

Behavioral modeling + optimization + machine learning

## A New Type of Intelligence for Intelligent User Interfaces

An An alternative to the Fin "deep learning temptation"

userinterfaces.aalto.fi

### A new type of intelligence for IUI

### Interaction

### Computation

Solve design problems algorithmically using as objective functions...

...computational HCI models...

...learned from data...

Improve usability and experience of computers via...

... that predict consequences of actions on users

Behavioral sciences

## CS and EE at Aalto University

## I'm a computational cognitive scientist working on HCI



**I model** human-technology interaction

... and develop **new computational principles** of design and adaptation

…in order to improve computing for humans







### userinterfaces.aalto.fi

## Interactive systems Design Optimization Machine learning Modeling

**Behavioral sciences** 

## **Opportunities for intelligent Uls**





- Mar 1

ces

Hard to get right: UID among top 3 reasons for success/fail of ICT projects [Miettinen 2013]

Interface design affects productivity, enjoyability, satisfaction, customer loyalty, inclusion, health,

Discrete input devices

Panel-and-pushbuttons interfaces



Touch interfaces

declars Setup		
Choose	Interface	Options
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His PC OPT dash (INFIC: eNAL) (PT Langle line (or		
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Dialogue interfaces

### Most UIs are dumb (non-adaptive)

"One size fits all" design. Costly updates

> Most adaptations concern recommendations, search lists, and ads

Design creates barriers

Increasing reliance on e-services widens the digital gap [OECD 2018]

### Novel UIs is a major area of tech investment

Abysmal success rate

> We're bad at transferring knowledge

## Design practice not an engineering discipline

Decisions done outside of software and coded to programs manually

## Historical backdrop

## Methods for intelligent UIs studied since 1970s

Logic Information Control **Optimization** Agents **Cognitive models** Learning **Probability Neural networks** 



**Computational Interaction** (edited)

Oxford University Press 2018



## **A paradox!** If algorithmic methods are superior, where are they?

### Four waves of AI that have hit HCI

Wave 0: Cybernetics Wave 1: Rules and logic Wave 2: Cognitive modeling Wave 3: Pre-DL supervised learning Wave 4: Deep learning

> Let's go through them to learn why they have <u>not</u> revolutionarized the field

Oulasvirta, Antti ICWE 2019 A complex system representation that must be refined for <u>every</u> design iteration (manually)

### **Operations research started and stopped with keyboards**



Burkard et al. 1977; Light & Anderson 1993; Zhai et al. 2000

## Psychology as the science of design





**Herbert Simon** 

**Stuart Card** 



### Predictive cognitive models (1980s)



## Card et Models do not design anything, they simply evaluate

Oulasvirta, Antti ICWE 2019

## **Generative cognitive models**

#### Threaded Cognition (ACT-R, a driving simulator)

BRING AVE	Tasks Drivers Scenario Results		
Interfaces	interface		
		Search Find next item Encode item Press down button If item = target, Press target item Continue search Interrupt search	Driving Attend lane center Attend lead car Encode lead car Encode lead car If car is stable. Resume search: If first iteration after interruption, Increment time limit
	Parts of t (task scri	he cognitive r pt) must be re	model edefined

every time design changes

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## Tools for using cognitive models in evaluation

#### CogTool



Work of Bonnie John / IBM and CMU

## **Big data and machine learning**

#### "Correlationalism and the data deluge"



"Theory is dead. Data is the new king!"



Oulasvirta, Antti ICWE 2019

#### Generative art by deep learning



#### Expero



Oulasvirta, Antti **ICWE 2019** 

#### Autodesk

#### MODEL 1

Solid bars Traditional design Weight: 10.3 kilograms . . Displacement: 0.8 micrometers .

### Combination of DL and <u>physics</u> <u>models</u> has been a success in computational design. But is insufficient for HCI

Displacement: Displacement: ..... 4.2 micrometers ...... 6.1 micrometers





## Wix promises Al website design, but fails to deliver true artificial intelligence

Wix's new automated design functionality is helpful, but it doesn't match the definition of artificial intelligence

#### 000000

A silver peak

SD-WAN IDG eGuide: SD-WAN Has Arrived



## Lots of hot air and broken promises...



**3 Design is ill-specified** 4 Hard to and combines creative change designs and problem-solving activities User interface design is hard 2 Humans are hard to predict **1 Very large** search spaces

## **Design is "speculation"**

A useful theory contains <u>counterfactual</u> information about what will happen <u>if</u> a design decision is taken:

### If design was <this>

#### then

#### interaction *would* be <this>



## Design involves very large search spaces



**Aalto Universitv** 

## Example: Menu with 50 items can be organized in 10<sup>80</sup> ways

## **Physics** Behavioral and cognitive sciences

## **Design is ill-specified**

2. Define

1. Discover

"Concept"

Designers learn and solve at the same time when designing

3. Develop

"Artefact"

UK Design Council

4. Deliver

## Designs are "best achievable compromises"

#### Single-objective results

**Multi-objective result** 





## Deep learning has had limited success in UI generation & adaptation

## Deep learning has many limits

#### Deep Learning: A Critical Appraisal

Gary Marcust New York University 10 problems for deep learning

1 Deep learning thus far is data hungry

- Deep learning thus far is shallow and has limited capacity for transfer
- Deep learning thus far has no natural way to deal with hierarchical structure

arXiv, Jan-

Abstract

# Issues for HCI: poor transfer poor transparency difficult to engineer with

trusted 10. Deep learning thus far is difficult to engineer with

#### **Gary Marcus**

dete



## **1 Approach 2** Applications This talk: 3 Summary

### Lots of examples coming up
# Approach

## Vision: A new type of MI for IUI

- (1) Able to anticipate the consequences of its actions
- (2) Represents its rationale in human-relatable terms
- (3) Chooses designs counterfactually
- (4) Learns and updates itself in the light of user data
- (5) Operates conservatively, admitting the inherent fallibility of its input data and model

## The design problem

Find the design (*d*) out of candidate set (*D*) that maximizes goodness (*g*) in given conditions ( $\theta$ ):







"Choose the design that maximizes expected goodness to users, given observations"

 $\max_{d \in D} E(g(d)|o)$ 

"Choose the design that maximizes expected goodness predicted by a model inferred from observations"

$$= \max_{d \in D} \int g(M(\theta, d)) p(\theta|o) d\theta$$

# Inspired by simulation models in science and engineerings



# Why we need <u>causal</u> models

- **1. Very hard inference problems**
- Many possible explanations to human behavior
- 2. The is-ought problem
- Data alone does not prescribe a desirable future
- 3. High costs of design error
- Very few chances to "try one's luck" in interaction

#### 4. Deferral of reward

FCAT

The value of an action to humans is rarely directly observable

We cannot solve these with a correlationalist approach

# "Machines that think like humans"

In press at Behavioral and Brain Sciences. Building Machines That Learn and Think Like People Brenden M. Lake,<sup>1</sup> Tomer D. Ullman,<sup>2,4</sup> Joshua B. Tenenbaum,<sup>2,4</sup> and Samuel J. Gershman<sup>3,4</sup> <sup>1</sup>Center for Data Science, New York University <sup>2</sup>Department of Brain and Cognitive Sciences, MIT <sup>3</sup>Department of Psychology and Center for Brain Science, Harvard University <sup>4</sup>Center for Brains Minds and Machines Abstract Recent progress in artificial intelligence (AI) has renewed interest in building systems that learn and think like people. Many advances have come from using deep neural networks trained end-to-end in tasks such as object recognition, video games, and board games, achieving perforend-to-end in tasks studi as object recognition, valeo games, and usard games, armeting period-mance that equals or even beats humans in some respects. Despite their biological inspiration and performance achievements, these systems differ from human intelligence in crucial ways. We review progress in cognitive science suggesting that truly human-like learning and thinking machines will have to reach beyond current engineering trends in both what they learn, and how they learn it. Specifically, we argue that these machines should (a) build causal models of the world that support explanation and understanding, rather than merely solving pattern recognition problems; (b) ground learning in intuitive theories of physics and psychology, to support and enrich the knowledge that is learned; and (c) harness compositionality and learning-to-learn to rapidly acquire and generalize knowledge to new tasks and situations. We suggest concrete challenges and promising routes towards these goals that can combine the strengths of recent neural network advances with more structured cognitive models. 1 Introduction Artificial intelligence (AI) has been a story of booms and busts, yet by any traditional measure of

Artificial intelligence (AI) has been a story of booms and bursts, yet op any transition measures success, the last few years have been marked by exceptional progress. Much of this progress has come from recent advances in "theop learning", characterized by learning large neural-activit-activimodels with multiple layers of representation. These models have achieved remarkable gains in market and the start of the start Hinton, 2015; Schmidhuber, 2015]. In object recognition, Richersky, Sutskever, and Hinton (2012) trained a deep canodizional neural network (converts, LeCum et al., 1989) that nearly halved the error rate of the previous state-of-the-act on the most challenging bercharmack to late the years since, converts commune to dominate, recently approaching human-level performance on some object recognition bendmarket (He, Zhang, Ren, & Sun, 2015, Russakovsky et al., 2014). Soggedy et al., 2014). In antoincic speech recognition, Richer 1990, yet this framework been the leading approach since the late 1986 (Juang & Rabiner, 1990), yet his framework been the leading approach since the late 1986 (Juang & Rabiner, 1990). (a) build causal models of the world that support explanation and understanding, rather than merely solving pattern recognition problems;

(b) ground learning in intuitive theories of physics and psychology, to support and enrich the knowledge that is learned;

(c) harness compositionality and learning-to-learn to rapidly acquire and generalize knowledge to new tasks and situations.

Lake et al. 2016

#### FCAI

arXiv:1604.00289v3 [cs.AI] 2 Nov 2016



## "Grey boxing"

We combine models of human behavior with optimization and probabilistic inference



Hard to construct

Low generality

### "The stool"



# Model-driven human-computer interaction



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## Achievements 2010-2019: Overview

Solve design problems using optimization

- Many HCI problems defined by now
- Significant improvements in usability in hard problems
- Support designers' creativity and problem-solving
- Provide guarantees for result quality

Assist in the interpretation of complex behavioral data Drive adaptive interfaces

• Improvements to an individual 5-25% in usability



## Lots of advances last 10 years

A bit more detail...

# Mathematical definition of design tasks

# Model-driven human-computer interaction



## Defining design problems Example: IP definition of label selection

subject to

$$\min \left( \sum_{\ell \in L} t_{\ell} y_{\ell}, \sum_{u \in U} \sum_{\ell \in L_{u}} m_{u\ell} x_{u\ell}, \sum_{k,\ell \in L} d_{k\ell} y_{k} y_{\ell} \right)$$

$$\text{et to} \quad \sum_{\ell \in L_{u}} x_{u\ell} = 1 \qquad \qquad \forall u \in U$$

$$y_{\ell} \ge \sum_{u \in U_{\ell}} x_{u\ell} \qquad \qquad \forall \ell \in L \qquad (20)$$

$$y_{\ell} \le 1 \qquad \qquad \qquad \qquad \forall u \in U, \ell \in L$$

$$y_{\ell} \ge 0 \qquad \qquad \forall \ell \in L \qquad \qquad \forall \ell \in L$$

Definition of a problem allows (1) analysis of problem complexity and (2) choice of best solver



# Defining textbook-level GUI design problems as optimization problems



Widget selection **Dialogue and form design** Command sets **Navigation structures** Windowing Notification scheduling Task allocation Assortment design



## **Advances in 2014-2019**

# Formulation of an existing scope of UI design problems as *known* combinatorial problems





[Oulasvirta et al. submitted]

A bit more detail...

# Predictive models of human behavior

# Model-driven human-computer interaction



## Many modeling families

#### **Behavioral heuristics**

if-then rules

# Mathematical models $y = f(\mathbf{x}, \boldsymbol{\beta}) + \epsilon$

#### **Generative models**

E.g., symbolic, neural, or biomechanical

→ A multi-objective function for design  $g(\boldsymbol{x}) = \omega_1 g_1(\boldsymbol{x}) + \dots + \omega_q g_q(\boldsymbol{x})$ 

**57**.6.2019

## **Example: Model of menu selection**

$$T(\theta) = \frac{1}{R} \sum_{i=0}^{i=l} G_s(i,\theta) + G_d(i,\theta) + G_p(i,\theta)$$

$$G_s(i,\theta) = \begin{cases} a_s \times \exp(-b_s \times p_i) + c_s & \text{if } i \le t \\ 0 & \text{otherwise} \end{cases}$$

$$G_d(i,\theta) = \psi_{t,\sigma_d^2}(i) \times (a_d \times \exp(-b_d \times p_i) + c_d)$$

$$G_p(i,\theta) = a_p + b_p \times \log(1 + \alpha \times t) \times \psi_{t,1,1}(i)$$

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Bailly, Oulasvirta, Brumby, Howes CHI 2014

## interfacemetrics.aalto.fi

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CHOOSE HETRICS		
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# Machine learning is revolutionarizing cognitive modeling

## **How should I search for "politics"?**



# ML can predict users' behavioral strategies (how people adapt)



Payne & Howes 2013; Chen et al. 2015



Automated assessment of task completion time on point-and-click UIs with reinforcement learning & KLM





Leino et al. Proc. IUI'19



Robotic simulation of human buttonpressing

)ulasvirta CHI'18]

## Visual sampli

#### Modeling visual searcl





# Visual sampling after layout change

# Reorganization of visual search behavior after a layout has changed



Jokinen et al. Proc. CHI 2017

## **Results: example**

# Effects of layout change on visual sampling strategy and therefore search costs



# Personal note on how revolutionary this is

Likelihood-free inference allows learning model A bit more detail... parameters from data

# Inference

# Model-driven human-computer interaction



## What are we allowed to infer from a click?





### Algorithmic Sherlock Holmes

74.6.2019

# Fitting simulator parameters to log data with Bayesian methods

#### **Approximate Bayesian Computation (ABC)**





#### **16**.6.2019 **How ABC works**



# Model Predictions Discrepancy Observation Data




















# Example: A model of menu search

Finds optimal gaze pattern given menu design and parameters of the visual and cognitive system

**Aalto University** 

[Chen et al. CHI'15]



# ABC helps us infer model parameters from data logs

#### Given click times, predict model (HVS) parameters

	Parameter	Description		ATTENDING	SPONSORING
	fdur	Fixation duration	24	Frogram	<u> </u>
Click times	$\frac{d_{sel}}{d_{sel}}$	Time cost for selecting an item (added to the duration of the last fix- ation of the episode if the user made a selection)		Reportation Telepresence Attendance Housing	H 20
	Prec	Probability of recalling the seman- tic relevances of all of the menu items during the first fixation of the episode		Keynotes Special Statement Day of Service	RE INNOVATE
	Psem	Probability of perceiving the seman- tic relevance of and below of the <b>Generate</b>	use	r-like	
	Table 1. Pa	rameters inferred wit <b>behavior</b> 1	for	new de	esigns

Kangasrääsiö et al. CHI 2107, Cognitive Science

# **ABC yields posterior estimations**

# Bayesian inference yields a posterior distribution for model parameters



*"Possible explanations for the data"* 



88.6.2019 ABC improves fit over manual tuning

#### Task Completion Time (ms)



#### 0 500 1000 1500 2000 2500 3000

Mean TCT 1.49 s

Mean TCT 0.93 s

Mean TCT 0.92s

Aalto University

Kangasrääsiö et al. CHI 2107

### **Examples of model-driven inferences**

Visual attention: The items the user is looking for are hard to find

**Motor control:** The interactions are too hard or cumbersome to execute

**Navigation**: User does not understand site structure

Aesthetics: The page is perceived ugly and confusing

**Skills:** User does not have sufficient motor or conceptual skills to use the page

Intentions and preferences:

What items and which types of services or interaction users like

**Errors and mistakes**: Users inadvertently do something they would not have liked to

**Cultural background**: Language and other cultural explanations to style of use

**Decision-making**: Users' strategies and goals in decision-making

# **Example: Getting lost**



# Applications

### **Computational design of keyboard layouts**

The new standard for the French AZERTY keyboard



Anna Feit, Mathieu Nancel et al.

## **Example: Hierarchical menus**

#### Niraj Dayama

#### Ordering commands and assigning them into tabs and groups. two objectives: selection time and associativity:

#### Tab 1 Full-Screen-Mode

Read-Mode Read-Aloud Print Properties Save-As Send-File Ópen Revert Close Exit Save Save-As-Other

#### Tab 3 Cascade Take-A-Snapihot Deselect-All Copy-file-to-clipboard

Tile Zoom Page-Nevigation New-Window Minimize-All-Windows Rotate-View Page-Display

#### Check-Spelling Find

Advanced-Search Analysis

### Table Lock up selected word 26% faster to use than commercial designs

#### Browser (Firefox)

Tab 4

Home

Back

Forwa

Reset

Page-I Reload-3

Stop

Undo

Redo

Find

Reader app (Adobe)

Tab 2

Copy

Cut

Delete

Undo

Paste

Redo

Select-All

Tab 1
New
Open-File
Open-Location
Select-All
Find-Again
Save-Page-As
Print
Page-Setup
Clear-Recent-History
User-History-Item
Start-Page
Show-All-History
Restore-Previous-Sessi

Tab 2	
Downloads	
About-Mozzila-Firefo	¢
Subscribe-To-This-Pag	ţe
Check-for-Updates	
Unsorted-Bookmarks	
Web-Search	
Bookmark-This-Page	
Bookmark-All-Pages	
Show-All-Bookmarks	
Add-Ons	
Work-Offline	

#### Tab 3 Private-Browsing New-Window Close-Window Email-Link Start-Dictation RecentlyClosed-Tab Recently-Closed-Windows Close-Tab Customize Zoom-In Minimize Zoom Zoom-Out

8	Tab S
	Copy
	Paste
	Delet
rd	Cut
nfo	

	Copy
	Paste
	Delete
	Cut
- 5	

**Aalto University** 

#### Antti, you`re right.

But ... You're not dreaming BIG enough

**Donald Norman** 

# ... at my NordiCHI keynote in 2014

#### (a) App menus



No.	349	
Reset	Chesik for Updates	1.5
BOOMMAN AN TABL	Radu	114
Show All Bookmarks	Unale	1.3
Stoe 41 matery	Delete	
Neward	Paile	15
Customian	Citer	
		16
Oswriteels .	Find.	
16oma	Salaret All	

#### (b) Menu systems

-	416	(Marcol)	All and a second	Res .	(Mark)
Chesik for Updates	Clear Tab	User Halory laws Add-Ora	Ald-Ora	Subscribe To This Page Booknack This Tage Page Into Page Into Sant Page Start Page	Reason Pennas Several
Rade	Open File New Yull New Window Open Lacation	Private Browsing	About Meaths Firefox		Arem Club
Delete Pallete Factor		Recently Dosent Talls Recently Dosent Mindows	Return Web Search		Mouniae Shap Asam
		binored Bookmarks			
Cut.	One Writiw	Email Sink			Start (Detarion
Find Select All					

#### (c) Gesture controls



(d) Widget controls



#### (e) Visualizations



#### (f) Web page (sketches)



# Example: Perceptual optimization of scatterplots

Matplotlib default design





Micallef et al. IEEE TGCV 2017

## **Optimizing skim reading**

### Spotlights: Attention-Optimized Highlights for Skim Reading

Byungjoo Lee, Olli Savisaari, Antti Oulasvirta Aalto University, Finland CHI2016





#### AdaM Adapting Multi-User Interfaces for Collaborative Environments in Real-Time

Seonwook Park, Christoph Gebhardt, Roman Rädle, Anna Feit, Hana Vrzakova, Niraj Dayama, Hui-Shyong Yeo, Clemens Klokmose, Aaron Quigley, Antti Oulasvirta, Otmar Hilliges



Tool concepts that "empower not just automate" designers

### Interactive optimization and learning systems

# Interactive support for design

### MenuOptimizer: Interactive Optimization of Menu Systems



### **Interactive example galleries**

#### [Ramesh et al. submitted]



# **Style transfer**

		ärage
Rame	User name here	
ddress	1600, Penn Avenue, WA	-
Comments	Some comments here	
	Submit	

Initial sketch

1		-
USERID	<< Une manager id i	
Problem Area	Unidentified	
Priority	High	
Time of detection	da-men-yyyp	
Problem Description	k.	

Closest Match in Library



Transferred design

# Using bandits to adapt suggestions to designer's style



[Koch et al. CHI'19]

# Ability-based adaptation

# Model-driven human-computer interaction



# Many sources of individual differences

Anatomical Physiological Perceptual Attentional Motoric Cognitive **Motivational Learning styles** Social Cultural

# Individual differences are represented as model parameters

 $L_{confirm}$ 



Table 1. Individual abilities modeled by Touch-WLM

Variable	Explanation	Domain
Eve move	ments	
$e_K$	Encoding time	Foveal encoding
$e_k$	Eccentricity factor	Parafoveal encoding
$t_{prep}$	Saccade preparation	Oculomotor command
$t_{exec}$	Saccade execution	Oculomotor command
$t_{sacc}$	Saccade velocity	Oculomotor performance
Motor per $m_k$	formance Total resource	Motor performance
$m_{lpha}$	Speed-accuracy bias	Motor performance
Strategy		
$m_a$	Finger accuracy	Motor strategy
l	Letters before proofing	Cognitive strategy
Constants		
$s_{key}$	Search time for key	Visual search

Thinking

Backspace confirmation

An or 2.50 An of 2.60 An of

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#### Sarcar et al. 2018 IEEE P C

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Sarcar et al. 2018 IEEE P C

# Web interaction

Toward self-optimizing web services...

### **Browser-based menu adaptation**

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WIKIPEDIA	Welcome to Wikipedia, the test employed that anywer set with 0.13.100 preserve import	+ Ans + Han + Biography + Mat + Geography + Biog	Cherrorite contractory     Cherrorite contractory     Cherrorite contractory     All portails
Conterna Instanti	From today's featured article	In the news	
Contractioners Names attain Security of Whighels Mana Whighels Mana Whighels Contraction Contrection Contraction Contraction C	Centered (1941) is the second musical to the team of Robard Polyper (music) and Dear Hermensen E (book and yind), after their M Distaturar (1940). It was adapted hon Ferens Mahain's 1909 play Liker, humplering the setting in the U.S. state of Manes. Canada tasker Dity Digetow's contance with relivoire Jule Jordan cost from their plot, which strengts a noticely that goes tagging wrong. It is given a theore to make thing right. The short includes the score, if i strengt to the Manes. Canada tasker Dity Digetow's contance with relivoire all the Jordan cost from their plot, where a minimediate the whole of Ald Dow's and "work ferene that Acoust". I speed on Romanow, and duprate the scores is the Mane Tarrier 1965. It has been repeatedly worked and recorded. A 1982 production by Kohnea Hyter eropyed access in Linder, in New Yen, we are two for Digetor inter were the Canada was to leave to all the materias in 1990. The magazene remet if the been received of works control was to leave to all the materias in 1990. The magazene remet if the been received that controls. (Here and the 200 control (Here and the Score) - Etherate A Access in grand. How Yen, and the team strengt of the strengt and the score of the strengt and the score of the score o	An least 2017 people are killed in an Argeman A assah in Agenta.     Im golf, Parmit Read wins the Maximum Tourin Gast Chill (solar wind the Linked States).     A haspectral strends asseption attack in Ch people.     In the Hamperian partiamentary electron, an Vision Childr wine its third assessmentary electron, of Recent deaths. Factor Mathews - Web Dimanto of Recent deaths. Factor Mathews - Web Dimanto, of	er Foroe figueten is Nit einemet erment af Auguste Nationer nume, Byris, Nito dezens af anstellen Reine, Nito dezens af ausstellen ind by Prime Ministell Ausembig bestellen Biller Agnes i John Lambe
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#### [Gobert et al. IUI'19]

# Individualizing web pages

#### [Todi et al. IUI 2018]





# "Layout as a service"

On-going work led by Dr. Markku Laine Team: Dr. Ai Nakajima, Dr. Niraj Ramesh, Kseniia Palin, Dr. Kashyap Todi, Samuel de Pascale

# Layout as a Service (concept)

Bootstrap supported atm



### Runtime architecture

**Overview** 



Layout as a Service
### Adaptation lifecycle Enables self-optimizing web pages



# **Demo 1/2** Optimizes for: Perceptual fluency, saliency, selection time

#### **User clicking:** 60% sports, 20% entertainment, 20% business



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# **Demo 2/2** Optimizes for: Perceptual fluency, saliency, selection time

### **Optimized layout**



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### A powerful way to solve HCI problems

Increasing scope of problems successfully addressed

# Summary

Plenty of work remains to go beyond proof-ofconcepts

# Levels of intelligence in design

Level 0: Design by intuition Level 1: Design by models Level 2: Design by optimization Level 3: Design by learning

## Level 4: Combine Levels 0 - 3

# Future: Combine model-based methods with deep learning

Benefit from their high representational power while retaining causal mechanisms that enable counterfactual decisions and controllability



## Two very hard challenges

### The Winograd & Flores' argument

Design depends on linguistic intelligence from the user

### The Dreyfus argument

Human-like being-in-the-world and social acculturation required for real intelligence



Visuo-spatial-motor aspects of design are within reach, but social and linguistic not yet?

Oulasvirta, Antti ICWE 2019



$$\max_{d \in D} \int g(M(\theta, d)) p(\theta|o) d\theta$$

# Thank you

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