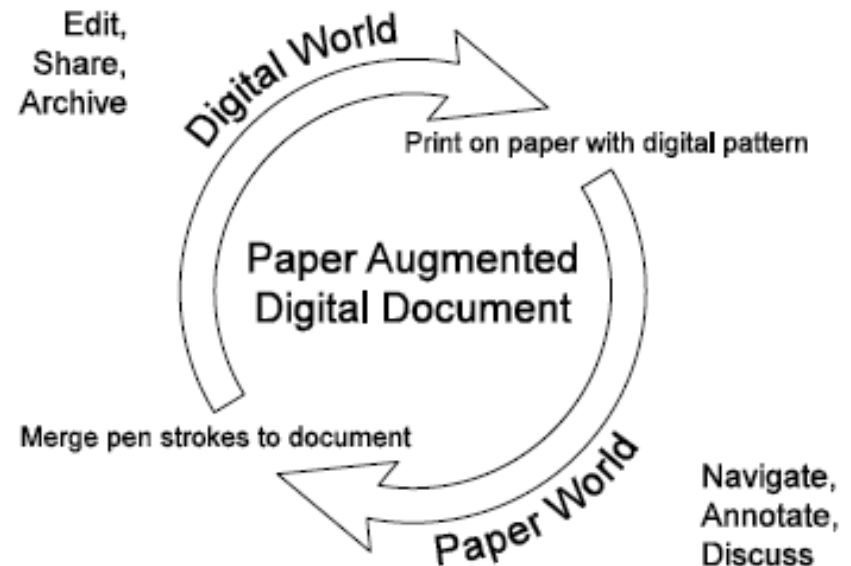
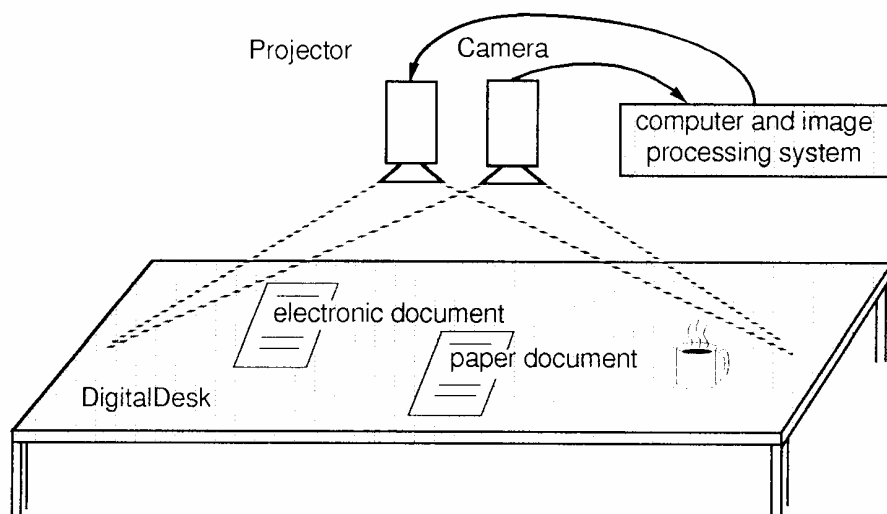
Fig. 9. MVC and MCRit interaction models.



Paper-Digital Integration

[Wellner 1993]

[Guimbretière 2003]



Physical-Digital Toolkits

Papier-Mâché

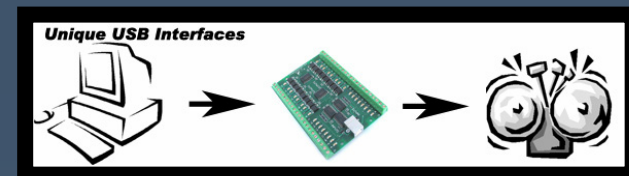
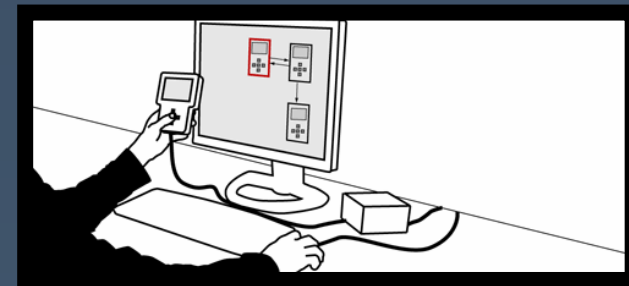
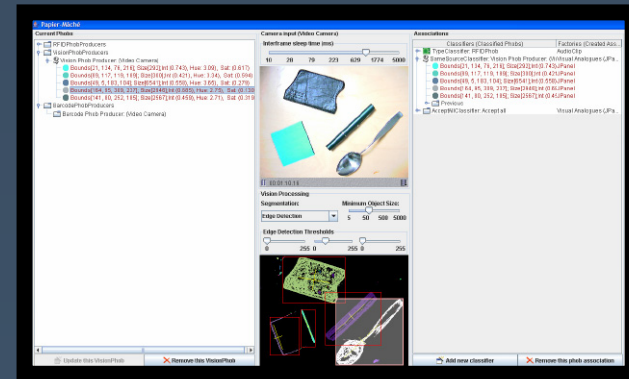
- [Klemmer et al. 2004]
- vision, passive

d.tools

- [Hartmann et al. 2006 (TR)]
- tethered, active

Phidgets

- [Greenberg & Fitchett 2001]
- tethered, active



Anoto Software Tools

Paper Buttons for Pre-Defined Actions

- With a Synchronization Step

Ink/Forms-Based Capture

Ink-Sample Level Abstraction

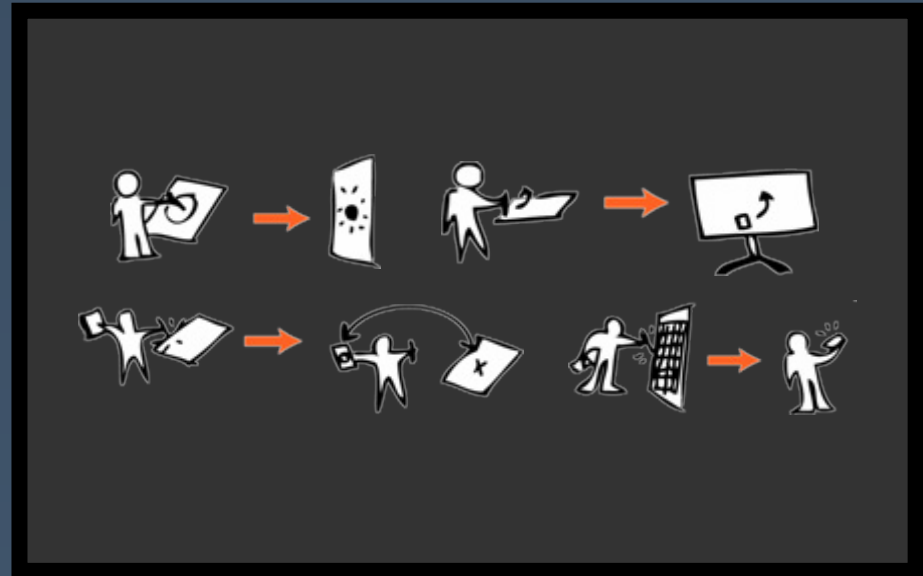
- OK for Programmers
- Wrong level for Most Designers and End-Users

We propose...

Duet: Paper-Digital Ensembles Toolkit

Interactions

- Select
- Manipulate
- Associate
- Transport



Support Iterative Design

[Design → Prototype → Test → Analyze]

Our Target Users

Designers

- Visual Authoring of Paper-Digital Interactions
- WOz Testing
- GUI to Facilitate Analysis of User Tests

Programmers

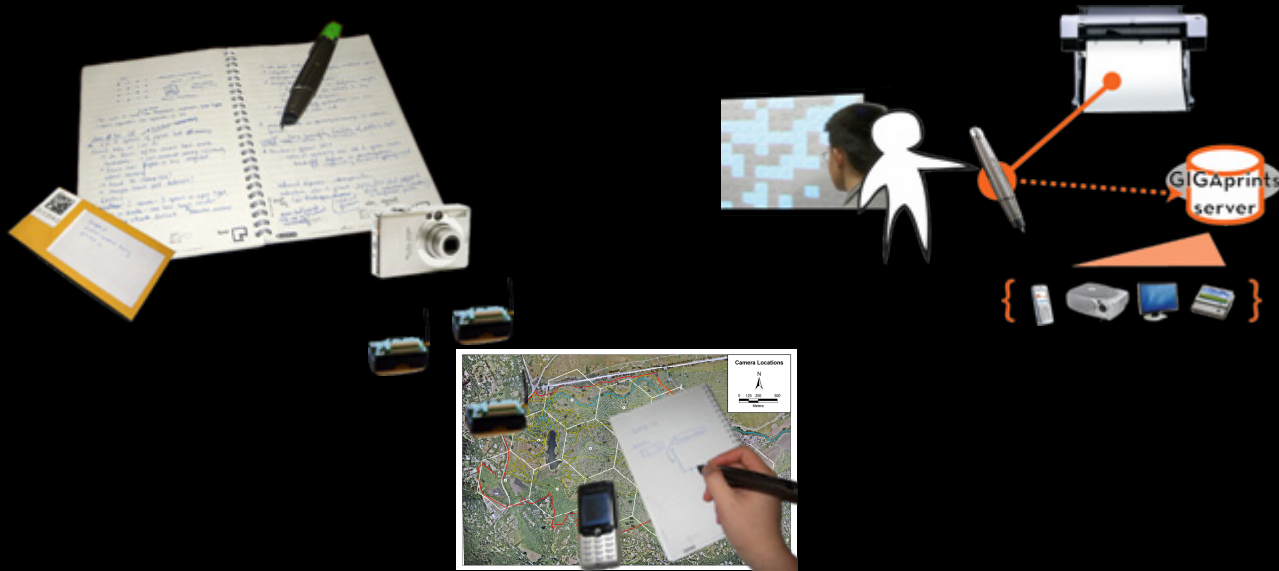
- Java & Python-Based Toolkit
- Event-Based Architecture
- Abstract Away “Dealing with Ink Samples on Paper”

Users (End-User Programming)

- Programming by Example
- Visual Authoring

**Defined and Motivated
Ensemble Interactions**

**Three Projects
Demonstrating Them**



**Proposing Toolkit Support
for Paper-Digital Ensembles**



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