MAKING WITH A SOCIAL PURPOSE

Jon Froehlich | Assistant Professor | Computer Science
Our Mission

Design, build, & study interactive tools & techniques to address pressing societal challenges.
MAKEABILITY LAB
ITERATIVE RESEARCH PROCESS

Formative Studies  Prototyping  Lab-based Studies  Refinement  Field Deployments
MAKEABILITY LAB

FOUR FOCUS AREAS

ENVIRONMENTAL SUSTAINABILITY

HEALTH & WELLNESS

ACCESSIBILITY

STEM EDUCATION
FOUR FOCUS AREAS

ENVIRONMENTAL SUSTAINABILITY

HEALTH & WELLNESS

ACCESSIBILITY

STEM EDUCATION
# Environmental Sustainability

## Pervasive Thermography

With UMD CS PhD Student Matt Mauriello

<table>
<thead>
<tr>
<th>Context</th>
<th>Subjects</th>
<th>Misc./Fun</th>
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<tr>
<td>(a) Indoor (64.2%)</td>
<td>(c) Walls (71.6%)</td>
<td>(g) Light Fixtures (23.8%)</td>
</tr>
<tr>
<td>(b) Outdoor (35.6%)</td>
<td>(e) Electronics (24.7%)</td>
<td>(j) People/Pets (4.7%)</td>
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<td>(d) Windows (30.3%)</td>
<td>(f) Doors (24.4%)</td>
<td>(h) Ceilings (22.7%)</td>
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<tr>
<td>(i) Play/Experiments (1.0%)</td>
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[UbiComp’13, CHI’15 Honorable Mention, HBI’16, CHI’17]
MAKEABILITY LAB
FOUR FOCUS AREAS

ENVIROMENTAL SUSTAINABILITY

HEALTH & WELLNESS

ACCESSIBILITY

STEM EDUCATION
FOUR FOCUS AREAS

- ENVIRONMENTAL SUSTAINABILITY
- HEALTH & WELLNESS
- ACCESSIBILITY
- STEM EDUCATION
FOUR FOCUS AREAS

- Environmental Sustainability
- Health & Wellness
- Accessibility
- STEM Education
FOUR FOCUS AREAS

ENVIRONMENTAL SUSTAINABILITY

HEALTH & WELLNESS

ACCESSIBILITY

STEM EDUCATION
How to...
make the *physical world* more accessible for people with disabilities
THREAD 1: ACCESSIBILITY

IMPROVING ACCESS TO THE PHYSICAL WORLD

PROJECT SIDEWALK
[ASSETS'12, CHI'13, HCOMP'13, ASSETS'13 Best Paper, UIST'14, TACCESS'15, SIGACCESS'15, CHI'16]

HANDSIGHT
[ACVR'14, ASSETS'15, GI'16, TACCESS'16]

GLASSEAR
[CHI'15]
How can we...

develop scalable solutions that map the accessibility of urban infrastructure?

PROJECT SIDEWALK
[ASSETS'12, CHI'13, HCOMP’13, ASSETS’13 Best Paper, UIST’14, TACCESS’15, SIGACCESS’15, CHI’16]
30.6 million U.S. adults have a mobility impairment

Source: US Census, 210
15.2 million use an assistive aid

Source: US Census, 210
Accessible infrastructure has a significant impact on the independence and mobility of citizens.

[Thapar et al., 2004; Nuernberger, 2008]
The National Council on Disability noted that there is no comprehensive information on “the degree to which sidewalks are accessible” in cities.

National Council on Disability, 2007
The impact of the Americans with Disabilities Act: Assessing the progress toward achieving the goals of the ADA
We are pursuing a two-fold solution
To develop scalable methods that mine massive repositories of online map imagery to identify accessibility problems semi-automatically
To create new accessibility-aware mapping tools that support people with disabilities and provide unprecedented views of urban accessibility.
MAPPING THE ACCESSIBILITY OF THE WORLD
TWO FOCUS AREAS

SCALABLE DATA COLLECTION METHODS
[ASSETS’12, CHI’13, HCOMP’13, ASSETS’13, UIST’14, TACCESS’15]

NEW ACCESSIBILITY GIS TOOLS
[SIGACCESS ’15, CHI’16]
Is online map imagery a good source for accessibility data?

Can we create interactive tools that enable crowd workers to find accessibility problems?

How can we leverage computational techniques to scale our approach?
THE TEAM

PROFESSORS

- Jon Froehlich
- David Jacobs
- Kotaro Hara
- Manaswi Saha
- Jin Sun
- Ladan Najafizadeh
- Soheil Behnezhad

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- Christine Chan
- Maria Furman
- Daniil Zadorozhnyy
- Zach Lawrence
- Alex Zhang

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- Anthony Li
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- Maria Furman
- Daniil Zadorozhnyy
- Zach Lawrence
- Alex Zhang
Is online map imagery a good source for accessibility data?

Can we create interactive tools that enable crowd workers to find accessibility problems?

How can we leverage computational techniques to scale our approach?

SCALABLE DATA COLLECTION METHODS
[ASSETS'12, CHI'13, HCOMP'13, ASSETS'13, UIST’14, TACCESS’15]
How well do accessibility problems found in Google Street View correspond with the real world?
IS GSV A GOOD DATASET FOR ACCESSIBILITY AUDITS?

PHYSICAL AUDITS VS. GOOGLE STREET VIEW

179 BUS STOPS
Washington DC & Seattle | 42 km surveyed

273 INTERSECTIONS
Washington DC & Baltimore | 34 km surveyed
IS GSV A GOOD DATASET FOR ACCESSIBILITY AUDITS?

COMPARISON RESULTS: SPEARMAN RANK COEFFICIENTS

**BUS STOPS**

**PHYSICAL AUDIT DATA** vs. **GSV AUDIT DATA**

**INTERSECTIONS**

**PHYSICAL AUDIT DATA** vs. **GSV AUDIT DATA**

\[ \rho = 0.88 \] vs. \[ \rho = 0.98 \]

All results statistically significant at \( p < 0.001 \)
IS GSV A GOOD DATASET FOR ACCESSIBILITY AUDITS?

CITY INFRASTRUCTURE CHANGES SLOWLY

Consistent with literature, see: Odgers et al., 2012; Wilson et al., 2013; Kelly et al., 2013; Bader et al., 2017

AVG IMAGE AGE IN BUS STOP DATASET

1.7 yrs (SD=0.7)

AVG IMAGE AGE IN INTERSECTION DATASET

1.5 yrs (SD=0.7)
Google Street View is a reasonable proxy for studying the state of street-level accessibility.
Is online map imagery a good source for accessibility data?

Can we create interactive tools that enable crowd workers to find accessibility problems?

How can we leverage computational techniques to scale our approach?

SCALABLE DATA COLLECTION METHODS
[ASSETS’12, CHI’13, HCOMP’13, ASSETS’13, UIST’14, TACCESS’15]
CROWDSOURCING ACCESSIBILITY AUDITS

INITIAL CROWDSOURCING SYSTEM

LABELING INTERFACE

VERIFICATION INTERFACE
4-STEP PROCESS

1. Find & label problem
CROWDSOURCING ACCESSIBILITY AUDITS

LABELING INTERFACE

4-STEP PROCESS
1. Find & label problem
CROWDSOURCING ACCESSIBILITY AUDITS

LABELING INTERFACE

4-STEP PROCESS
1. Find & label problem
2. Categorize problem
CROWDSOURCING ACCESSIBILITY AUDITS

LABELING INTERFACE

4-STEP PROCESS
1. Find & label problem
2. Categorize problem
CROWDSOURCING ACCESSIBILITY AUDITS

LABELING INTERFACE

4-STEP PROCESS
1. Find & label problem
2. Categorize problem
3. Rate problem severity
1. Find & label problem
2. Categorize problem
3. Rate problem severity
CROWDSOURCING ACCESSIBILITY AUDITS

LABELING INTERFACE

4-STEPS PROCESS
1. Find & label problem
2. Categorize problem
3. Rate problem severity
4. Submit work
4-STEP PROCESS
1. Find & label problem
2. Categorize problem
3. Rate problem severity
4. Submit work

Receive another image to label & process repeats.
1. Verify label
2. Verify rating
3. Provide details
1. Create image dataset
2. Generate ground truth labels
3. Deploy our tools to crowd
4. Compare performance to ground truth
1. CROWDSOURCING ACCESSIBILITY STUDY METHOD
2. DOWNLOADED 229 GSV IMAGES

- NEW YORK
- BALTIMORE
- WASHINGTON DC
- LOS ANGELES
1. Create image dataset

2. Generate ground truth labels
CROWDSOURCING ACCESSIBILITY STUDY METHOD
CREATE GROUND TRUTH LABELS

Bob
Bob’s Labels

Sue
Sue’s Labels

Alice
Alice’s Labels

Majority Vote

Researcher Ground Truth
1. Create image dataset
2. Generate ground truth labels
3. Deploy our tools to crowd
CROWDSOURCING ACCESSIBILITY STUDY RESULTS

MTURK STUDY STATISTICS

185
LABELERS

7,517
LABELS

35.2s
LABEL AN IMAGE

273
VERIFIERS

19,189
VERIFICATIONS

10.5s
VERIFY AN IMAGE

3x as fast!
1. Create image dataset
2. Generate ground truth labels
3. Deploy our tools to crowd
4. Compare performance to ground truth
Are crowd workers capable of finding accessibility problems in online map imagery?
CROWDSOURCING ACCESSIBILITY STUDY RESULTS

OVERALL LABELING ACCURACY
With one labeler per image

- Sidewalk Ending: 85%
- Missing Curb Ramps: 79%
- Surface Problem: 77%
- Object in Path: 73%
CROWDSOURCING ACCESSIBILITY STUDY RESULTS

OVERALL LABELING ACCURACY

With one labeler per image

SIDEWALK ENDING: 85%
MISSING CURB RAMPS: 79%
SURFACE PROBLEM: 77%
OBJECT IN PATH: 73%

AVERAGE OVERALL ACCURACY

Multiclass Overall: 78%
Binary Overall: 81%
OVER LABELING
(i.e., tendency towards false positives)

RANDOM LABELS
(e.g., misunderstanding, malevolence)

CATEGORY ERRORS
(i.e., ambiguous problem category)
ACCURACY AS A FUNCTION OF LABELERS PER IMAGE

CROWDSOURCING ACCESSIBILITY STUDY RESULTS

- 1 turker (N=28): 78%
- 3 turkers (N=9): 84%
- 5 turkers (N=5): 87%
- 7 turkers (N=4): 87%
- 9 turkers (N=3): 88%

Error bars: standard error
CROWDSOURCING ACCESSIBILITY STUDY RESULTS

ACCURACY AS A FUNCTION OF LABELERS PER IMAGE

- **1 labeler**
  - Multiclass: 78%
  - Binary: 81%

- **3 labelers (majority vote)**
  - Multiclass: 84%
  - Binary: 87%

- **5 labelers (majority vote)**
  - Multiclass: 87%
  - Binary: 90%

- **7 labelers (majority vote)**
  - Multiclass: 87%
  - Binary: 91%

- **9 labelers (majority vote)**
  - Multiclass: 88%
  - Binary: 90%

Error bars: standard error

- **Multiclass**
- **Binary**
CROWDSOURCING ACCESSIBILITY STUDY RESULTS

ACCURACY WITH CROWD VERIFICATION

- **1 labeler**
  - Multiclass: 75%
  - Binary: 81%

- **1 labeler, 3 verifiers**
  - Multiclass: 78%
  - Binary: 88%

- **3 labelers**
  - Multiclass: 80%
  - Binary: 89%

- **3 labelers, 3 verifiers**
  - Multiclass: 82%
  - Binary: 93%

- **5 labelers**
  - Multiclass: 82%
  - Binary: 91%

**TIME COST**

Error bars: standard error; experiments run on subset of data
With basic quality control measures, **minimally trained crowd** workers can find accessibility problems with an accuracy of ~93%
Relied *purely on manual labor*. Can we do better?
Is online map imagery a good source for accessibility data?

Can we create interactive tools that enable crowd workers to find accessibility problems?

How can we leverage computational techniques to scale our approach?

SCALABLE DATA COLLECTION METHODS
[ASSETS’12, CHI’13, HCOMP’13, ASSETS’13, UIST’14, TACCESS’15]
Tohme
遠目・Remote Eye
svCrawl
Web Scraper
1. svCrawl Web Scraper

Street View images
3D-depth maps
Top-down map images
GIS metadata

2. Street Dataset

Google Street View Panoramas

3D Point-cloud Data

Top-down Google Maps Imagery

GIS Metadata

<Latitude & longitude/>
<GSV image age/>
<Street & city names/>
<Intersection topology/>
svCrawl Web Scraper

Street Dataset

Scraped Area: 11.3 km²

Dataset Statistics

- 1,086 intersections
- 2,877 curb ramps
- 647 missing curb ramps
- 2.2 yrs (SD=1.3) average GSV image age

Street View images
3D-depth maps
Top-down map images
GIS metadata
SVCrawl: Web Scraper

svDetect: Automatic Curb Ramp Detection

Street View images
3D-depth maps
Top-down map images
GIS metadata

Street Dataset
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

Street View images
3D-depth maps
Top-down map images
GIS metadata

Street Dataset
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

1. Street View images
2. 3D-depth maps
3. Top-down map images
4. GIS metadata

True Positive
1. svCrawl Web Scraper
2. Street Dataset
3. svDetect Automatic Curb Ramp Detection

Street View images
3D-depth maps
Top-down map images
GIS metadata

True Positive
False Positive
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

Street View images
3D-depth maps
Top-down map images
GIS metadata

Street Dataset

False Positive
False Negative
True Positive
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

svControl
Automatic Task Allocation

svVerify
Crowd Verification

Street Dataset
Street View images
3D-depth maps
Top-down map images
GIS metadata

Predicted CV success
1. svCrawl
   Web Scraper

2. Street Dataset
   Street View images
   3D-depth maps
   Top-down map images
   GIS metadata

3. svDetect
   Automatic Curb Ramp Detection

4. svControl
   Automatic Task Allocation

5. svVerify
   Crowd Verification
   Predicted CV success
   Predicted CV failure

6. svLabel
   Crowd Labeling
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

svControl
Automatic Task Allocation

svVerify
Crowd Verification

Street View images
3D-depth maps
Top-down map images
GIS metadata

Street Dataset
1. svCrawl: Web Scraper

2. Street Dataset
   - Street View images
   - 3D-depth maps
   - Top-down map images
   - GIS metadata

3. svDetect: Automatic Curb Ramp Detection

4. svControl: Automatic Task Allocation

5. svVerify: Crowd Verification

Predicted CV success
svCrawl Web Scraper

svDetect Automatic Curb Ramp Detection

svControl Automatic Task Allocation

svVerify Crowd Verification

Street View images
3D-depth maps
Top-down map images
GIS metadata

Predicted CV success
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

svControl
Automatic Task Allocation

svVerify
Crowd Verification

Street View images
3D-depth maps
Top-down map images
GIS metadata

Predicted CV success
svCrawl Web Scraper

svDetect Automatic Curb Ramp Detection

svVerify Crowd Verification

svControl Automatic Task Allocation

svLabel Crowd Labeling

Street View images
3D-depth maps
Top-down map images
GIS metadata
svCrawl
Web Scraper

svDetect
Automatic Curb Ramp Detection

svControl
Automatic Task Allocation

svVerify
Crowd Verification

svLabel
Crowd Labeling

Street View images
3D-depth maps
Top-down map images
GIS metadata

Predicted CV failure
1. svCrawl: Web Scraper

2. Street Dataset
   - Street View images
   - 3D-depth maps
   - Top-down map images
   - GIS metadata

3. svDetect: Automatic Curb Ramp Detection

4. svControl: Automatic Task Allocation

5. svVerify: Crowd Verification

6. svLabel: Crowd Labeling
Verifiers **cannot fix false negatives** 
(i.e., they cannot add new labels)
TOHME
遠目 Remote Eye

svCrawl Web Scraper

svDetect Automatic Curb Ramp Detection

svControl Automatic Task Allocation

svVerify Crowd Verification

svLabel Crowd Labeling

Street Dataset
Street View images
3D-depth maps
Top-down map images
GIS metadata

Task Allocation

svLabel Crowd Labeling
1. Deformable part model (DPM)
2. Post-processing DPM
3. SVM-based classifier
AUTOMATIC CURB RAMP DETECTOR
DEFORMABLE PART MODEL

Felzenszwalb et al., CVPR’08, CVPR’10
AUTOMATIC CURB RAMP DETECTOR
DEFORMABLE PART MODEL

Root filter
Parts filter
Displacement cost
**Automatic Curb Ramp Detector**

**Deformable Part Model**

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<tr>
<td>True Positives</td>
<td>1</td>
</tr>
<tr>
<td>False Positives</td>
<td>12</td>
</tr>
<tr>
<td>False Negatives</td>
<td>0</td>
</tr>
</tbody>
</table>
AUTOMATIC CURB RAMP DETECTOR
DEFORMABLE PART MODEL

True Positives: 1
False Positives: 12
False Negatives: 0

CURB RAMPS DETECTED IN SKY & ON ROOFS
MULTIPLE REDUNDANT DETECTION BOXES
2. Automatic Curb Ramp Detector

Post-Process DPM Output

3D-Point Cloud to Remove Curb Ramps Above Ground
Non-maximum suppression to remove overlapping detections
True Positives: 1
False Positives: 5
False Negatives: 0
SVM-BASED REFINEMENT

SVM filters detections based on size, color, & position in scene.
True Positives: 1
False Positives: 3
False Negatives: 0
True Positives: 6
False Positives: 11
False Negatives: 1
**True Positives**: 6
**False Positives**: 4
**False Negatives**: 1
True Positives | 6
False Positives | 4
False Negatives | 1

FALSE NEGATIVE (HARD TO CORRECT)
FALSE POSITIVES (EASY TO CORRECT)
SMART TASK ALLOCATOR

**SVM TRAINED WITH 23 INPUT FEATURES**
Binary classifier trained to predict occurrence of false negatives from svDetect stage

- **Curb Ramp Detector Output (16 Features)**
  - Raw # of bounding boxes
  - Descriptive stats of confidence scores
  - Descriptive stats of XY-coordinates

- **3D-Point Cloud Data (5 Features)**
  - Descriptive stats of depth information (e.g., average, median, variance) of pixel depth

- **Intersection Complexity (2 Features)**
  - Cardinality (# of connected streets)
  - Amount of road
1. svCrawl
   Web Scraper

2. svControl
   Street Dataset
   Street View images
   3D-depth maps
   Top-down map images
   GIS metadata

3. svDetect
   Automatic Curb Ramp Detection

4. svControl
   Task Allocation

5. svVerify
   Crowd Verification
   Predicted CV success
   Predicted CV failure

6. svLabel
   Crowd Labeling
CROWD INTERFACES

VERIFICATION TOOL
Correct false positives from computer vision
Correct false positives from computer vision

Playback Speed: 2x

This study is being conducted by the University of Maryland.
svCrawl - Web Scraper

svDetect - Automatic Curb Ramp Detection

svControl - Task Allocation

svVerify - Crowd Verification

svLabel - Crowd Labeling
CROWD INTERFACES

LABELING TOOL

Find and label the following:
- Explore
- Curb Ramp
- Missing Curb Ramp

Status
- Mission:
  Your mission is to find and label the presence and absence of curb ramps at intersections.
- Progress:
  You have finished 0 out of 5.

Labeled Landmarks:
- You've submitted 0 curb ramp labels and 0 missing curb ramp labels.

Keyboard Shortcuts:
- ESC: Cancel drawing
- Z / Shift+Z: Zoom in / Zoom out

Observed area: 14%

Please enter any comments about this intersection that may affect people with mobility impairment (optional)

Skip
Submit
1. Generate ground truth labels
2. Train computer vision & task controller
3. Deploy Tohme to Mechanical Turk
4. Compare Tohme to baseline
TOHME EVALUATION

OVERALL RESULTS

Manual Labeling

CV + Verification

Tohme System

100% bottom workflow

100% top workflow

full tohme system

Accuracy (%)

0%

20%

40%

60%

80%

100%

Precision

Recall

F-measure
TOHME EVALUATION

OVERALL RESULTS

Manual Labeling

CV + Verification

Tohme System

100% bottom workflow

100% top workflow

full tohme system

Accuracy (%)

Precision
Recall
F-measure
TOHME EVALUATION

OVERALL RESULTS

Manual Labeling

CV + Verification

Tohme System

Accuracy (%)

Precision | Recall | F-measure

84% | 88% | 86%

68% | 58% | 63%

83% | 86% | 84%

100% bottom workflow

100% top workflow

full tohme system

94s PER SCENE

42s PER SCENE

81s PER SCENE

14% faster
SV CRAWL
Web Scraper

SVDETECT
Automatic Curb Ramp Detection

SV CONTROL
Automatic Task Allocation

SV VERIFY
Crowd Verification

SVLABEL
Crowd Labeling

Street View images
3D-depth maps
Top-down map images
GIS metadata

TOHME EVALUATION
TASK CONTROLLER PERFORMANCE

80% SCENES CORRECTLY Routed
50% SCENES CORRECTLY Routed
TOHME EVALUATION

SIMULATED PERFECT TASK CONTROLLER

svControl
Automatic Task Allocation

svVerify
Crowd Verification

svLabel
Crowd Labeling

Simulated perfect task controller

100% SCENES CORRECTLY ROUTED

OVERALL SPEEDUP INCREASES OVER MANUAL BASELINE

14% SPEEDUP

27% SPEEDUP
1. Improving detection algorithms
2. Project Sidewalk
3. New workflows & interfaces
4. Developing new assistive technologies
APPLYING CONVOLUTIONAL NEURAL NETWORKS

Recently accepted to CVPR’17
Let's create a path for everyone

How you can help

Virtually explore city streets to find and label accessibility
Audit 1000ft of Fort Stanton

Your mission is to audit 1000ft of Fort Stanton and find all the accessibility features that affect mobility impaired travelers!
CURRENT & FUTURE WORK

PROJECT SIDEWALK CONTRIBUTIONS

500 USERS
470 MILES
66,000 LABELS
Are there curb ramps in these pictures? Click here for more instruction.

You have verified 0 images. 50 more to go!
CURRENT & FUTURE WORK

NEW HYBRID WORKFLOWS & INTERFACES

Are there curb ramps in these pictures? Click here for more instruction.

You have verified 0 images. 50 more to go!
FUTURE WORK

TRACKING ACCESSIBILITY INFRASTRUCTURE OVER TIME
PROJECT SIDEWALK

NOVEL ASSISTIVE TECHNOLOGY APPLICATIONS

New models & viz of city accessibility

Smart routing for people with impairments

Cross-city comparison tools
Access Features

This API serves point-level location data on accessibility features. The major categories of the features include: "Curb Ramp," "Missing Curb Ramp," "Obstacles," and "Surface Problem." You would occasionally find an accessibility feature like "No Sidewalk."

URL /v1/access/features
Method GET

Parameters Required:
You need to pass a pair of latitude coordinates to define a bounding box, which is used to specify where you want to query the data from.

- lat1=[double]
- lng1=[double]
- lat2=[double]
- lng2=[double]

Success Response 200
The API returns all the available accessibility features in the specified area as a Feature Collection of Point features.

Example /v1/access/features?lat1=38.909&lng1=-76.999&lat2=38.912&lng2=-76.982

Access Score: Streets

This API serves Accessibility Scores of the streets within a specified region. Accessibility Score is a numerical value between 0 and 1, where 0 means inaccessible and 1 means accessible.

URL /v1/access/score/streets
Method GET

Parameters Required:
You need to pass a pair of latitude coordinates to define a bounding box, which is used to specify where you want to query the data from.

- lat1=[double]
- lng1=[double]
- lat2=[double]
- lng2=[double]
THREAD 1: ACCESSIBILITY

IMPROVING ACCESS TO THE PHYSICAL WORLD

PROJECT SIDEWALK
[ASSETS’12, CHI’13, HCOMP’13, ASSETS’13 Best Paper, UIST’14, TACCESS’15, SIGACCESS’15, CHI’16]

HANDSIGHT
[ACVR’14, ASSETS’15, GI’16, TACCESS’16]

GLASSEAR
[CHI’15]
How can we... 
we sense & feed back non-tactile information about the physical world as it is touched?
In our work, we are exploring:

*How to computationally augment a blind person’s sense of touch to interpret non-tactile information about the world?*
Imagine, for example, gliding your finger along printed text and hearing the words read back to you in real-time, feeling the shape of a bar graph in a book or newspaper, or touching a piece of clothing and hearing a description of the underlying fabric.
Sensing + feedback for non-tactile information about the physical world as it is touched.
HANDSIGHT

PROTOTYPE EXPLORATIONS
VISION-AUGMENTED TOUCH
HANSDIGHT

FINGER HAPTICS

ENDOSCOPIC CAMERA (1MM³)

WRIST HAPTICS
For processing, power, additional sensing & feedback
HANDSIGHT

FOCUS AREAS

READING SUPPORT
[ACVR’14, TACCESS’15]

COLOR/TEXTURE RECOGNITION
In progress

TOUCH-BASED CONTROL
[ICPR’16]

HAPTIC + AUDITORY FEEDBACK
[TACCESS’15, GI’16]
HAPTIC VS AUDIO LINE GUIDANCE

The recent rise of finger-based reading has introduced a new paradigm in tactile and visually impaired education. Compared to traditional devices such as mobile phones, TVs, and regular paper, finger-based reading provides a more efficient and ergonomic way to read. However, the lack of pitch control in the spatial layout of a document, and provide better control over the reader's navigation, also introduces the need to guide the reader in physically navigating through the text. While previous work has proposed audio and haptic guidance, both reading have not provided an in-depth perspective on the finger-based reading process. To further investigate the effectiveness of finger-based sensory guidance, we conducted a comprehensive study using haptic and audio feedback.
**HAPTIC VS AUDIO LINE GUIDANCE**

TACCESS’16

**VIBRO-MOTORS**

Absolute error from line center

0.28 cm

**PITCH-CONTROLLED AUDIO**

Absolute error from line center

0.21 cm

$Z_{19} = -2.374$, $p = .018$, $r = .54$
WRIST HAPTICS

4 Motor Wristband

Wiring Vibro-motors

8 Motor Wristband

CROSS SECTION OF WRIST
(8 MOTOR DESIGN)

Up Left
Left
Up

Up Right
Right

Down Left
Down

Down Right

TESTED 32 MOVEMENT DIRECTIONS
(11.25° INTERVALS)
Directional movement error

8-motor wristband resulted in 9% lower movement error

\( t_{17} = -1.95, p = .034, d = 0.46 \)
WRIST HAPTICS FOLLOW-UP STUDY

TARGET FINDING

PATH TRACING

Red & green show user's finger trace
ICPR’16, two papers in submission

ON-BODY INTERACTION FOR VISUALLY IMPAIRED
# Handsight
## The Team

### Professors & Research Associates
- Jon Froehlich
- Rama Chellappa
- Leah Findlater
- David Ross

### Grad Students
- Lee Stearns
- Uran Oh
- Jonggi Hong

### Undergraduate Students
- Ruofei Du
- Anis Abboud
- Meena Sengottuvelu
- Alex Medeiros
- Harry Vancao
- Virginia Melandri
- Eric Lancaster

### High School Students
- Tony Cheng
- Victor Chen
- Catherine Jou
- Mandy Wang
- Ji Hyuk Bae
- Jessica Yin
- Chuan Chen
THREAD 1: ACCESSIBILITY

IMPROVING ACCESS TO THE PHYSICAL WORLD

PROJECT SIDEWALK
[ASSETS’12, CHI’13, HCOMP’13, ASSETS’13 Best Paper, UIST’14, TACCESS’15, SIGACCESS’15, CHI’16]

HANDSIGHT
[ACVR’14, ASSETS’15, GI’16, TACCESS’16]

GLASSEAR
[CHI’15]
How can we... we sense & visualize sound information on an HMD to improve sound awareness for people who are deaf or hard of hearing?
HMD CONVEYS SOUND DIRECTION & MAGNITUDE
NON-WEARABLE MICROPHONE ARRAY

HMD DISPLAY
GLASSEAR

Collaborators: Leah Findlater, Ramani Duraiswami, Dmitry Zotkin, Christian Vogler, & Raja Kushalnager

CURRENT & FUTURE WORK

MAJOR OBJECTIVES:

- True wearable design
- Precise localization & sound separation algorithms
- Oral conversation support
- Visualization design

Microphone Array
8-16 equispaced microphones will be embedded in the HMD

Transparent Display
Sounds are visualized on a display that is positioned over the retina
GLASSEAR

THE TEAM

PROFESSORS & RESEARCH ASSOCIATES

Jon Froehlich  Leah Findlater  Ramani Duraiswami  Dmitry Zotkin  Christian Vogler  Raja Kushalnagar

GRAD STUDENT

Dhruv Jain

HIGH SCHOOL STUDENTS

Jamie Gilkeson  Benjamin Holland
MAKEABILITY LAB
FOUR FOCUS AREAS

ENVIRONMENTAL SUSTAINABILITY
HEALTH & WELLNESS
ACCESSIBILITY
STEM EDUCATION
MAKEABILITY LAB
FOUR FOCUS AREAS

ENVIRONMENTAL SUSTAINABILITY

HEALTH & WELLNESS

ACCESSIBILITY

STEM EDUCATION
How can we...
design wearables that engage and scaffold children in life-relevant, personally meaningful STEM learning experiences.
Unprecedented amount of data
Inherently personalized & life-relevant
Can go where the child goes
Engages the body in learning (i.e., “embodied learning”)

Pecher, 2005; Lindgren, 2013; Lee, 2014)
THREAD 2: STEM EDUCATION

ENABLING NEW STEM LEARNING EXPERIENCES WITH WEARABLES

BODYVIS
[IDC’13, CHI’15 Honorable Mention, ICLS’16, IDC’16, CHI’17]

MAKERWEAR
[IDC’15, CHI’16 Best Poster, CHI’17 Best Paper]
Complex Problems
How can we...

design wearables that use the human body and physical activity as a platform for experimentation & scientific inquiry?

BODYVIS
[IDC’13, CHI’15 Honorable Mention, ICLS’16, IDC’16, CHI’17]
“Does my heart beat faster when running vs. reading a book? Why?”

“How does my breathing rate compare to my classmate’s and why may this be?”

“How does food travel through my body?”
ADVANCING SCIENCE LEARNING & INQUIRY EXPERIENCES THROUGH WEARABLES

BODYVIS TEAM

PROFESSORS

Jon Froehlich
Tamara Clegg
Leyla Norooz
Seokbin Kang
Virginia Byrne
Rafael Velez
Amy Green

GRAD STUDENTS

UNDERGRADUATE STUDENTS

Monica Katzen
Angelisa Plane
Vanessa Oguamanam
Thomas Outing
Anita Jorgensen

HIGH SCHOOL STUDENT

Sage Chen
BODYVIS PROTOTYPES

**PROTOTYPE 1: MID-FI**
- Stuffed fabric organs
- Heart rate only
- LEDS, EL-Wire
- Arduino Uno

**PROTOTYPE 2**
- Improved Anatomy
- Heart rate, Breathing
- LEDS
- Lilypad Arduino

**PROTOTYPE 3**
- Labeled, Removable Anatomy
- Heart rate, Breathing, Digestion
- LEDS, Sound, Touchscreen
- Arduino Uno, Smartphone

**PROTOTYPE 4: HI-FI**
- Added Organs (e.g., Bladder)
- Heart rate, Breathing, Digestion
- LEDS, Sound, Haptics, Touchscreen
- Arduino BLE Mini, Smartphone
BODYVIS PROTOTYPES

PROTOTYPE 1
Stuffed fabric organs
Heart Rate Only
LEDs, EL-Wire
Arduino Uno

PROTOTYPE 2
Improved Anatomy
Heart Rate, Breathing
LEDs
Lilypad Arduino

PROTOTYPE 3
Labeled, Removable Anatomy
Heart Rate, Breathing, Digestion
LEDs, Sound, Touchscreen
Arduino Uno, Smartphone

PROTOTYPE 4
Added Organs (e.g., Bladder)
Heart Rate, Breathing, Digestion
LEDs, Sound, Haptics, Touchscreen
Arduino BLE Mini, Smartphone
BODYVIS PROTOTYPES

BODYVIS: FOUR GENERATIONS

**PROTOTYPE 1**
Stuffed fabric organs
Heart rate only
LEDs, EL-Wire
Arduin0 Uno

**PROTOTYPE 2**
Improved Anatomy
Heart rate, Breathing
LEDs
Lilypad Arduino

**PROTOTYPE 3**
Labeled, Removable Anatomy
Heart rate, Breathing, Digestion
LEDs, Sound, Touchscreen
Arduino Uno, Smartphone

**PROTOTYPE 4**
Added Organs (e.g., Bladder)
Heart rate, Breathing, Digestion
LEDs, Sound, Haptics, Touchscreen
Arduino BLE Mini, Smartphone
The heart and lungs visualize wearers' live heart and breathing rate.
HOW IT WORKS

**MAGNETS**

**LEDs**

**Zephyr BioHarness 3 Physiological Sensor**

**LUNGS**

**Flexible LED Strips**

**STOMACH**

**Samsung Galaxy S4 Mini**
BODYVIS
SENSING SYSTEM

ZEPHYR BIOHARNESS 3
Worn directly on skin
Senses heart, breathing, movement

SAMSUNG GALAXY S4 MINI
Serves as stomach
Processes physiological data
Plays sound & vibrates

REDBEARLAB BLE MINI ARDUINO
Sewn into shirt
Directly wired to LEDs, Vibro-motors, digestion button, etc.
BODYVIS

EVALUATIONS (N=200)

TEACHER INTERVIEWS  AFTER-SCHOOL PROGRAMS  SCIENCE CAMPS  ELEMENTARY SCHOOLS
Overall reactions
BodyVis interactions & experiments
Learning potential
Unexpected things
OVERALL REACTIONS

High Engagement
OVERALL REACTIONS

High Engagement
BODYVIS INTERACTIONS
Actively Engaging Body

- Running
- Eating
- Jumping Jacks
- Dancing
- Resting
Body map drawing method: Cuthbert, 2000; Garcia-Barros *et al.*, 2011
LEARNING POTENTIAL

Body Map Drawing: Before & After

- 73% Included at least one new organ
- 56% Corrected positions of organs
- 30% Improved organ shapes
I now want to touch on two unexpected findings
UNEXPECTED FINDING 1

Disembodied Use

Her physiology visualized on shirt

She's wearing sensor
MIXED-REALITY SYSTEM
IDC’16, CHI’17

LARGE, COLLABORATIVE DISPLAY

WIRELESS PHYSIOLOGICAL SENSORS

KINECT DEPTH CAMERA
How Does It Work?

UNEXPECTED FINDING 2
THREAD 2: STEM EDUCATION

ENABLING NEW STEM LEARNING EXPERIENCES WITH WEARABLES

BODYVIS
[IDC’13, CHI’15 Honorable Mention, ICLS’16, IDC’16, CHI’17]

MAKERWEAR
[IDC’15, CHI’16 Best Poster, CHI’17 Best Paper]
How can we... enable young children to build their own interactive wearables?
ENGAGING YOUNG CHILDREN IN WEARABLE DESIGN

MAKERWEAR TEAM

PROFESSORS
- Jon Froehlich
- Tamara Clegg
- Majeed Kazemitabaar
- Liang He

GRAD STUDENTS

UNDERGRADUATE STUDENTS
- Jason McPeak
- Katie Wang
- Alex Jiao
- Thomas Outing
- Tony Cheng

HIGH SCHOOL STUDENT
- Chloe Aloimonos
MAKERWEAR INTRODUCTION

CURRENT WEARABLE TOOLKITS

EMBEDDED PROGRAMMING

BASIC CIRCUIT & ELECTRONICS KNOWLEDGE

MANUAL SKILLS LIKE SEWING / SOLDERING
MAKERWEAR INTRODUCTION

OVERARCHING RESEARCH QUESTIONS

How can we enable young children (elementary age) to design & build their own interactive wearables?

What do children want to build and how can we support these goals?

How does working with our tools & techniques impact skill development & perceptions of STEM?
**MAKERWEAR**

**DESIGN & EVALUATION PROCESS**

Initial Ideation → Participatory Design → Ideation / Prototyping → Design Probes → Refinement → Pilot Studies → Refinement → Single Session Workshops → Multi-Session Workshops
PARTICIPATORY DESIGN

Cooperative Inquiry

Guha, Druin, & Fails, 2013

Cooperative Inquiry: Guha, Druin, & Fails, 2013
PARTICIPATORY DESIGN

Initial Sessions
PARTICIPATORY DESIGN

Follow-up Sessions
DESIGN PROBE

STEM Educators
React to body movement & physiology (e.g., heartrate)

Recognize gestures & physical actions (e.g., recognize a jump)

Support social interaction (e.g., vibrate when friend nearby)

Augment play experiences (e.g., freeze tag)

Respond to environment (e.g., increase visibility at night)
React to body movement & physiology
Recognize gestures & physical actions
Support social interaction
Augment play experiences
Respond to environment

These are the **key things** that any wearable toolkit for children should support.
THE MAKERWEAR SYSTEM

https://github.com/MakerWear
1. Makerwear System

Tangible Modules
MAGNETIC SOCKET MESH

2

Socket Mesh

Socket Mesh
Provides **power** to all connected modules

**SENSORS**
Sense & translate physical phenomena into analog signals

**MODIFIERS**
Transform signals into other types of signals

**ACTIONS**
Translate signals into perceptual forms

**MISC**
Miscellaneous (e.g., DIY module)
# Module Library: 33 Modules

## 12 Sensors
- Motion Detector
- Distance
- Sunlight Detector
- Tilt Sensor
- Light Sensor
- Receiver
- Impact Sensor
- Color Detector
- Heartbeat
- Button
- Temperature
- Sound Sensor

## 9 Actions
- Light Bar
- Yellow Light
- Rotator
- Green Light
- MultiColor Light
- Spinner
- Blue Light
- Number
- Vibration
- Red Light
- Sender
- Sound Maker

## 7 Modifiers
- Volume Knob
- Sine Wave
- Threshold
- Counter
- Fade
- Inverter
- Square Wave

## 4 Misc
- Wire Start
- Wire End
- DIY Electronic
- Bridge

## 1 Power
- Power
MAKERWEAR SYSTEM

MODULE EXPLODED VIEW

**Temperature Sensor**

**Layer 1**
Exposed electronic component

**Layer 2**
Laser cut module cover

**Layer 3**
Custom PCB with embedded microcontroller & SMD components

**Layer 4**
Custom PCB with neodymium magnet & contact spring for socket connection
MAKERWEAR SYSTEM

SOCKET MESH

“PLUG-AND-PLAY”

6 I/O PINS

Vcc

GND
MAKERWEAR SYSTEM

TWO TYPES OF SOCKET MESHES
The number of sockets per mesh ranges from 14-23

1. SEWN INTO CLOTHES
2. FABRIC PATCH
Motion-reactive clothes!
MAKERWEAR EXAMPLES

“MOTION-REACTIVE CLOTHES”

Now with fade effect
“MOTION-REACTIVE CLOTHES”
MAKERWEAR EXAMPLES

“MOTION-REACTIVE CLOTHES”
“MOTION-REACTIVE CLOTHES”
We can create a diverse set of designs tangibly
MAKERWEAR EXAMPLES

“AUTO-HEADLAMP HAT”
“CHAMELEON CLOTHES”
MAKERWEAR EXAMPLES

“LASER TAG ARMBAND”

When button pressed, shoots “laser” (IR beam) and turns on blue LED

When “hit” by IR beam, turns red
**MAKERWEAR EXAMPLES**

**“LASER TAG ARMBAND”**

- Tracks hit count
- When button pressed, shoots “laser” (IR beam) and turns on blue LED
- Sets max hit count level
- When “hit” by IR beam, turns red
- Flashes lights & plays sound when max hit count level reached
MAKERWEAR EVALUATION
32 children (16 female; ages 5-12; avg=8.3)

Two single-session workshops (N=13)

Three four-session workshops (N=19)
### Makerwear Evaluation

**Workshop Sessions & Demographics**

<table>
<thead>
<tr>
<th></th>
<th>Ages (Avg)</th>
<th>N (female)</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
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<tr>
<td><strong>SINGLE SESSION</strong></td>
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<td>1</td>
<td>5-7 (6.0)</td>
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<td>2</td>
<td>8-12 (9.9)</td>
<td>8 (3)</td>
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<tr>
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<td>7 (3)</td>
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<tr>
<td>2</td>
<td>8-9 (8.8)</td>
<td>6 (1)</td>
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<tr>
<td>3</td>
<td>8-12 (10.2)</td>
<td>6 (4)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5-12 (8.3)</td>
<td>32 (16)</td>
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<tr>
<td>Group</td>
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<td><strong>32 (16)</strong></td>
</tr>
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</table>
MAKERWEAR EVALUATION

SINGLE-SESSIONS WORKSHOP PROCEDURE

Pre-study questionnaire

Building/playing with MakerWear

Design Challenge

Design Challenge

Post-study questionnaire

10 MINS  5  10 MINS  15 MINS  10 MINS

MakerWear introduction

Design Challenge
DAY 1
- Pre-study questionnaire (10 MINS)
- Intro (10 MINS)
- Introduce basic modules (50 MINS)
- Design Challenge (15 MINS)
- End-of-day questionnaire (10 MINS)

DAY 2
- “Fix-It” Design Challenge (10 MINS)
- Introduce more advanced modules & concepts (e.g., inverters, branching) (60 MINS)
- Design Challenge (15 MINS)
- End-of-day questionnaire (10 MINS)

DAY 3
- Brainstorm & sketch project ideas (15 MINS)
- Introduce lo-fi materials, communication modules, & advanced modifiers (60 MINS)
- Design Challenge (15 MINS)
- End-of-day questionnaire (10 MINS)

DAY 4
- “Fix-It” Design Challenge (10 MINS)
- Work on final projects (50 MINS)
- Final project presentations (25 MINS)
- Post-study questionnaire (10 MINS)
Session video
Design challenge performance (Radar et al., 1997)
End-user creations (Duncan et al., 2014; Hansen et al., 2015)
Artifact-based interviews (Brennan & Resnick, 2012)
Pre & post-study questionnaires
MAKERWEAR FINDINGS
MAKEREWEAR FINDINGS
OVERALL

Highly engaged in making
Wide variety of designs
Applied computational thinking
MakerWear understanding & CT

What did children make?
Some unexpected things
MAKERWEAR FINDINGS

INPUT/OUTPUT & SEQUENCING

EXAMPLE FIX-IT DESIGN CHALLENGES

Fix this so the light responds to the sensor

Power  Light Sensor  MultiColor Light

Fix this so the lightbar responds to the sensor

Power  Light Bar  Distance

Fix this so all light levels are controlled by the volume knob

Power  Yellow Light  Yellow Light  Volume Knob  Yellow Light

EXAMPLE SOLUTIONS

Power  Light Sensor  MultiColor Light

Power  Distance  Light Bar

Power  Volume Knob  Yellow Light  Yellow Light  Yellow Light
MAKERWEAR FINDINGS

INPUT/OUTPUT & SEQUENCING

Youngest=6.3; Middle=8.8; Oldest=10.2 years old

EXAMPLE FIX-IT DESIGN CHALLENGES

Youngest 81%
Middle 100%
Oldest 100%

Power  Light Sensor  MultiColor Light
Power  Light Bar  Distance
Power  Yellow Light  Yellow Light  Volume Knob  Yellow Light
Do these two designs behave differently?

Youngest: 6.3; Middle: 8.8; Oldest: 10.2 years old
### MAKERWEAR FINDINGS

#### PROGRESSIONS

Youngest = 6.3; Middle = 8.8; Oldest = 10.2 years old

<table>
<thead>
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<th>First Day</th>
<th>Last Day</th>
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<tbody>
<tr>
<td><strong>47%</strong></td>
<td><strong>77%</strong></td>
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<td>Sequencing</td>
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</table>

<table>
<thead>
<tr>
<th>First Day</th>
<th>Last Day</th>
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</thead>
<tbody>
<tr>
<td><strong>20%</strong></td>
<td><strong>78%</strong></td>
</tr>
<tr>
<td>Conditional Logic</td>
<td>Conditional Logic</td>
</tr>
</tbody>
</table>

Middle & Oldest Groups Only
MAKERWEAR FINDINGS

FINAL PROJECTS

Omar, Age 6
Justin, Age 8
Tyrese, Age 5
LeShawn, Age 6
Sarah, Age 9

Keisha, Age 6
Austin, Age 9
Amelia, Age 10
Tina, Age 8
Kayla, Age 6
AGE-RELATED DIFFERENCES IN FINAL PROJECTS
Youngest=6.3; Middle=8.8; Oldest=10.2 years old

Error bars are standard error
MAKERWEAR FINAL PROJECTS

WHAT DID CHILDREN MAKE?

SPORTS/FITNESS: 38%
ROLE PLAY: 31%
SOCIO-DRAMATIC PLAY: 19%
OTHER: 13%
MAKERWEAR FINAL PROJECTS
WHAT SENSORS DID THEY USE?

- Temperature
- Movement
  - Motion Detector
  - Impact Sensor
- Manual Input
  - Volume Knob
  - Button
  - Light Sensor
  - Sound Sensor
- Environment
  - Sunlight Detector
  - Color Detector
- Physiology
  - Heartbeat
- Social
  - Wire Start
  - Wire End
  - Receiver
  - Sender

MOVEMENT 33%
MANUAL INPUT 24%
ENVIRONMENT 19%
PHYSIOLOGY 14%
SOCIAL 10%
I want to highlight a few projects that demonstrate the breadth of designs, the span of technical sophistication, & illustrate the aforementioned themes.
MAKERWEAR FINAL PROJECTS

WHAT DID CHILDREN MAKE?

SPORTS/FITNESS  38%
ROLE PLAY  31%
SOCIO-DRAMATIC PLAY  19%
OTHER  13%
SUPER NINJA

Maker: Daniel, Age 7
9 modules: 5 actions, 2 misc, 1 sensor
2 socket meshes
2 lo-fi pieces

“UPPER CUT” ARMBAND

“NINJA” BELT

Light Bar
Blue Light
MultiColor Light
Impact Sensor
Power
Wire Start
Spinner
Red Light
Wire End
MAKERWEAR FINAL PROJECTS

WHAT DID CHILDREN MAKE?

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sports/Fitness</td>
<td>38%</td>
</tr>
<tr>
<td>Role Play</td>
<td>31%</td>
</tr>
<tr>
<td>Socio-Dramatic Play</td>
<td>19%</td>
</tr>
<tr>
<td>Other</td>
<td>13%</td>
</tr>
</tbody>
</table>
MAKERWEAR FINAL PROJECT
"MAGIC POKÉMON"

Austin, Age 9
MAGIC YVELTAL POKÉMON
Maker: Austin, Age 9
14 modules: 9 actions, 2 sensors, 1 modifier
2 socket meshes
3 lo-fi pieces + pokemon

VEST

POKÉMON DOLL

MultiColor Light
WHAT DID CHILDREN MAKE?

- **Sports/Fitness**: 38%
- **Role Play**: 31%
- **Socio-Dramatic Play**: 19%
- **Other**: 13%
MAKERWEAR FINAL PROJECT

“SMART LACROSSE STICK”

Sarah, Age 9
SMART LACROSSE STICK
Maker: Sarah, Age 9
8 modules: 6 actions, 1 sensor
1 socket mesh
3 lo-fi pieces + lacrosse stick
MAKERWEAR FINAL PROJECT

“NEXT GEN RUNNING CLOTHES”

Amelia, Age 10
NEXT GENERATION RUNNING CLOTHES

Maker: Amelia, Age 10
40 modules: 25 actions, 3 sensors, 5 modifiers
4 socket meshes; 2 lo-fi pieces

MOTION-REACTIVE LIGHT-UP SAFETY HAT & VEST

“AIR CONDITIONING” ARMBAND
“HEART TRACKER” ARMBAND

Wired Connection
NEXT GENERATION RUNNING CLOTHES
Maker: Amelia, Age 10
40 modules: 25 actions, 3 sensors, 5 modifiers
4 socket meshes; 2 lo-fi pieces

Activate hat & vest only when it’s dark AND the wearer is moving

MOTION-REACTIVE HAT

MOTION-REACTIVE VEST
NEXT GENERATION RUNNING CLOTHES

Maker: Amelia, Age 10
40 modules: 25 actions, 3 sensors, 5 modifiers
4 socket meshes; 2 lo-fi pieces

“HEART TRACKER” ARMBAND

Beeps & lights up on each heartbeat

Counts heartbeats up to 99
Finally, some unexpected things
CUSTOM OSCILLATOR
8 year old maker
CUSTOM OSCILLATOR

8 year old maker
“[he] hasn’t been captivated like that for any other activity in the museum”
MAKERWEAR FUTURE WORK
More flexible
Reduced weight
Thinner
Sample Application:
Making a fitness tracker using a Motion Detector and a HeartBeat Detector.
Children can program complex behavior via a novel machine learning interface.
FOUR FOCUS AREAS

E N V I R O N M E N T A L  S U S T A I N A B I L I T Y
H E A L T H  &  W E L L N E S S
A C C E S S I B I L I T Y
S T E M  E D U C A T I O N
ACKNOWLEDGEMENTS

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Google  IBM  NSF  Department of Defense CDMRP

MAPPING ACCESSIBILITY OF THE WORLD
NSF #1302338, Google, IBM
PI Froehlich, Co-PI David Jacobs

HMD SOUND AWARENESS
Google Faculty Research Award
PI Leah Findlater, Co-PI Froehlich

BODYVIS & SHAREDPHYS
NSF #1441184
PI Froehlich, Co-PI Tamara Clegg

MAKERWEAR
NSF CAREER #1652339
PI Froehlich

HANDSIGHT TOUCH VISION
Department of Defense CDMRP
PI Froehlich, Co-PIs Leah Findlater & Rama Chellappa
MAKING WITH A SOCIAL PURPOSE
Jon Froehlich | Assistant Professor | Computer Science