Multi-touch Technology

6.810 Engineering Interaction Technologies

Prof. Stefanie Mueller | MIT CSAIL | HCI Engineering Group

how would you
build a multi-touch device?

- which hardware do you use?
- how do you know where the fingers are?

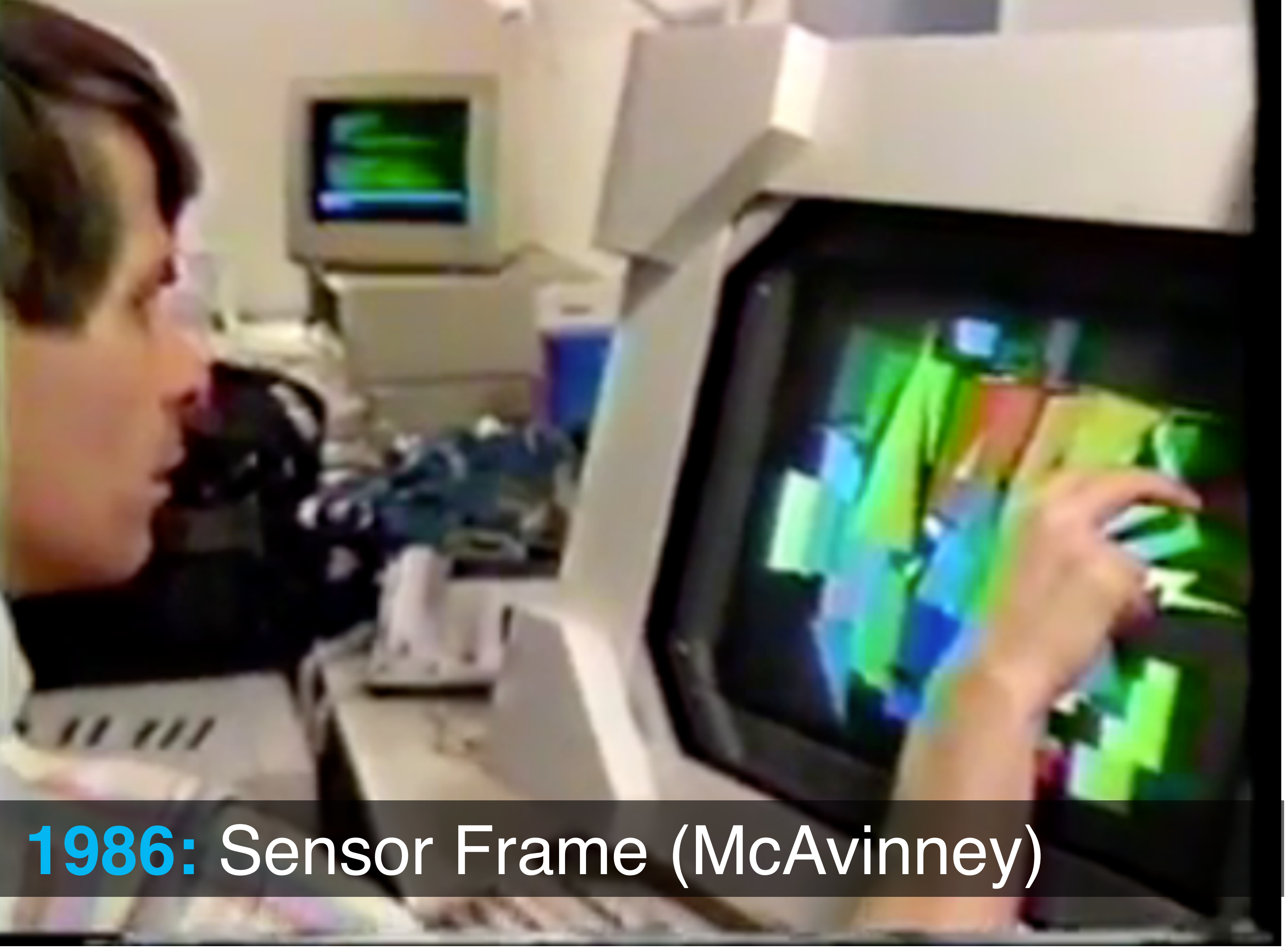
draw some **sketches!**

<2 minute brainstorming>

in which year
was the **first touch screen** invented?

<30s brainstorming>

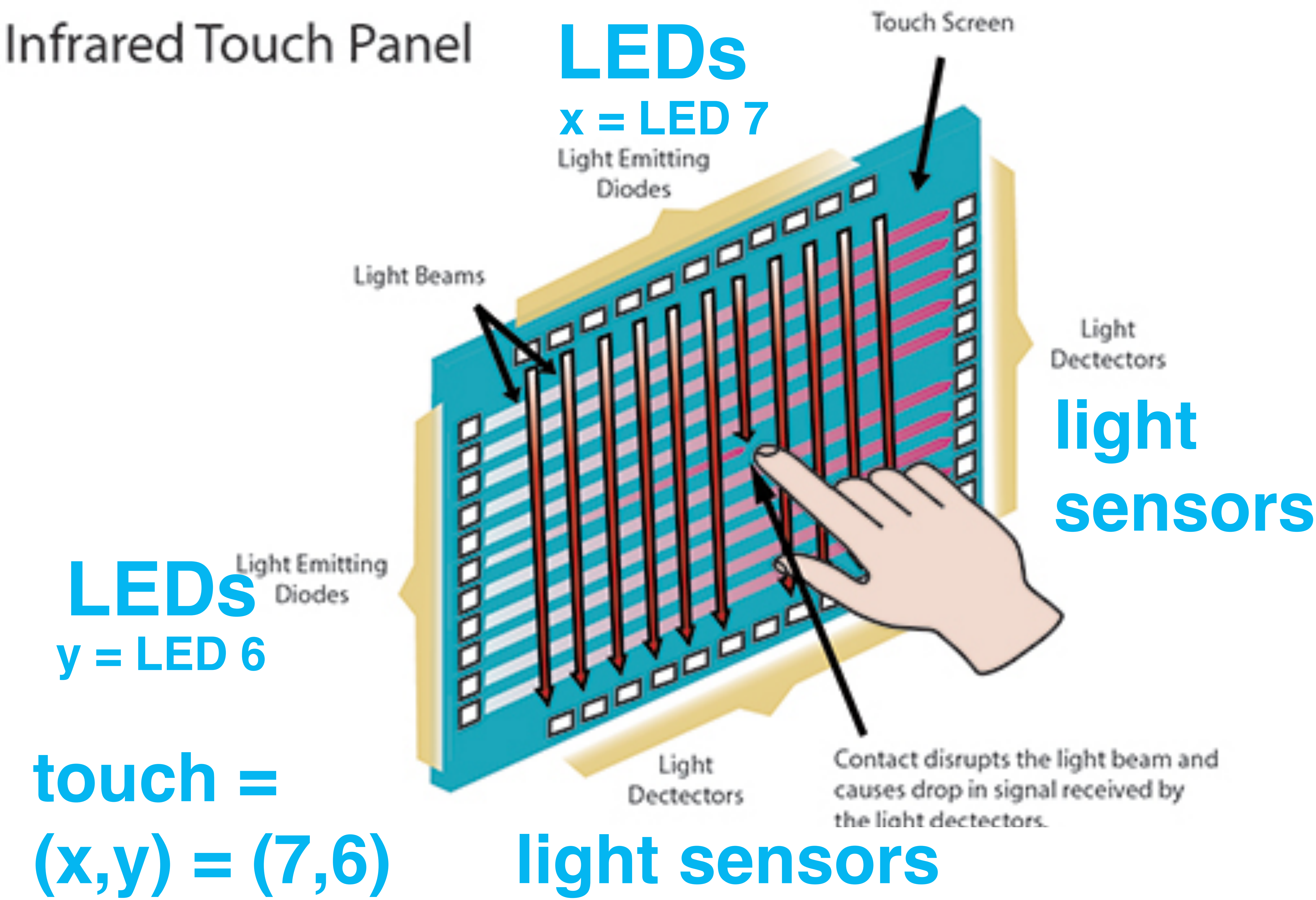
1986: Sensor Frame (McAvinney)



1986: Sensor Frame (McAvinney)

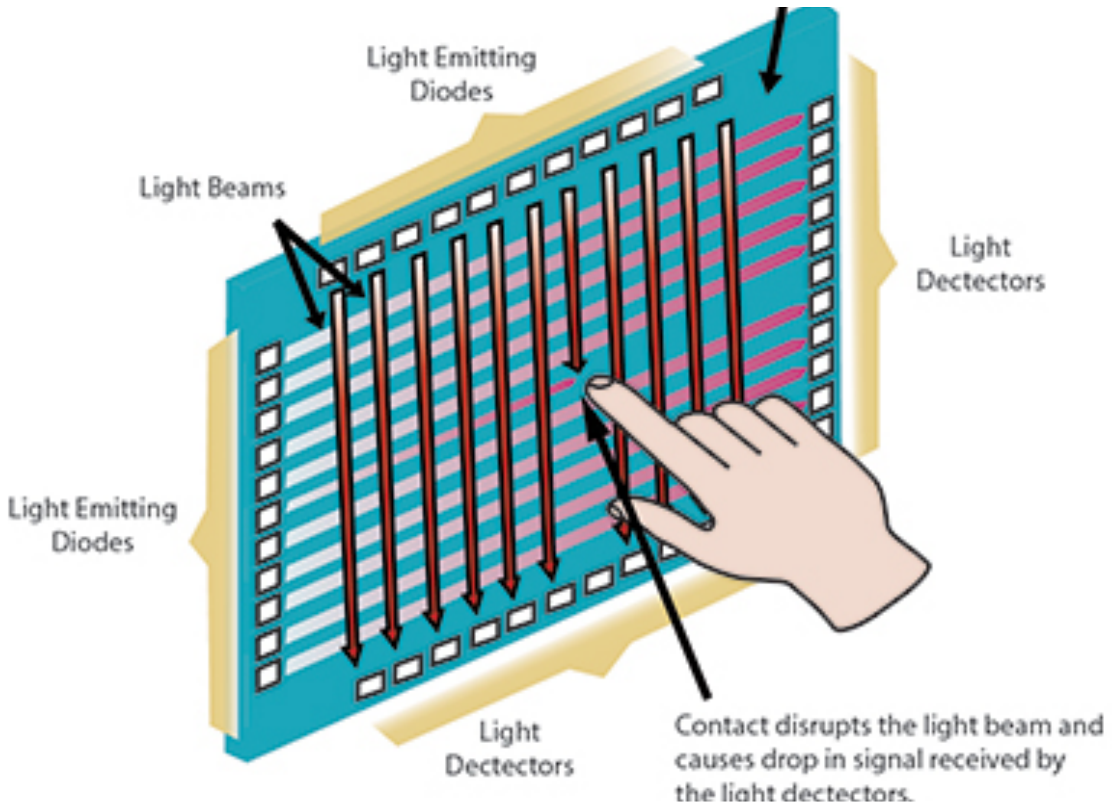
how does his sensor frame recognize touch?

<30s brainstorming>

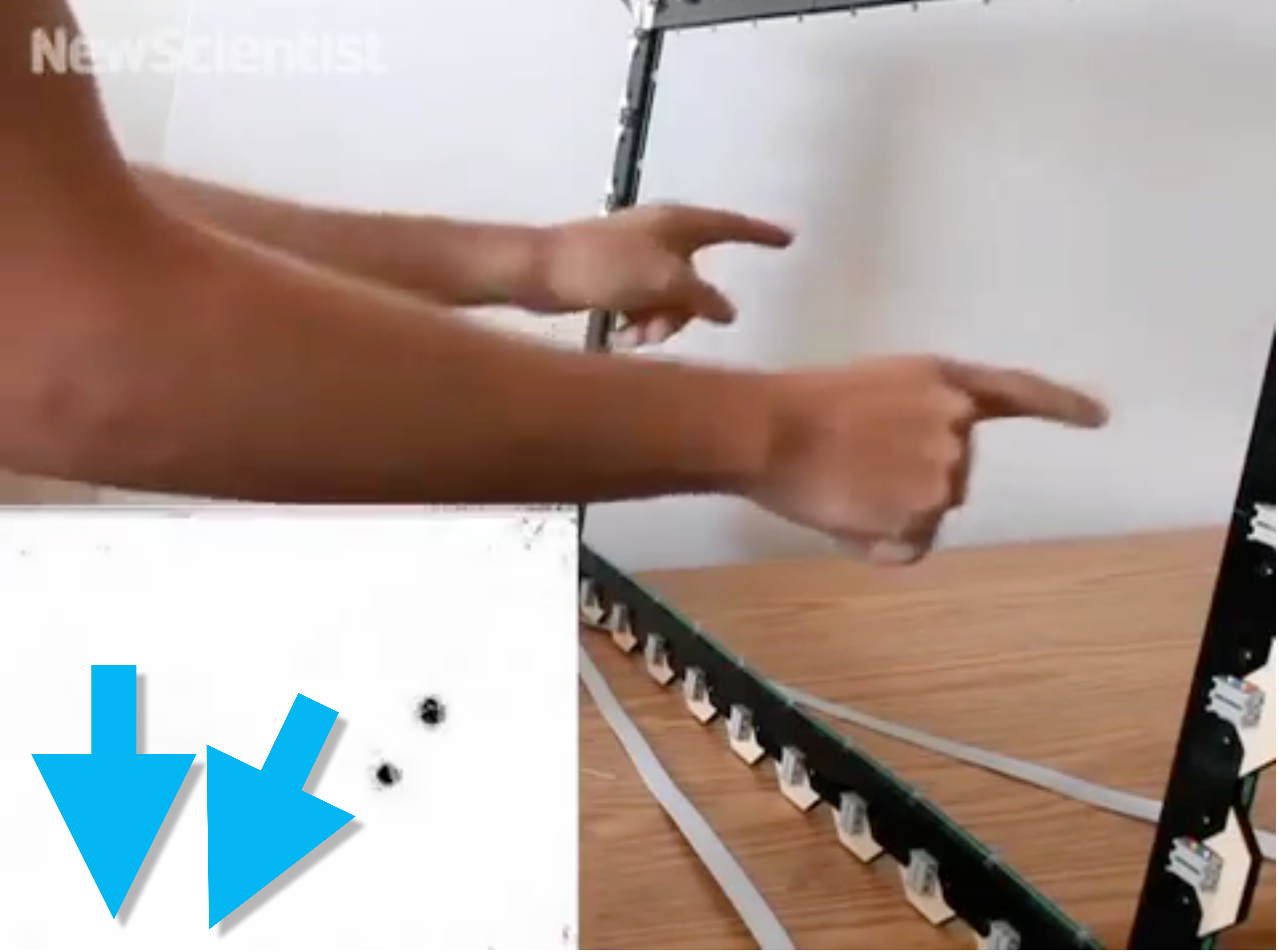

Infrared Touch Panel
LEDs
x = LED 7
Light Emitting
Diodes
Touch Screen
Light Beams
Light
Dectectors
light
sensors
LEDs
Light Emitting
Diodes
y = LED 6
Light
Dectectors
Contact disrupts the light beam and
causes drop in signal received by
the light dectectors.
touch =
(x,y) = (7,6)
light sensors

infrared touch panels (ITP)

- **infrared LEDs** and **light sensors**
- placed in a grid on bezel
- LEDs transmit light to light sensors on the other side
- anything that disrupts light, will register as touch




this is old, why are we learning this?
1986: Sensor Frame (McAvinney)



2011: ZeroTouch

Steve Jobs, 2007 (30 years later):
“And we have invented
a new technology
called multi-touch,
which is phenomenal.
[0:33:33]

ZeroTouch: An Optical Multi-Touch and Free-Air Interaction Architecture

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ABSTRACT

ZeroTouch (ZT) is a unique optical sensing technique and architecture that allows precision sensing of hands, fingers, and other objects within a constrained 2-dimensional plane. ZeroTouch provides tracking at 80 Hz, and up to 30 concurrent touch points. Integration with LCDs is trivial. While designed for multi-touch sensing, ZT enables other new modalities, such as pen+touch and free-air interaction. In this paper, we contextualize ZT innovations with a review of other flat-panel sensing technologies. We present the modular sensing architecture behind ZT, and examine early diverse uses of ZT sensing.

Author Keywords

Multi-touch; ZeroTouch; Free-Air; Interaction; Sensing

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Input Devices*

General Terms

Design; Experimentation

INTRODUCTION

Flat-panel multi-touch technologies are slowly but surely scaling to larger and larger screen-sizes. What was once predominantly the domain of bulky vision-based camera/projector multi-touch systems is now being rapidly encroached upon by more space-efficient technologies, albeit at higher relative cost/screen area.

is unsuitable for integration with the large contingent of non-multi-touch displays already in the world.

There are a number of technologies that enable multi-touch interaction on non-interactive displays in the market today, and the majority of these employ optical-based touch sensing. Some use cameras and computer vision techniques, and some use optical sensors and emitters to detect touch.

In this paper, we detail ZeroTouch (ZT), a hardware/software architecture for multi-touch sensing [16]. ZeroTouch is a flat-panel optical multitouch technology using a linear array of modulated light receivers which surround the periphery of a display to detect touch. It is designed with a modular architecture. A complete sensor is built from a number of smaller sensing modules, allowing a full sensor to be built at any practical size.

First, we present an overview of flat-panel optical multi-touch techniques, and position ZeroTouch amidst the multi-touch sensing landscape. Next, we go deeper into the technology of ZT, describing its modular architecture, sensing technique, and temporal and spatial resolution characteristics of the sensor. Finally, we develop [illegible] with case studies. We wrap up with a discussion and implications for the technology.

OPTICAL FLAT-PANEL SENSING TECHNOLOGIES

There are a few techniques for optical flat-panel sensing, some which sense from the sides, and some which sense directly behind or within the display itself. We will discuss

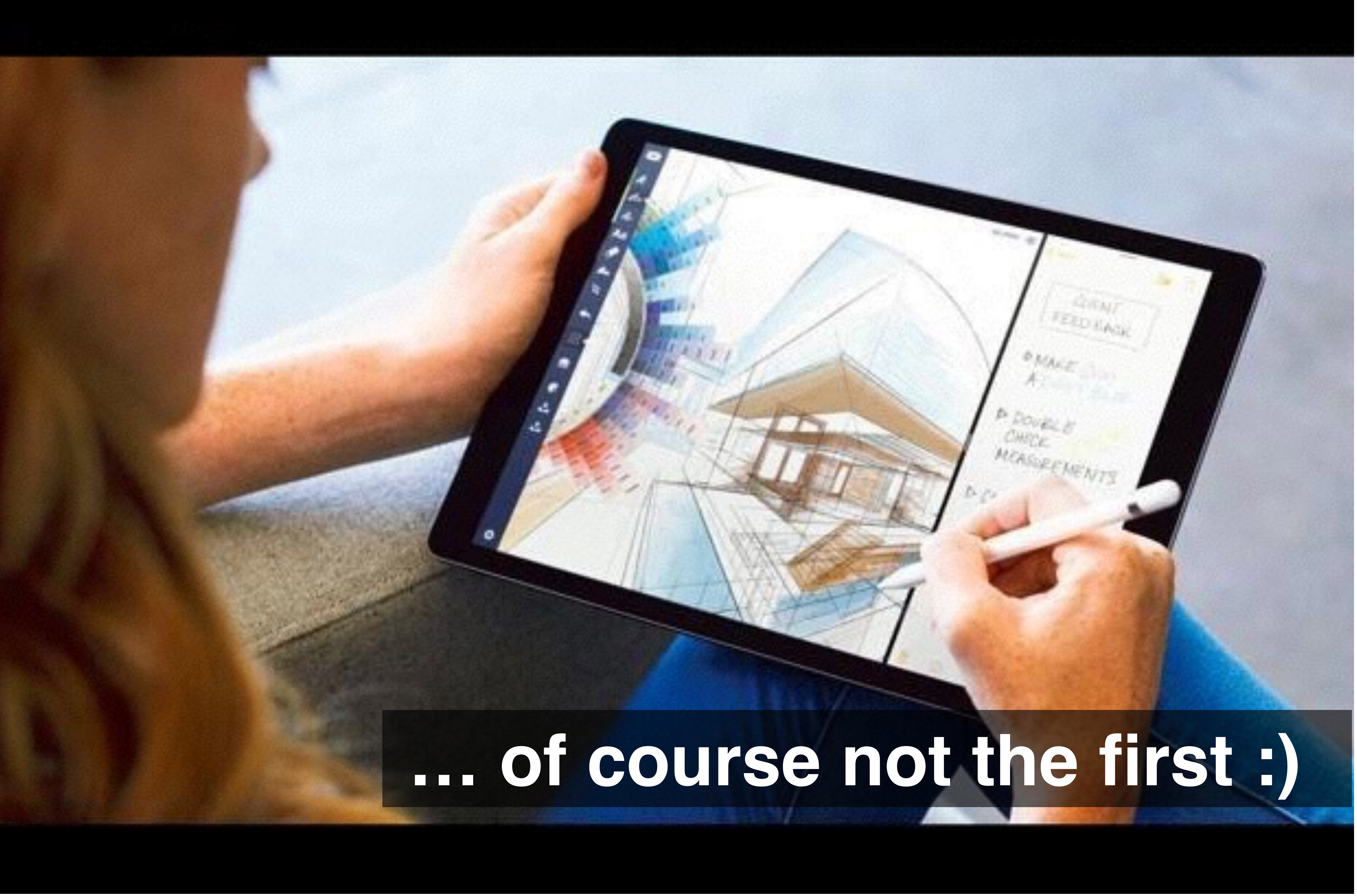
CHI Conference = Computer-Human Interaction


Xin (UTA)
buy & trash cycle is rapidly speeding up
large sustainability problem

CHI 2018

let’s look at another example:
first pen / stylus interaction?

<30s brainstorming>



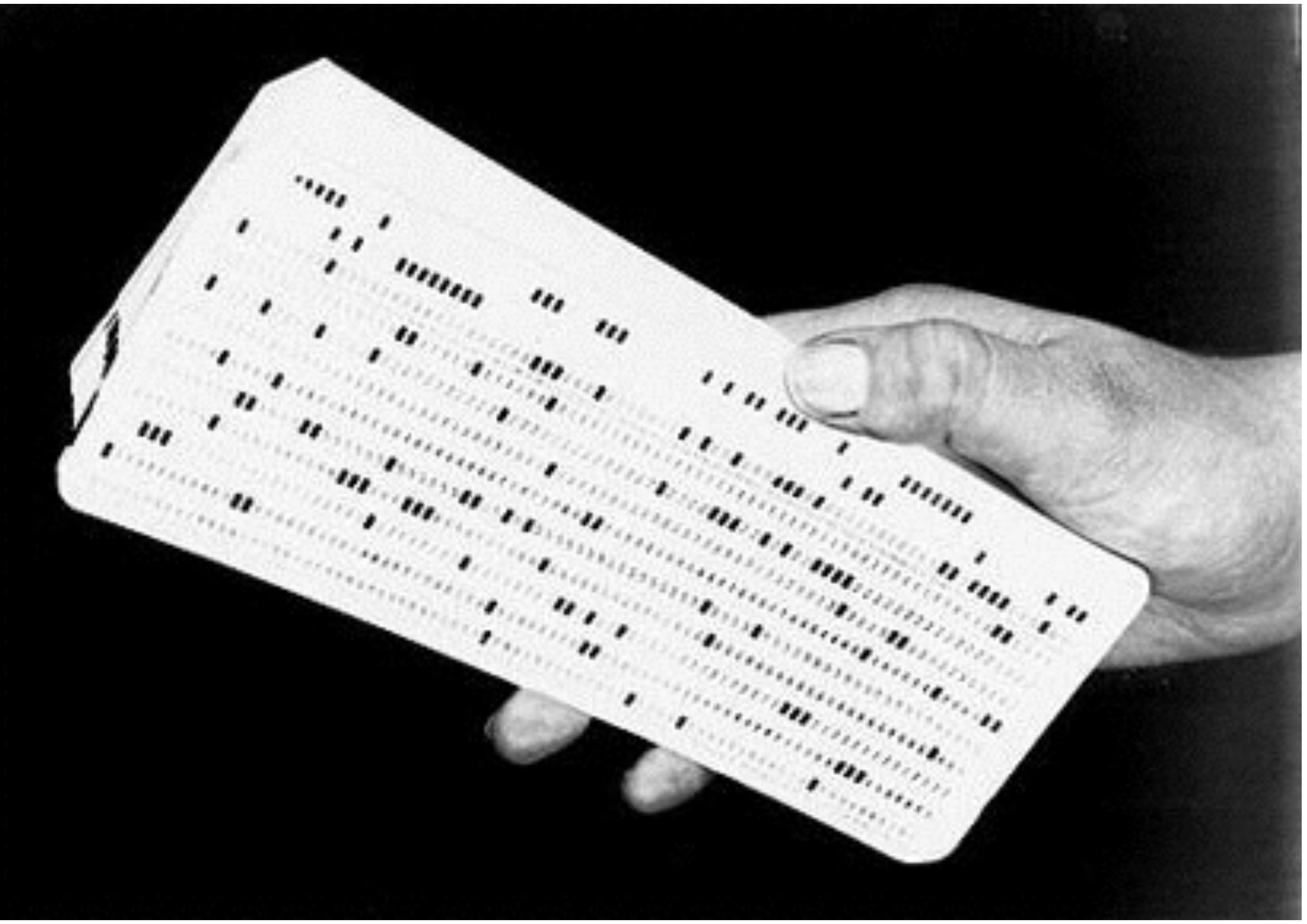
2015 Apple Pencil

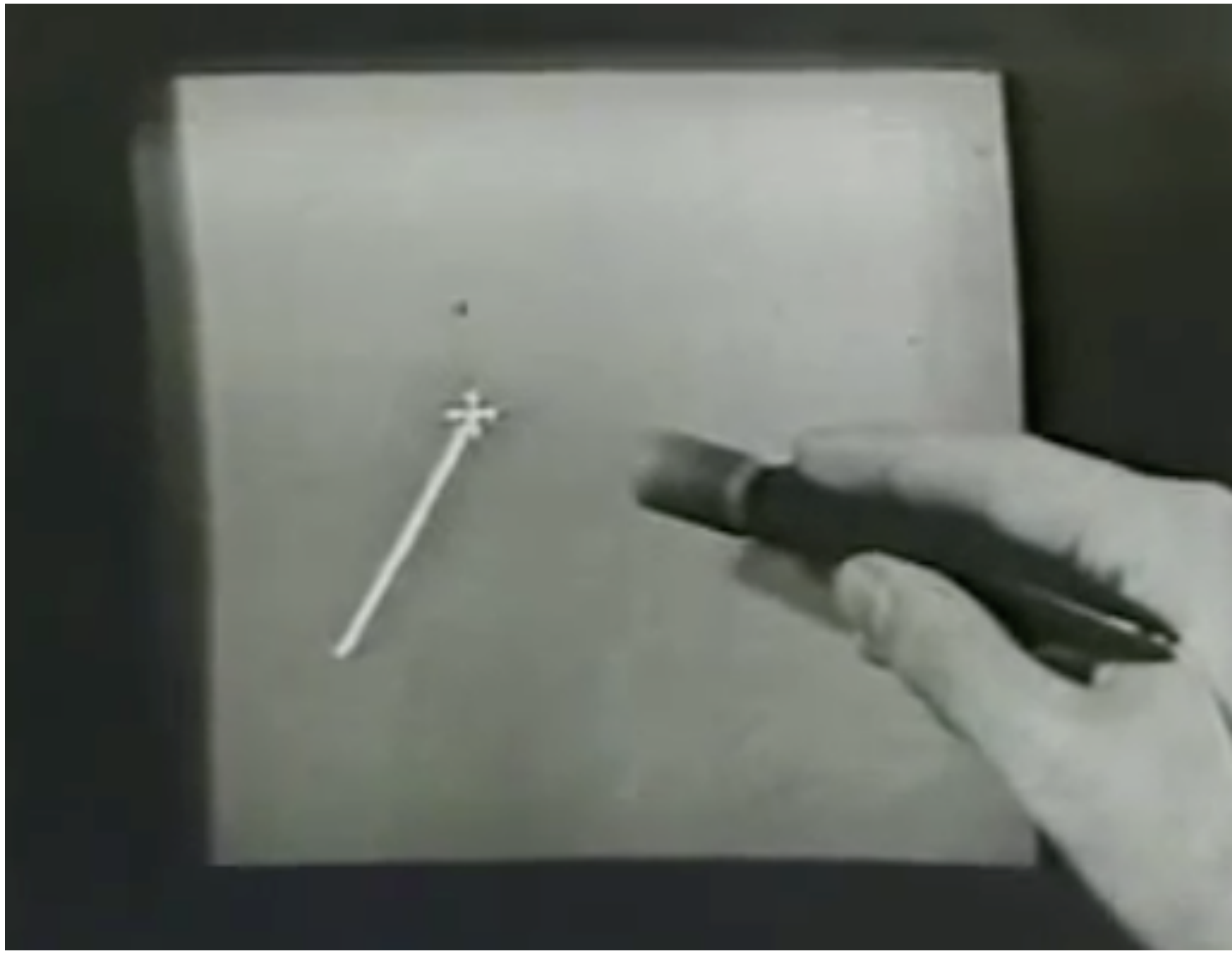
pay attention to how they explain **snapping!**

1963: Light Pen, Ivan Sutherland (as part of SketchPad)

1963: Light Pen, Ivan Sutherland (as part of SketchPad)

this was mind-boggling at the time when
punched cards where still the main input method





Human-Computer Interaction (HCI):

inventing new ways
how humans interact with computers

1963: Light Pen

how did this work?

how was the pen input recognized?

<30s brainstorming>

in the 60s, they only had

CRT monitors (cathode ray tube)


THE SOFTWARE TOOLWORKS

CRT monitors (cathode ray tube)

- micro-controller tells the electron beam where to point (x,y)
- thus, the micro-controller knows where the beam is pointing at

light sensor in the pen

- pen is also connected to the micro-controller
- when the electron beam hits the pen, the pen tells the micro-controller to save the (x,y) position of the beam at that time
- **= pen location**

30 years later, multi-touch and pen-input have reached the consumer market…

but there are still **interaction concepts** that haven’t reached the consumer market yet

1991: Pierre Wellner, Digital Desk

1991: Pierre Wellner, Digital Desk

The DigitalDesk Calculator: Tangible Manipulation on a Desk Top Display

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Abstract

Today's electronic desktop is quite separate from the physical desk of the user. Electronic documents lack many useful properties of paper, and paper lacks useful properties of electronic documents. Instead of making the electronic desktop more like the physical desk, this work attempts the opposite: to give the physical desk electronic properties and merge the two desktops into one. This paper describes a desk with a computer-controlled camera and projector above it. The camera sees where the user is pointing, and it reads portions of documents that are placed on the desk. The projector displays feedback and electronic objects onto the desk surface. This DigitalDesk adds electronic features to physical paper, and it adds physical features to electronic documents. The system allows the user to interact with paper and electronic objects by *touching* them with a bare finger (digit). Instead of "direct" manipulation with a mouse, this is *tangible* manipulation with a finger. The DigitalDesk Calculator is a prototype example of a simple application that can benefit from the interaction techniques enabled by this desktop. The paper begins by discussing the motivation behind this work, then describes the DigitalDesk, tangible manipulation, and the calculator prototype. It then discusses implementation details and ends with ideas for the future of tangible manipulation.

input device, workstation, desk, desktop

Introduction

Many of us work at a desk, and an important part of desk activities involve "paper pushing," or the manipulation of paper documents. Although paperwork on the desk and electronic work on the workstation are often related, the two activities are quite distinct. Interaction techniques in the two environments are very different, and mastering one does not help master the other. Given the amount of time we spend at work, the quality of this desk interface makes up an important element in our quality of life. The conventional outlook for computerized desktops is that personal workstations are destined to evolve into faster machines with integrated 3D graphics and full-motion audio/video. More and more functionality is expected to migrate onto these super-workstations and off the conventional paper pusher's desktop. This paper presents an alternative.

Advances in digital technology are enabling computers to sense and synthesize many aspects of our environment. This has been exploited in the field of human-computer interaction (HCI) primarily through the study of virtual reality (VR), where users can interact with completely synthesized worlds using, for example, 3D head-mounted displays and data gloves [Spri91]. Even the traditional workstation is a limited sort of virtual reality, where the world resembles a desk work surface adorned with windows, icons and menus.

Computerized reality

exploit the familiar world, not by simulating it electronically, but by enhancing it. Instead of virtual reality, these systems create *computerized* reality (CR). Users do not have

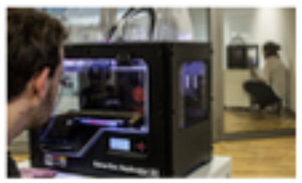
UIST Conference =
User Interface Software and Technology

Harshit Agrawal, Udayan Umapathi, Robert Kovacs, Johannes Frohnhofen, Hsiang-Ting Chen, Stefanie Mueller, Patrick Baudisch.
Protopiper: Ph…cally Sketch…g Room-Sized Objects at Actual Scale.
In *Proceedings …f UIST 2015.*

DOI | Pap… | … | Project Page

Dustin Beyer, Serafima Gurevich, Stefanie Mueller, Hsiang-Ting Chen, Patrick Baudisch.
Platener: Low-F… …tion of 3D Objects by Substituting 3D Print with Laser-Cut Plates.
In *Proceedings …f UIST 2015.* [B…ST PAPER NOMINEE]

DOI | Pap… | Video | Slides | Project Page



Stefanie Mueller, Martin Fritzsche, Jan Kossmann, Maximilian Schneider, Jonathan Striebel, Patrick Baudisch.
Scotty: Relocating Physical Objects Across Distances Using Destructive Scanning, Encryption, and 3D Printing.
In *Proceedings of TEI 2015.*

DOI | Paper | Video | Project Page

Stefanie Mueller, Sangha Im, Serafima Gurevich, Alexander Teibrich, Lisa Pfisterer, François Guimbretière, Patrick Baudisch.
WirePrint: 3D P…ted Previe… for Fast Prototyping.
In *Proceedings …f UIST 2014.*

DOI | Pap… | … | Slides | UIST Talk | Project Page

Stefanie Mueller, Tobias Mohr, Kerstin Guenther, Johannes Frohnhofen, Patrick Baudisch.
faBrickation: …ast 3D printi… of Functional Objects With Building Blocks.
In *Proceedin…s of CHI 2014.* […EST PAPER NOMINEE]

DOI | P… | … | Slides | CHI Talk | Project Page

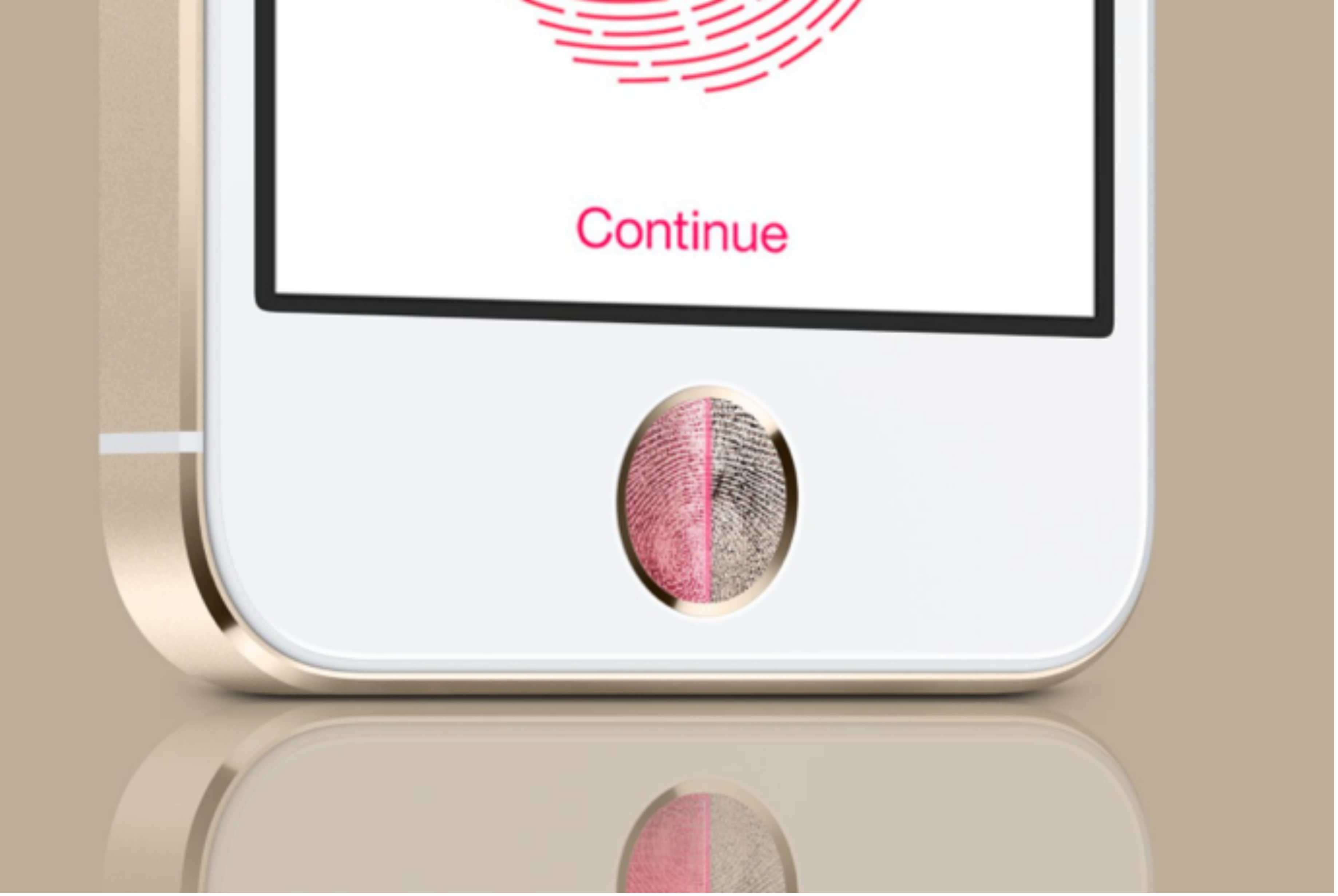
Stefanie Mueller, Bastian Kruck, Patrick Baudisch.
LaserOrigami: …aser-Cutting …D Objects.
In *Proceedings …f CHI 2013.* [BE…T PAPER AWARD]

DOI | Pap… | … | Slides | CHI Talk | Project Page

Stefanie Mueller, Pedro Lopes, Patrick Baudisch.
Interactive Co…truction: …ctive Fabrication of Functional Mechanical Devices.
In *Proceedings …f UIST 2012.*

DOI | Pap… | … | Slides | UIST Talk | Project Page

and one more example
for the **future of touch…**

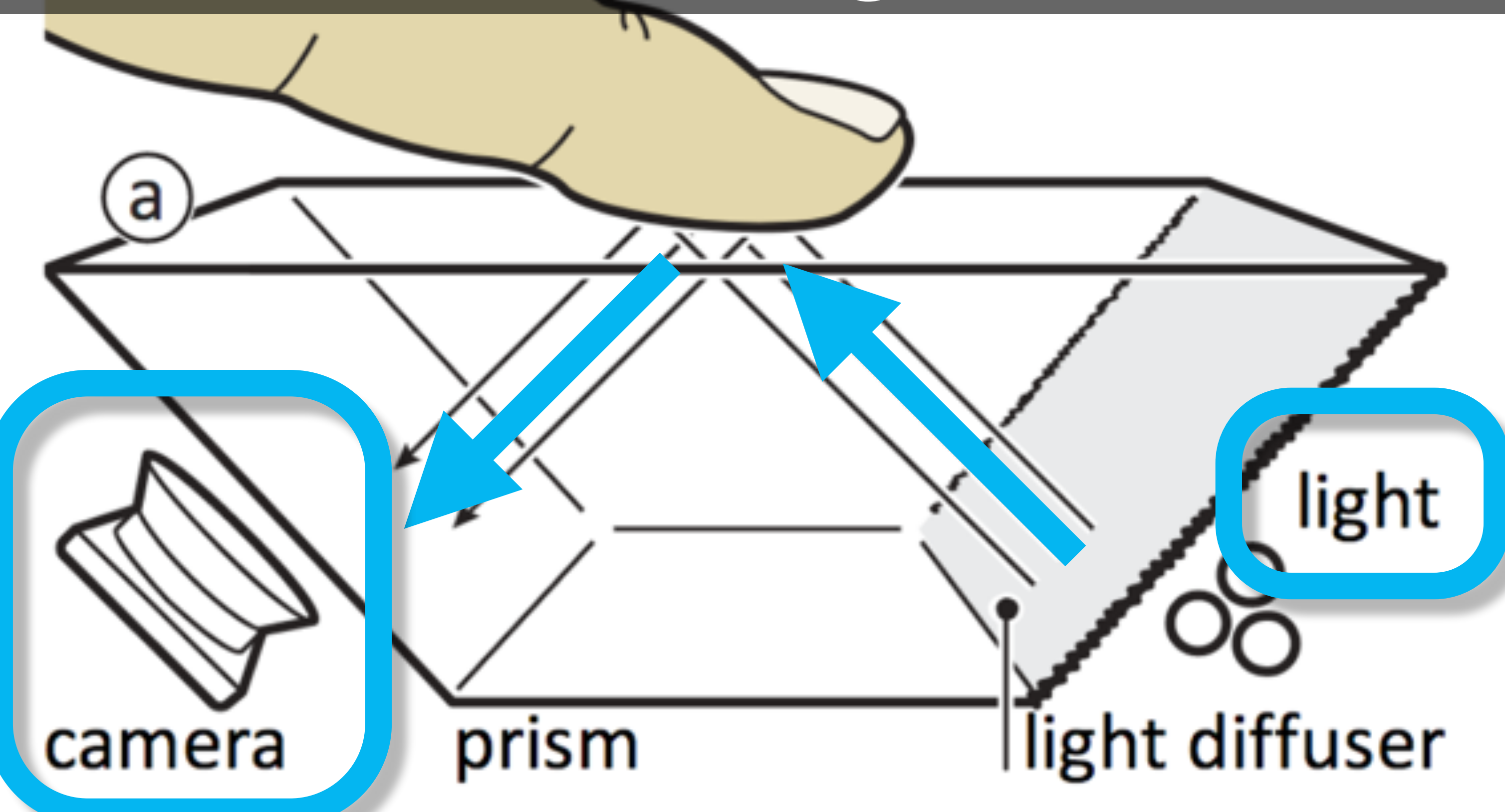


what if we had **finger print** detection on the entire screen?

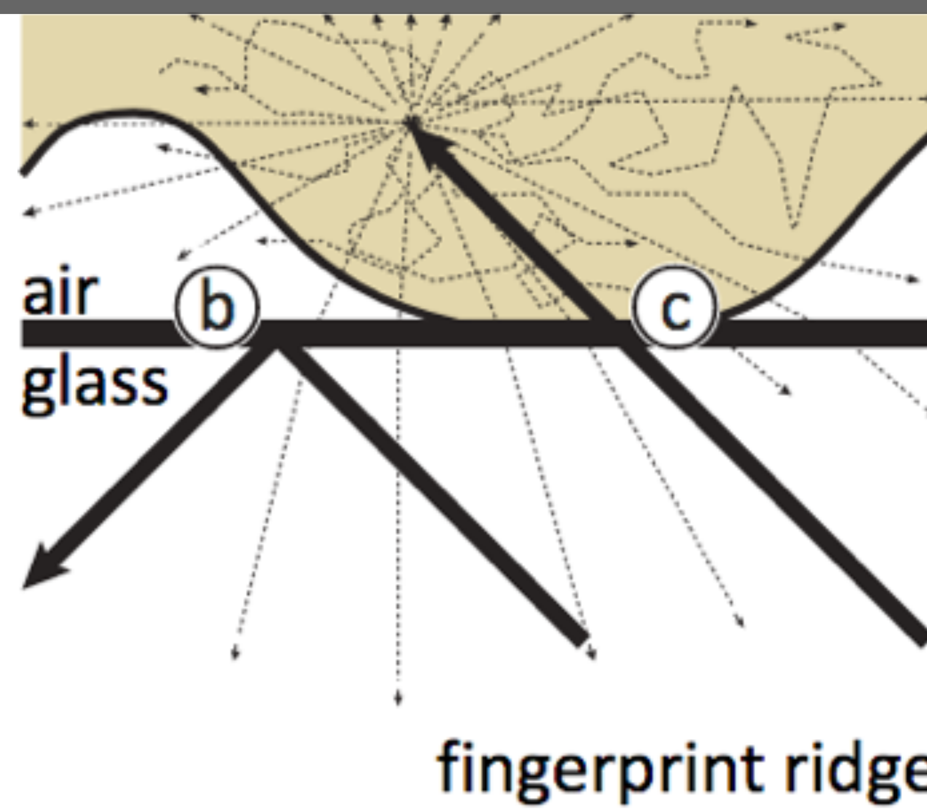
<30 second brainstorming>

2013: Fiberio

here's how fingerprint scanners work:



if finger ridges do not touch,
light gets reflected,
hits the camera
= bright spot



if finger ridges touch,
light gets scattered,
does not hit the camera
= black spot

Fiberio: A Touchscreen that Senses Fingerprints

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ABSTRACT

We present Fiberio, a rear-projected multitouch table that identifies users biometrically based on their fingerprints *during* each touch interaction. Fiberio accomplishes this using a new type of screen material: a large fiber optic plate. The plate *diffuses* light on transmission, thereby allowing it to act as projection surface. At the same time, the plate *reflects* light specularly, which produces the contrast required for fingerprint sensing. In addition to offering all the functionality known from traditional diffused illumination systems, Fiberio is the first interactive tabletop system that authenticates users during touch interaction—unobtrusively and securely using the biometric features of fingerprints, which eliminates the need for users to carry any identification tokens.

Author Keywords

Touchscreens; multitouch; user identification; fingerprints.

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. Input devices & strategies.

INTRODUCTION

Several researchers have proposed techniques that allow interactive tabletop systems to distinguish users during interaction. The ability to associate each touch with a particular user has allowed such systems to personalize interaction [21], log user activity [2], and ensure that only the authorized users can access private objects [31] or perform privileged activities [6].

A number of existing approaches address this challenge. Unfortunately, they either require users to carry identification tokens, such as RFID tags [28], rings [30], or marker gloves [21] or they can only distinguish among a small group of users, for example by recognizing their shoes [29], their hand contours [31], or the chairs they sit in [6].

Researchers have therefore pointed to fingerprint recognition as a possible solution to the problem. Fingerprint-based authentication is secure [20] and—in conjunction with touch interaction—would be unobtrusive for users. First steps in this direction include a separate fingerprint scanner placed *next* to the touchscreen [32] and an interactive

Figure 1: *Fiberio* is a rear-projected tabletop system that identifies users based on their fingerprints *during each interaction*—unobtrusively and securely. The shown application uses this to verify that the respective user has the authority to perform the current activity, here approve invoices above a certain value. The key that allows Fiberio to display an image *and* sense fingerprints at the same time is its screen material: a fiber optic plate.

system, i.e., to sense fingerprints and display a computer-generated image *in the same space at the same time.*

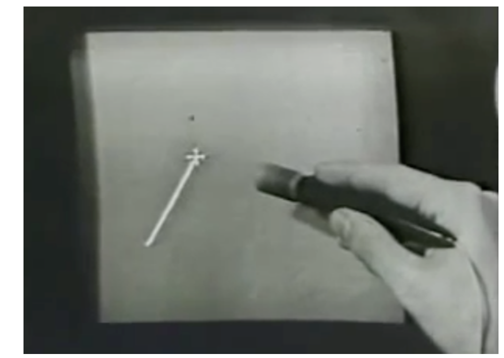
This challenge boils down to two contradicting requirements with respect to the screen material. On the one hand, the screen has to reveal fingerprints, i.e., produce contrast between the ridges and valleys of the fingerprint. Known solutions require a *specular* screen surface to accomplish optical fingerprint scanning. On the other hand, to be used as a display, the screen has to allow the rear-projection to produce a visible image, which requires the screen material to be *diffuse*. Unfortunately, specular and diffuse are contradictory requirements for such a surface.

research:
speculating about the future.

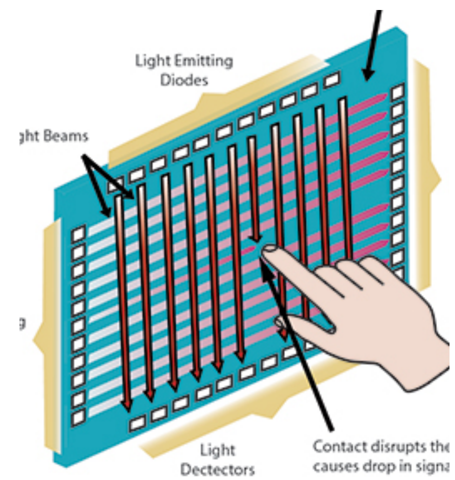
then see who was right/wrong
20 years later.

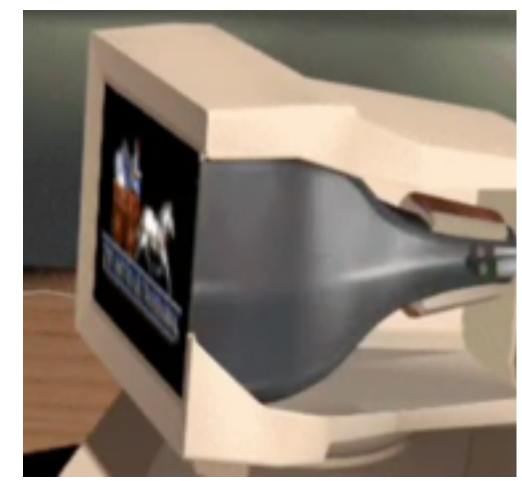
6.810 Engineering Interactive Technology

- learn about **history** of interactive technologies

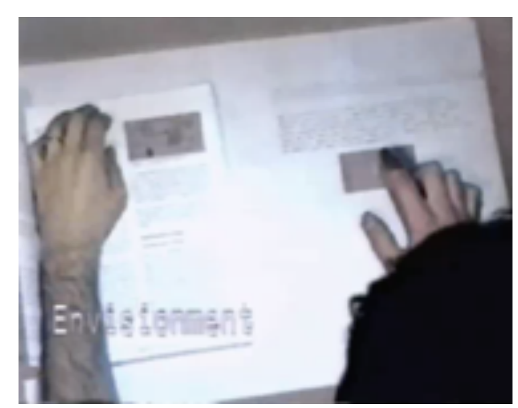


- understand the **underlying technology**





- **invent future** interactive technologies



let's look at some more touch technologies

how does my phone **recognize touch?**
and why the… do I need to press so hard on **airplane screens…?**

types of touch technology::

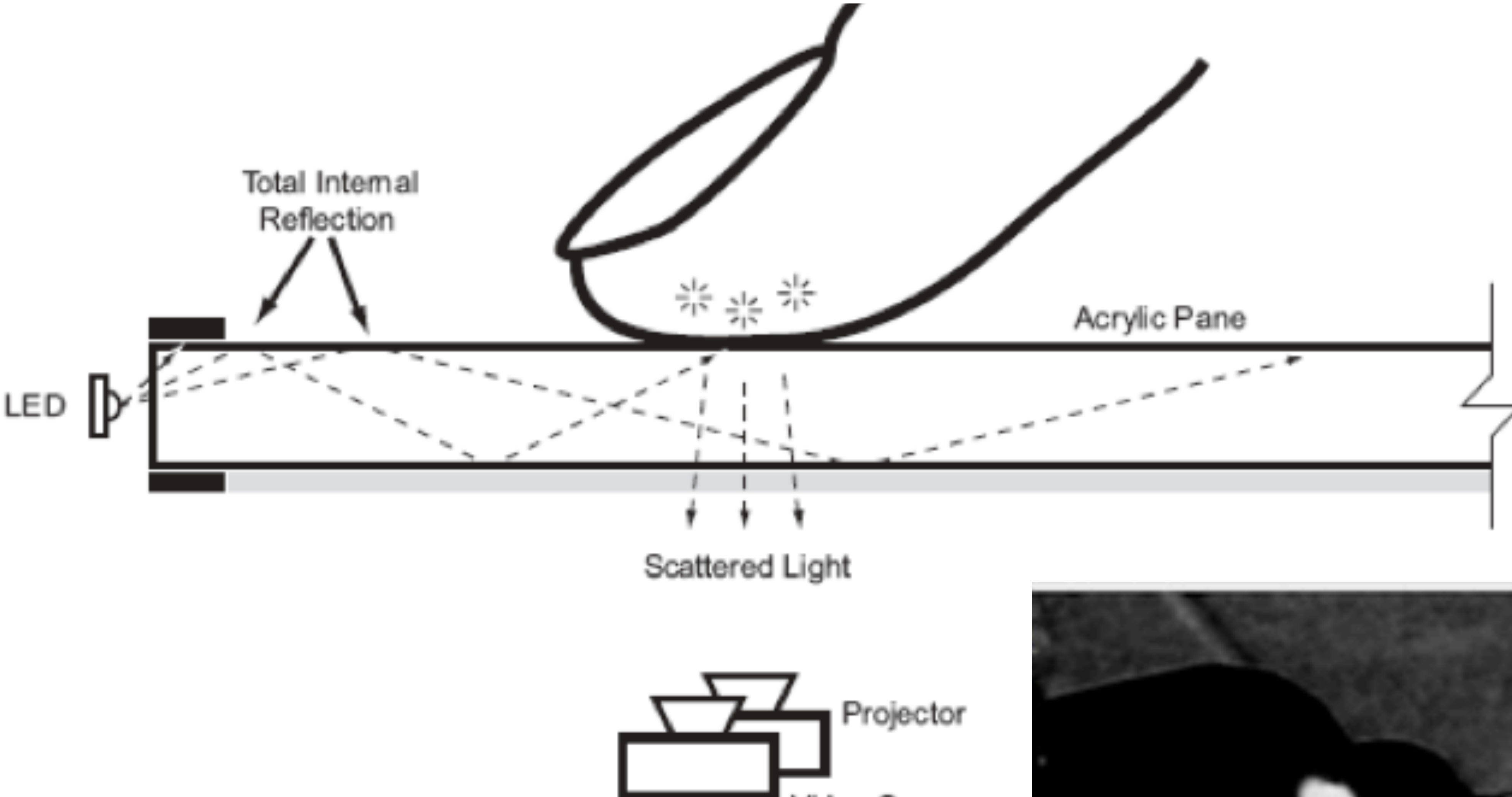
- resistive
- capacitive
- camera-based
- […]

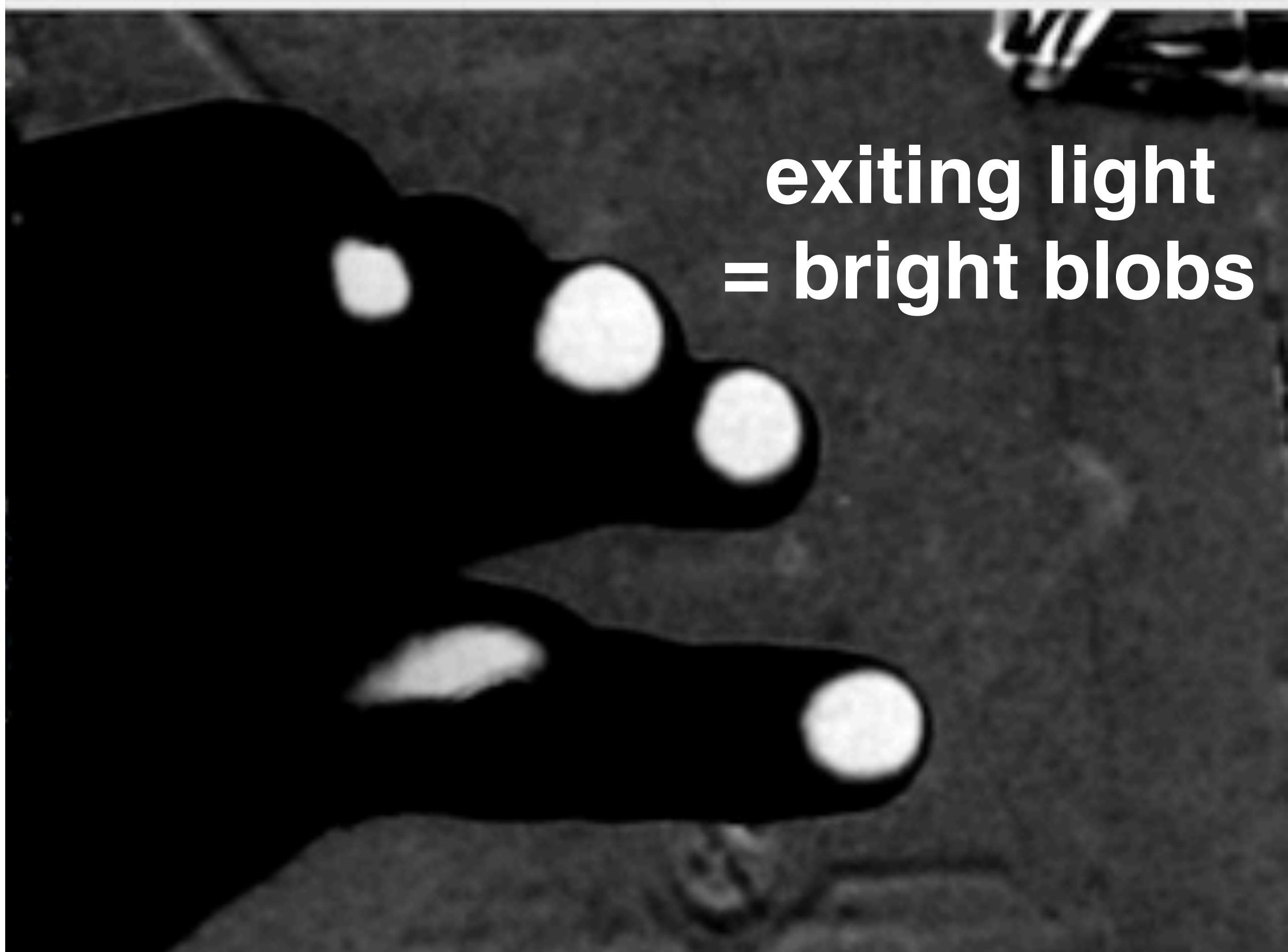
camera based #1:

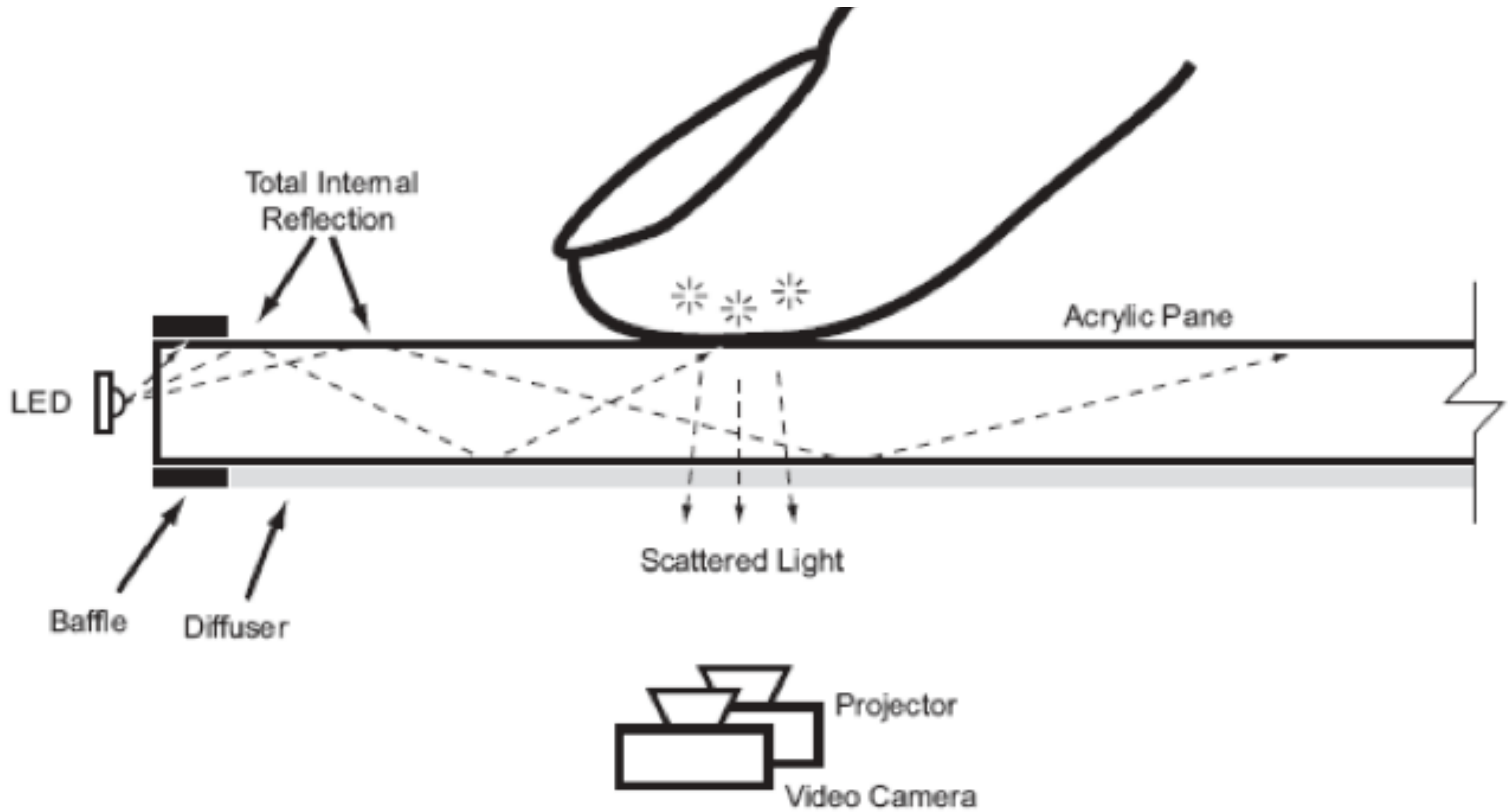
frustrated total internal reflection

frustrated total internal reflection (FTIR)

frustrated total internal reflection (FTIR)

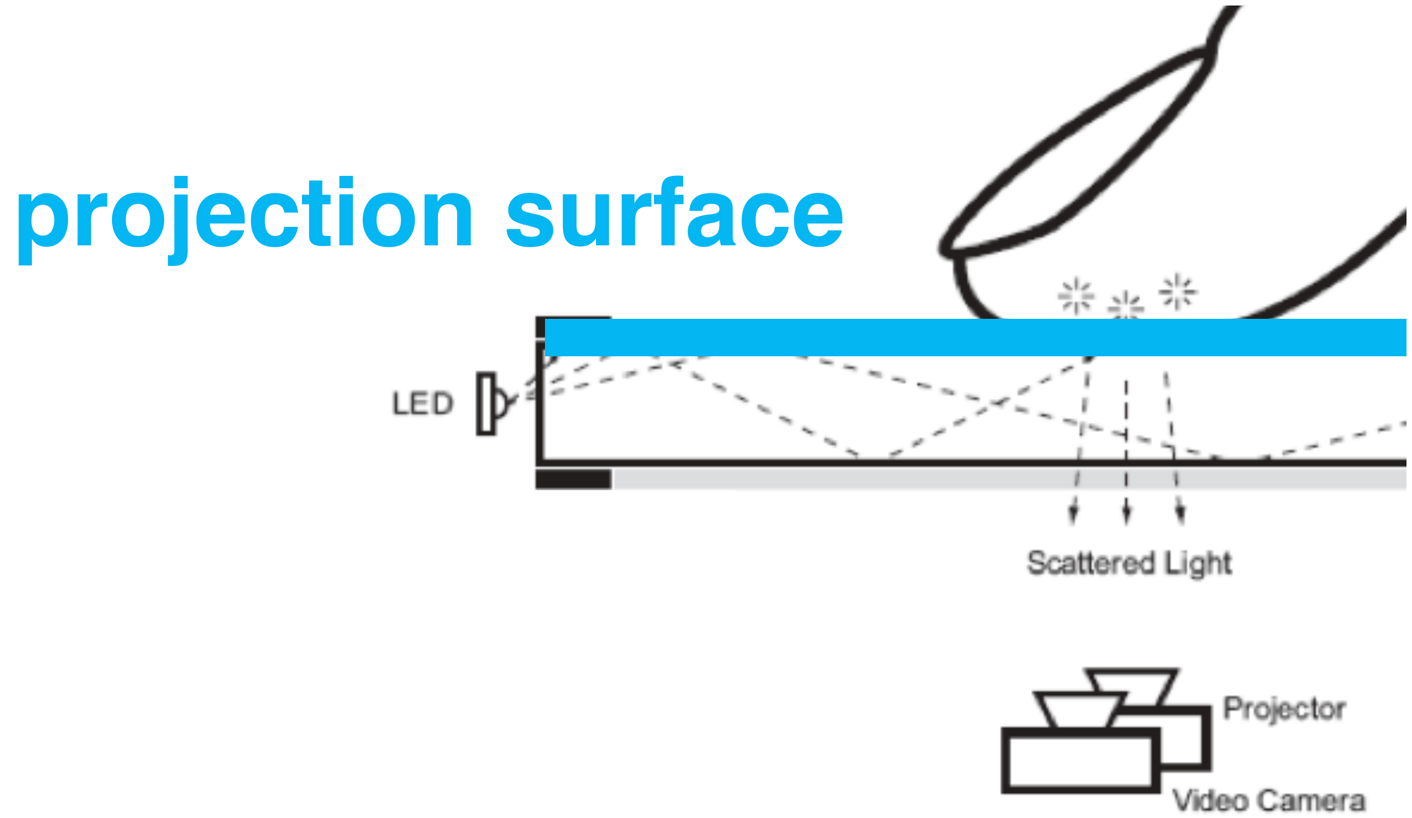






frustrated total internal reflection (FTIR)

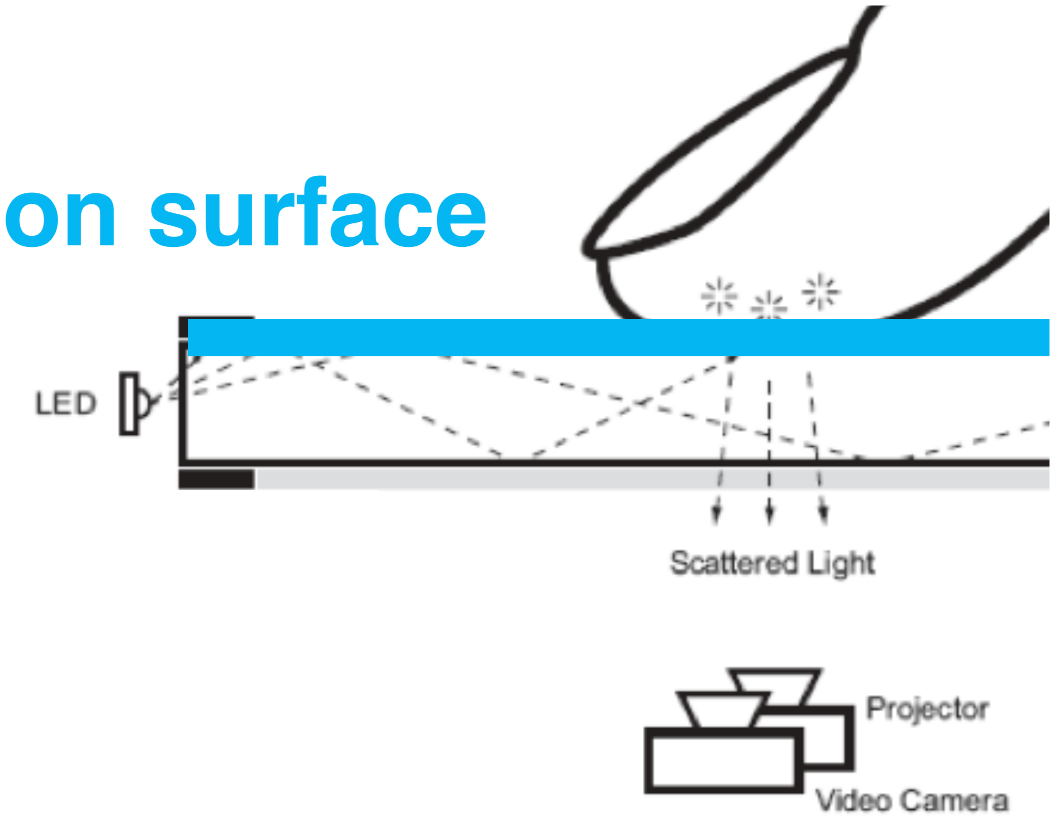
- **light is inserted** into the sides of acrylic panel
- light **internally reflects** because of FTIR phenomena
- when **finger touches** panel, light gets ‘frustrated’
- it escapes internal reflection and **scatters downwards**
- you can see this as **bright spots** in the camera image



optional: projection surface

- since acrylic is transparent, you cannot project on it
- thus, add a projection surface
- allows to **display an image**

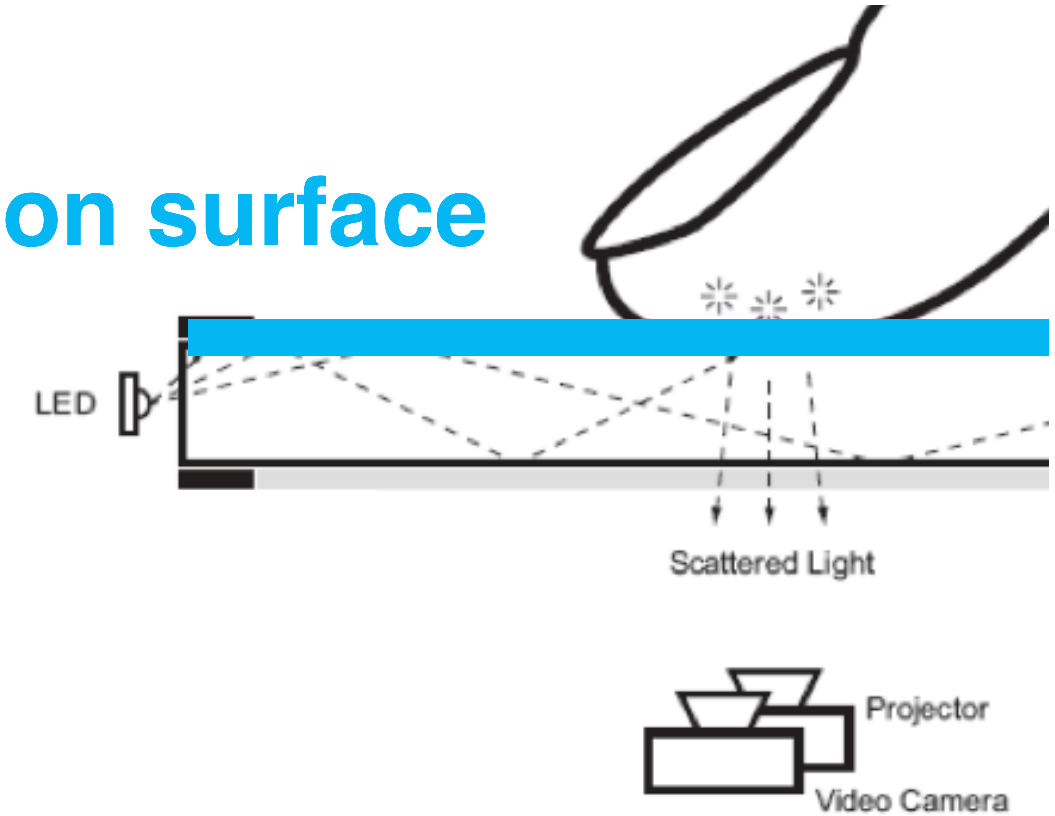
projection surface



to not interfere with the projection,
which type of LEDs do you use
for the internal total reflection?

<30 second brainstorming>

projection surface

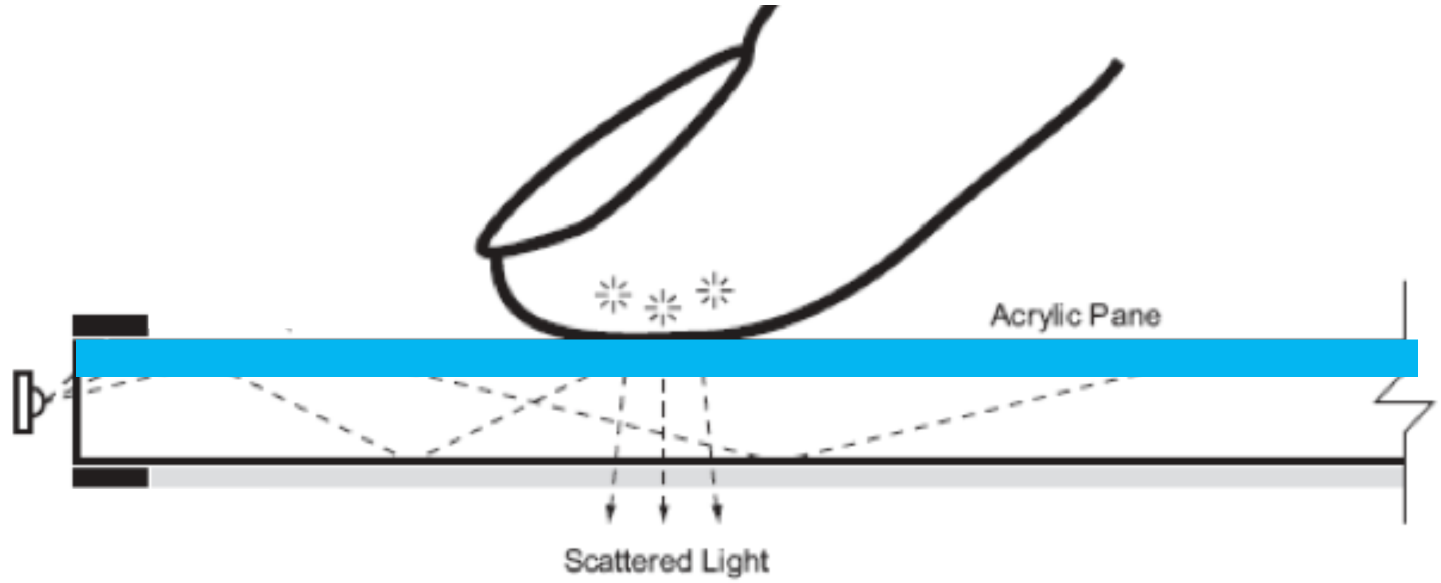


infrared LEDs

because otherwise your
injected light for finger tracking
overlays with your projected content

camera also needs to be able to see infrared!

infrared LEDs



visible light projector

infrared camera

2006: FTIR, Jeff Han

Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection

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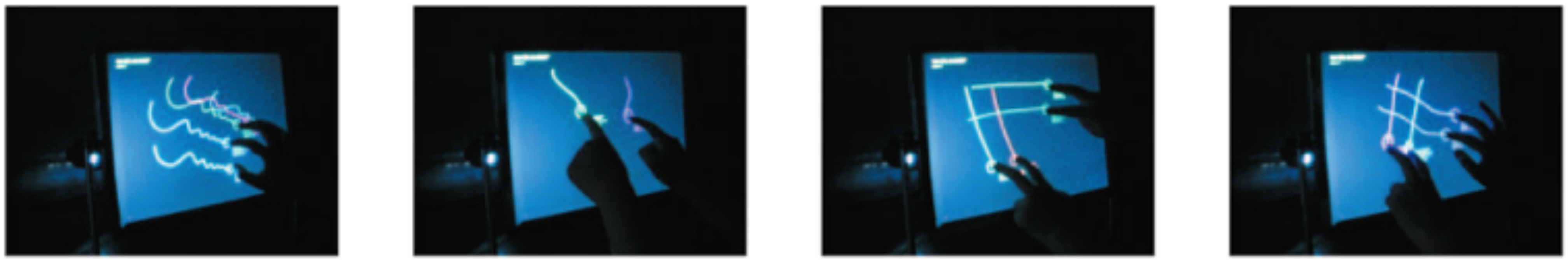


Figure 1: Simple examples of multi-touch interaction using our FTIR technique

ABSTRACT
This paper describes a simple, inexpensive, and scalable technique for enabling high-resolution multi-touch sensing on rear-projected interactive surfaces based on *frustrated total internal reflection*. We review previous applications of this phenomenon to sensing, provide implementation details, discuss results from our initial prototype, and outline future directions.

ACM Classification: H.5.2 [**User Interfaces**]: Input Devices and Strategies

General Terms: Human Factors

Keywords: multi-touch, touch, tactile, frustrated total internal reflection

We present a simple technique for robust multi-touch sensing at a minimum of engineering effort and expense. It is based on *frustrated total internal reflection (FTIR)*, a phenomenon familiar to both the biometric and robot sensing communities. It acquires true touch image information at high spatial and temporal resolutions, is scalable to large installations, and is well suited for use with rear-projection. It is not the aim of this paper to explore the multi-touch interaction techniques that this system enables, but rather to make the technology readily available to those who wish to do so.

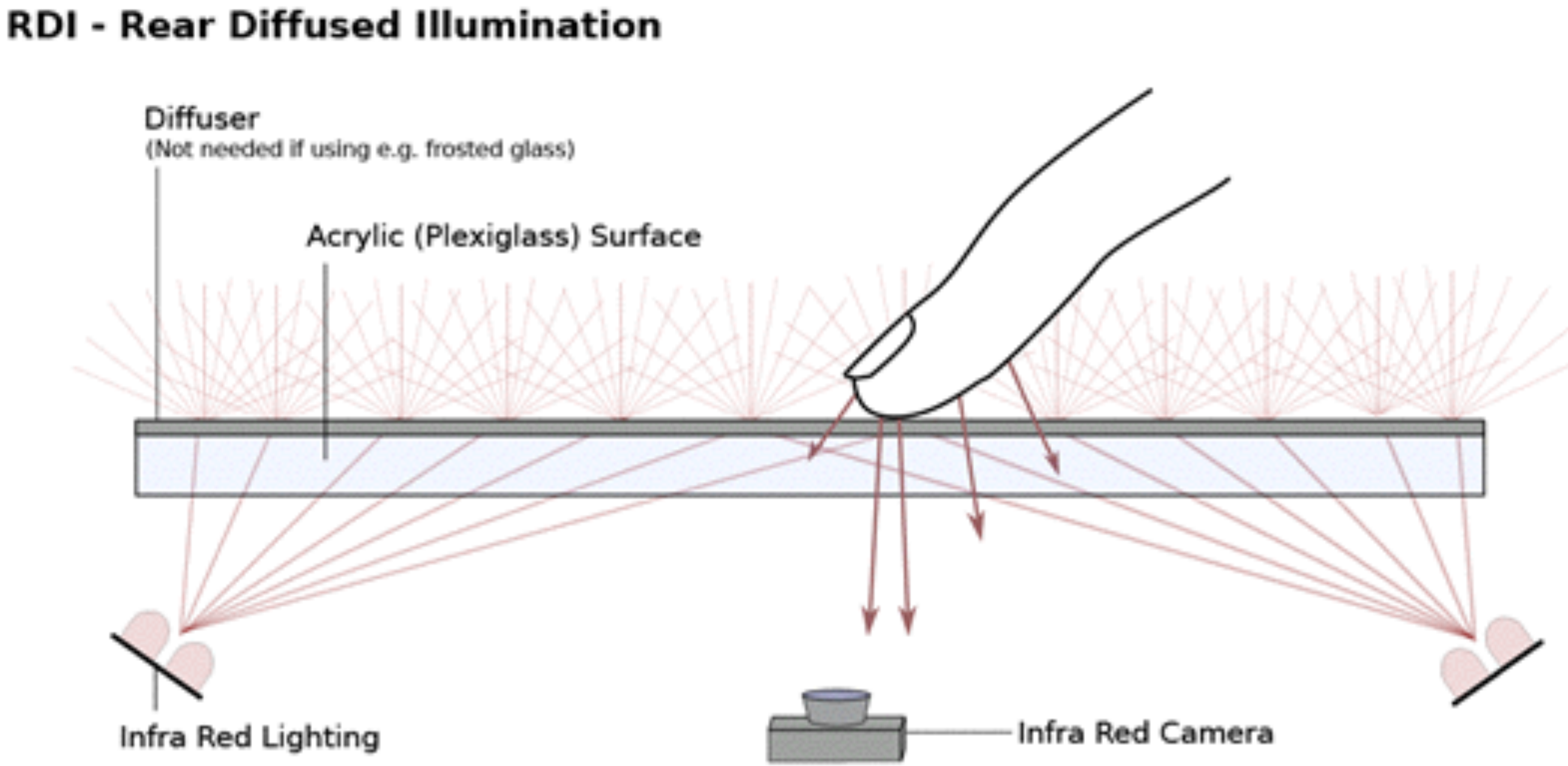
RELATED WORK
A straightforward approach to multi-touch sensing is to simply utilize a plurality of discrete sensors, making an individual connection to each sensor as in the *Tactex MTC Express* [20]. They can also be arranged in a matrix configuration with some active element (e.g. diode, transistor) at each node

UIST 2005 paper (just got lasting impact award)

Steve Jobs, 2007:
“And we have invented a new technology called multi-touch, which is phenomenal.
[0:33:33]

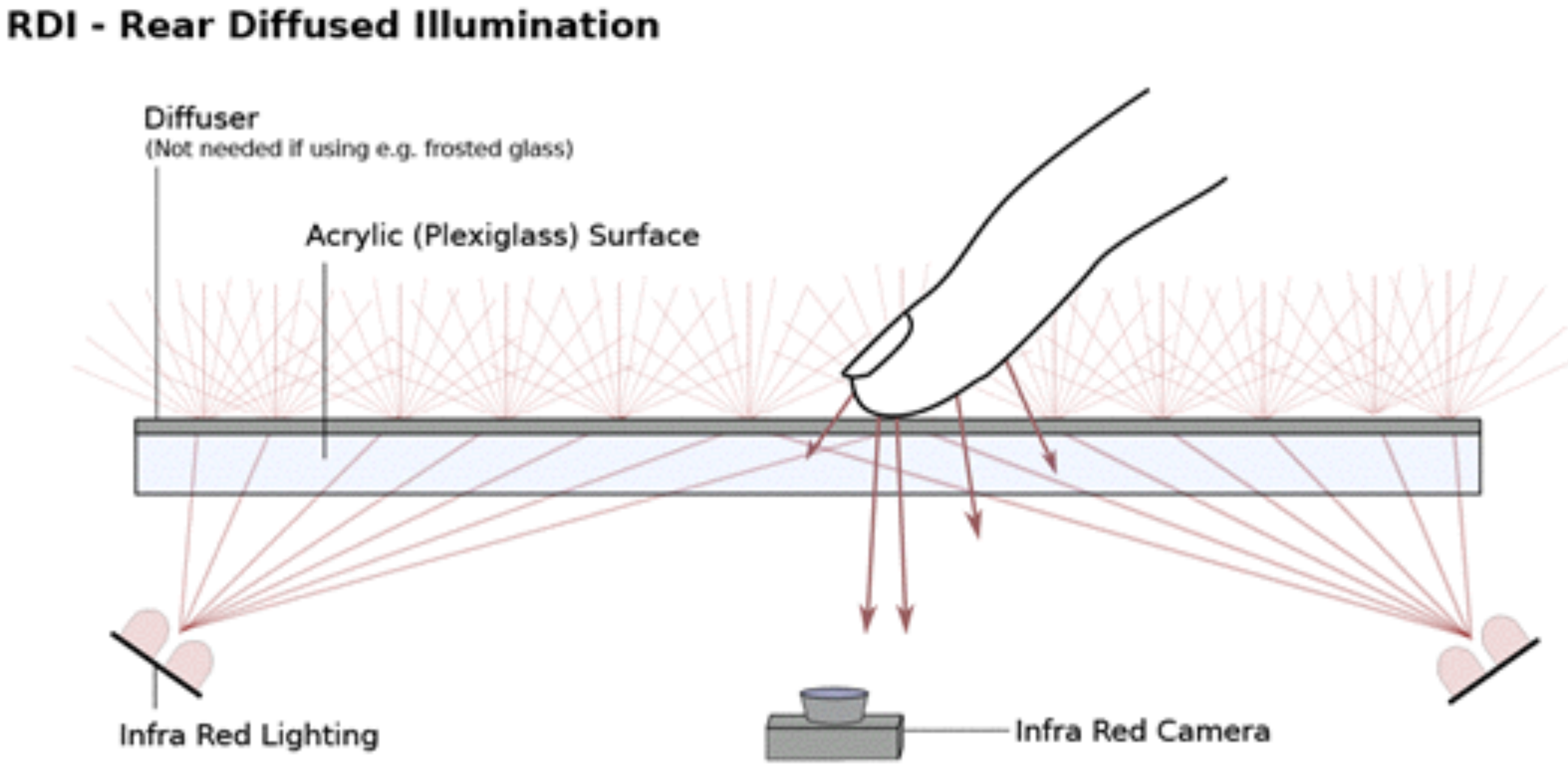
camera based #2:

rear diffused illumination (rear DI)



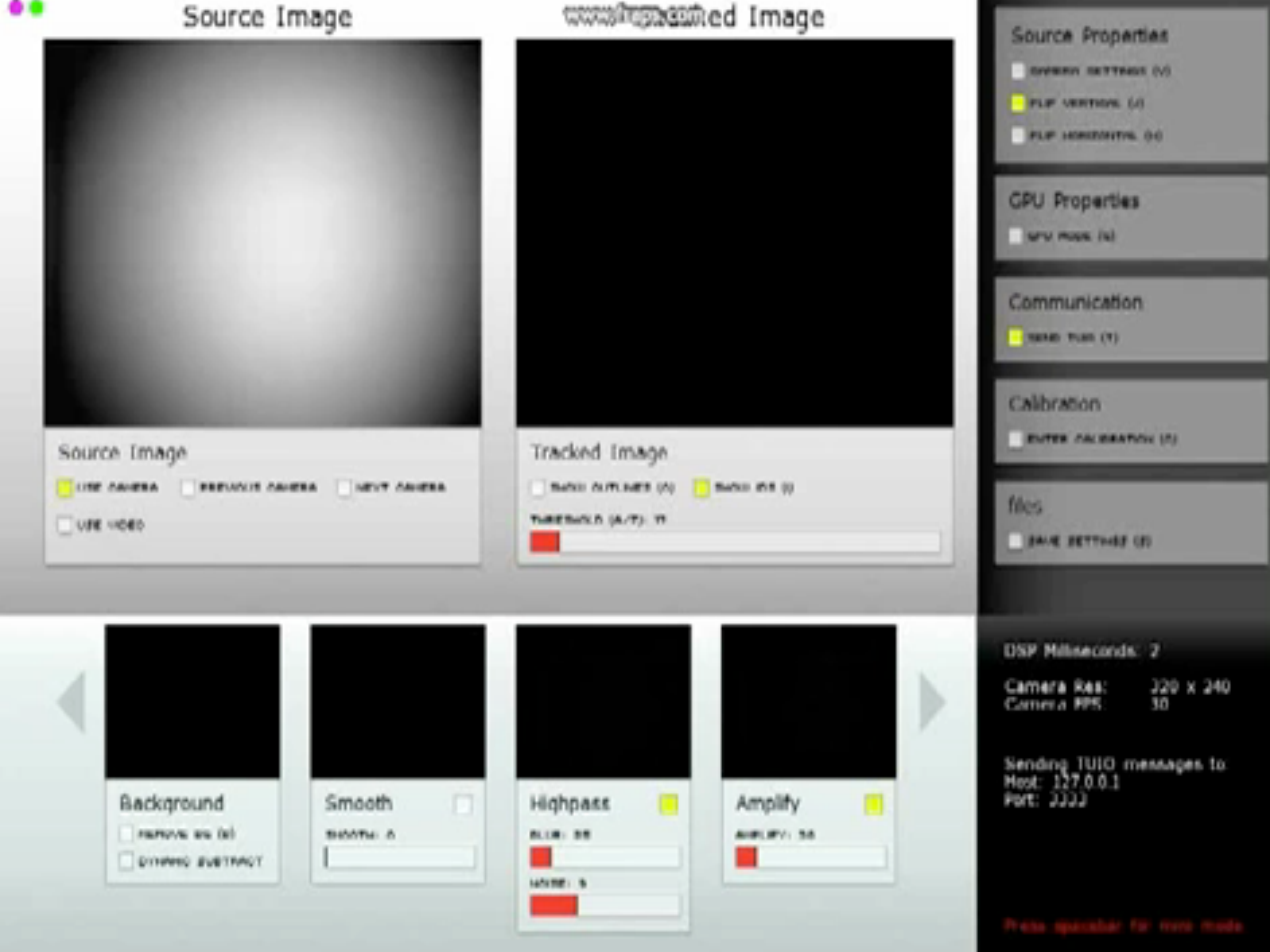
how does it work?
how does the camera image look like?
white or black spots?

<30 second brainstorming>

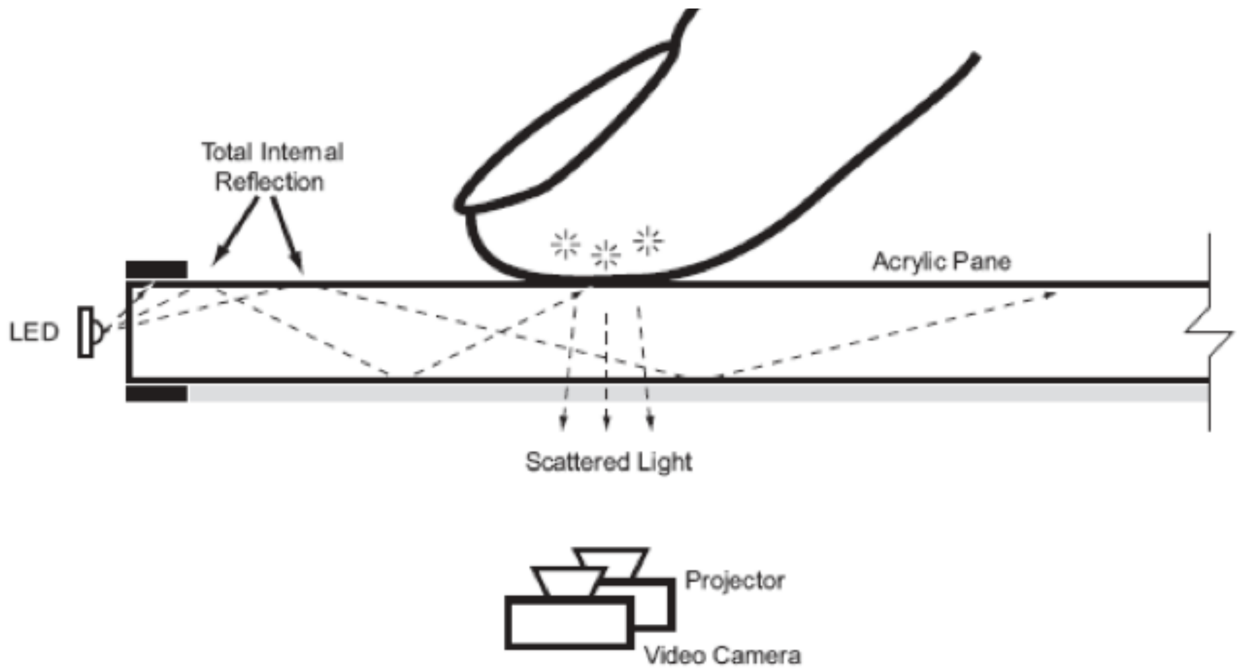


rear diffused illumination (rear DI)::

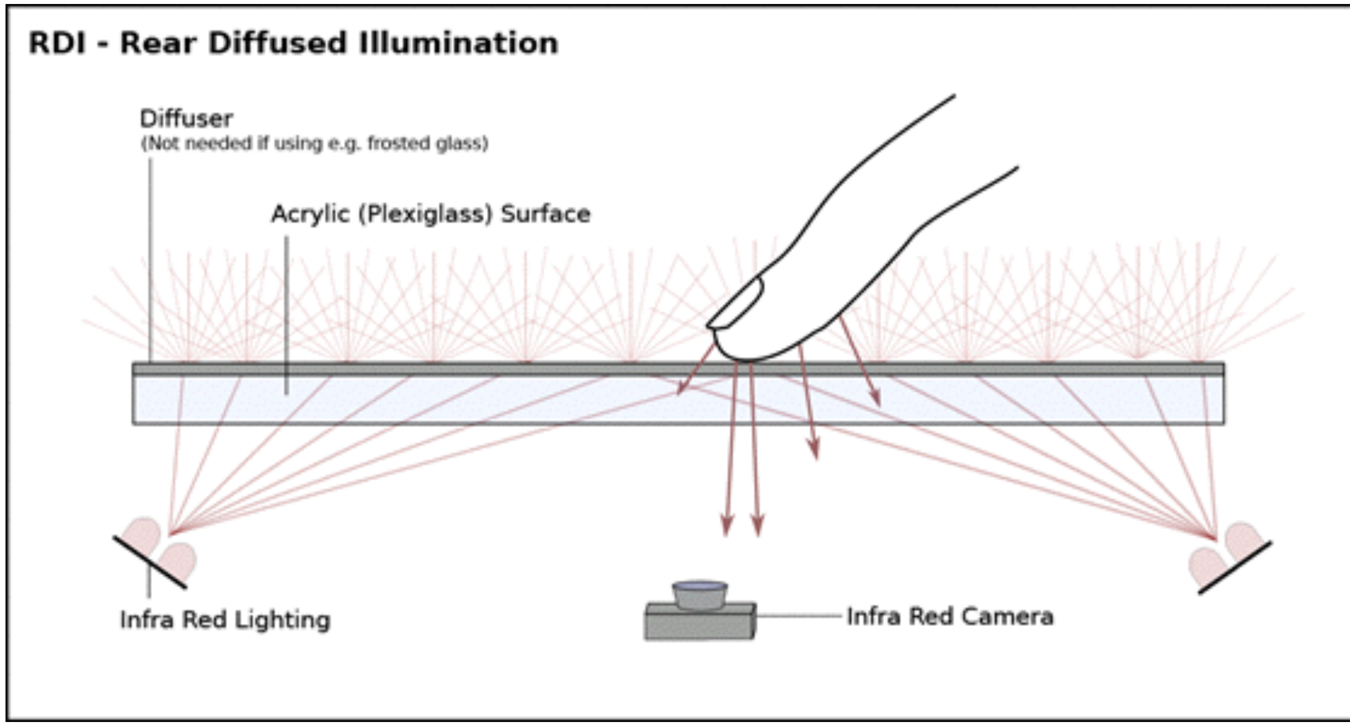
- **light shined from below** the touch surface
- when the light hits a finger, light is **reflected downwards**
- appears as **bright blob** in the camera image


Source Image
Source Properties
GPU Properties
Communication
Calibration
files
Source Image
Tracked Image
Background
Smooth
Highpass
Amplify
DSP Milliseconds: 2
Camera Res: 320 x 240
Camera FPS 30
Sending TUIO messages to
Host: 127.0.0.1
Port:

FTIR



rear-DI

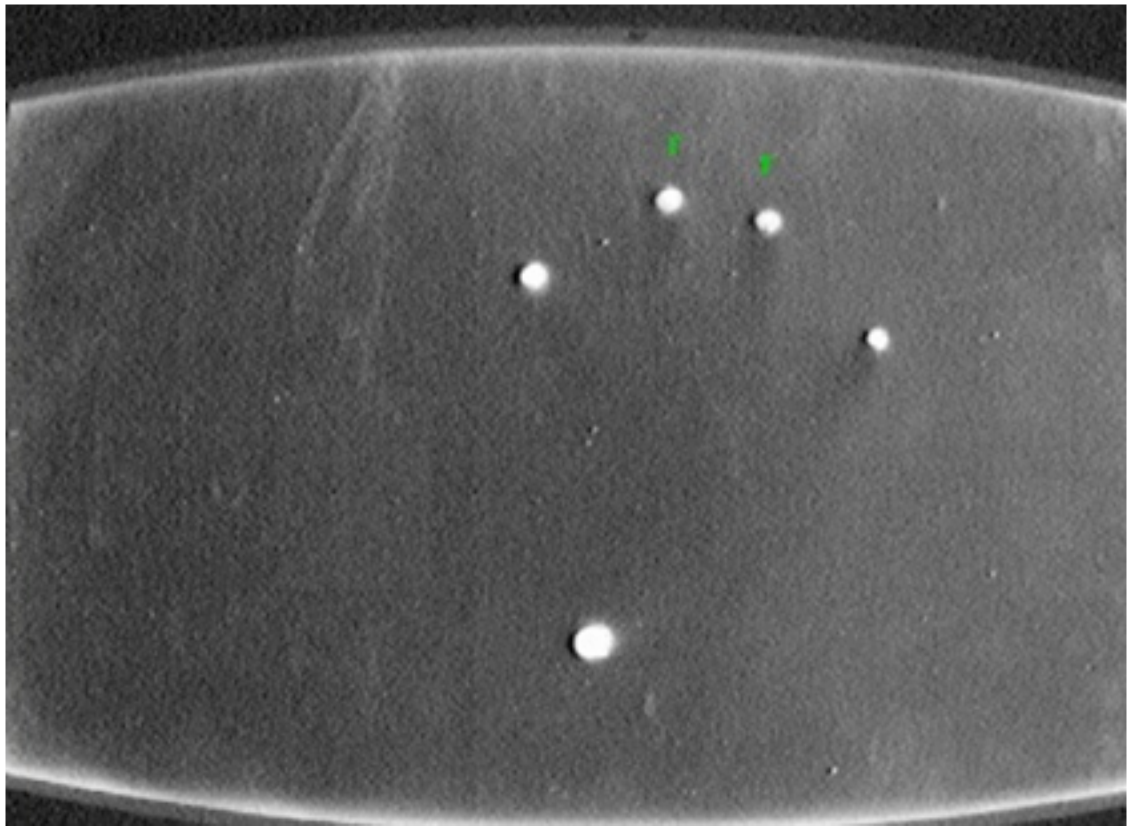


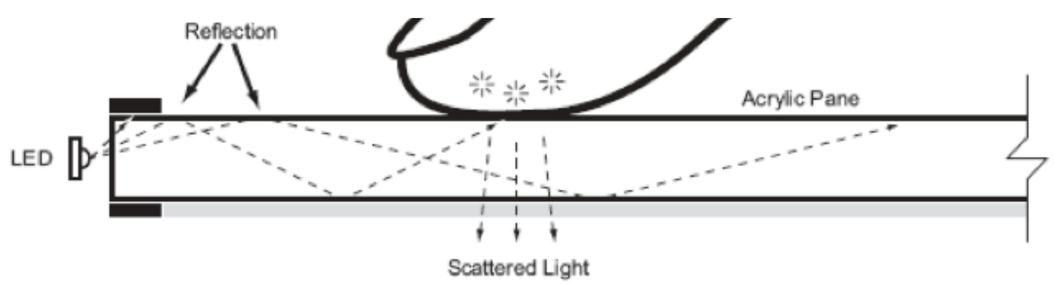
mh, so both show bright finger blobs…
the result is the same as with FTIR… right?

what can **rear diffuse illumination detect** that FTIR cannot?

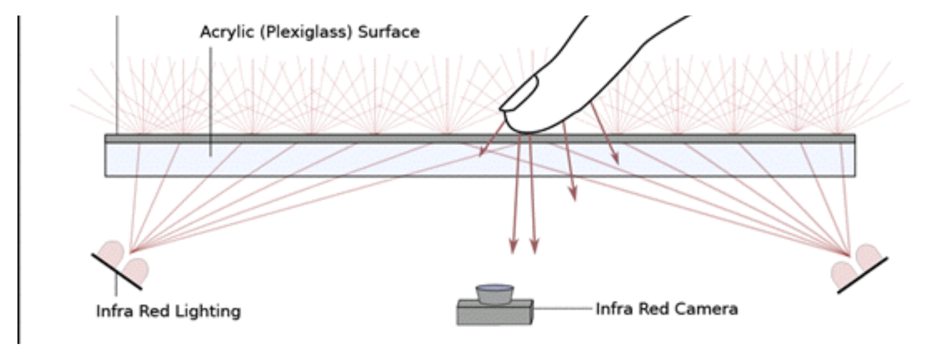
<30 second brainstorming>

FTIR vs. rear-DI





detects only objects
in **direct contact** with surface
(light bounces inside sheet)

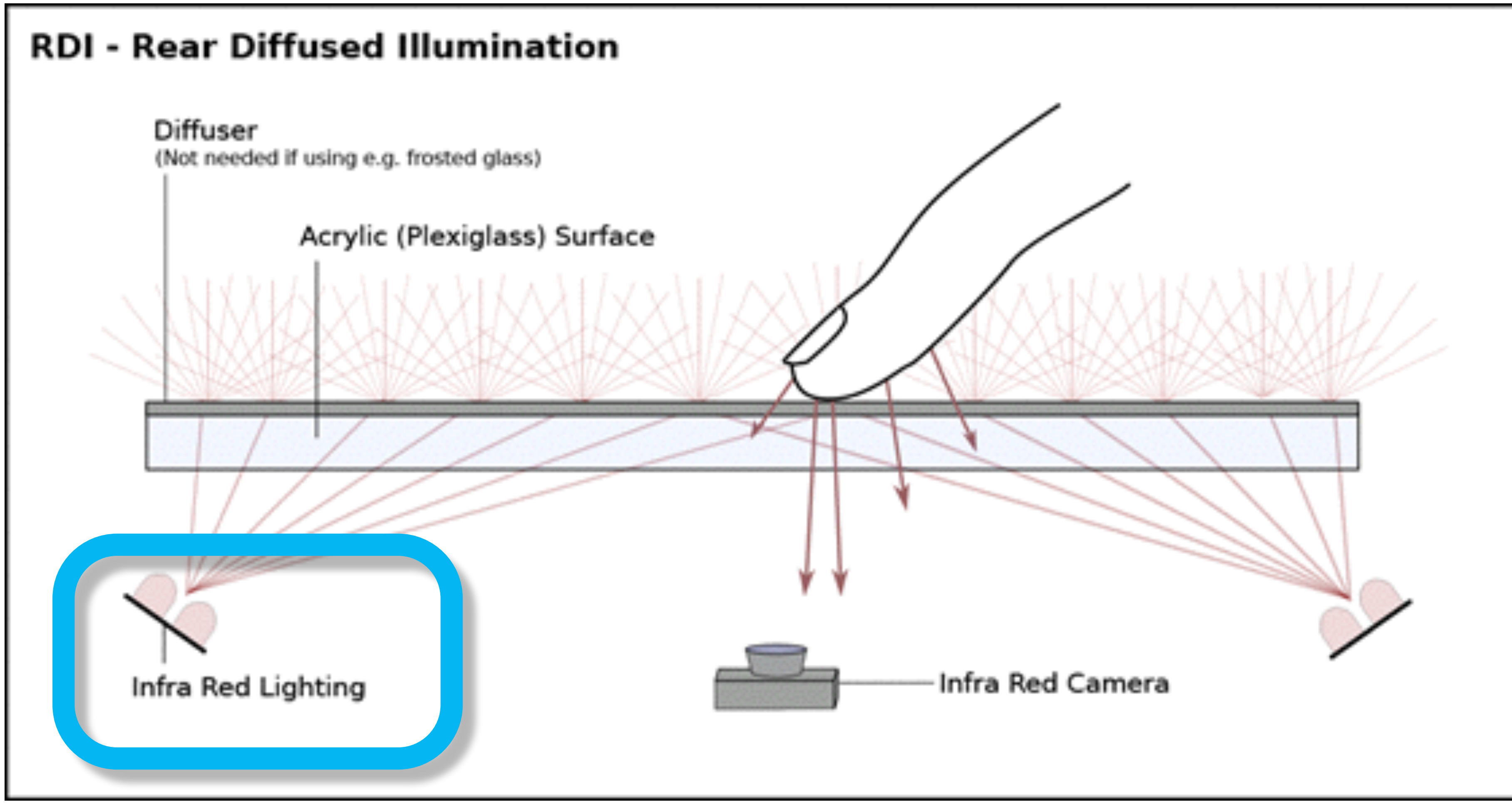


can detect objects
hovering over the surface
(light reaches above sheet)

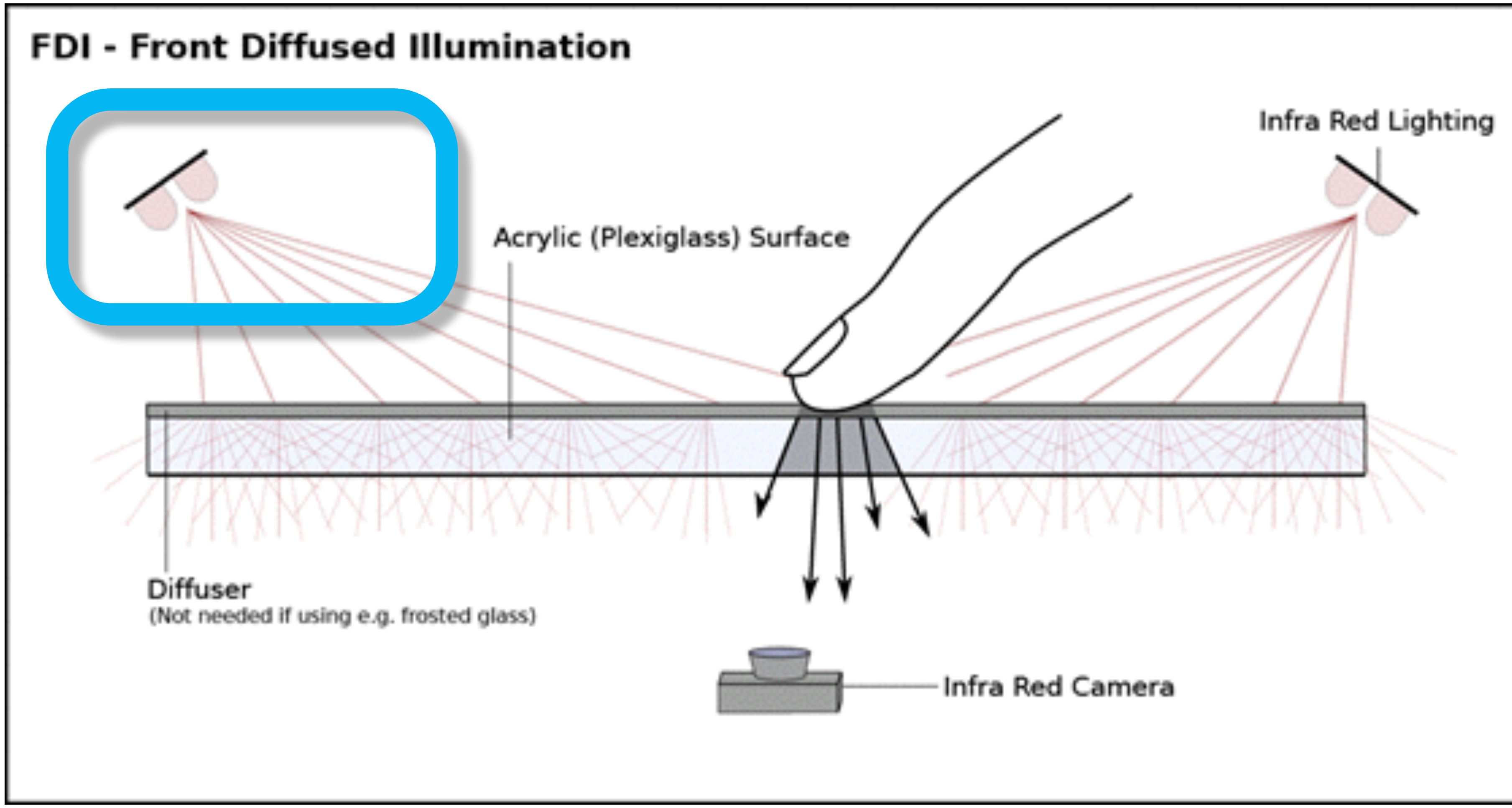
camera based #3:

front diffused illumination (front DI)

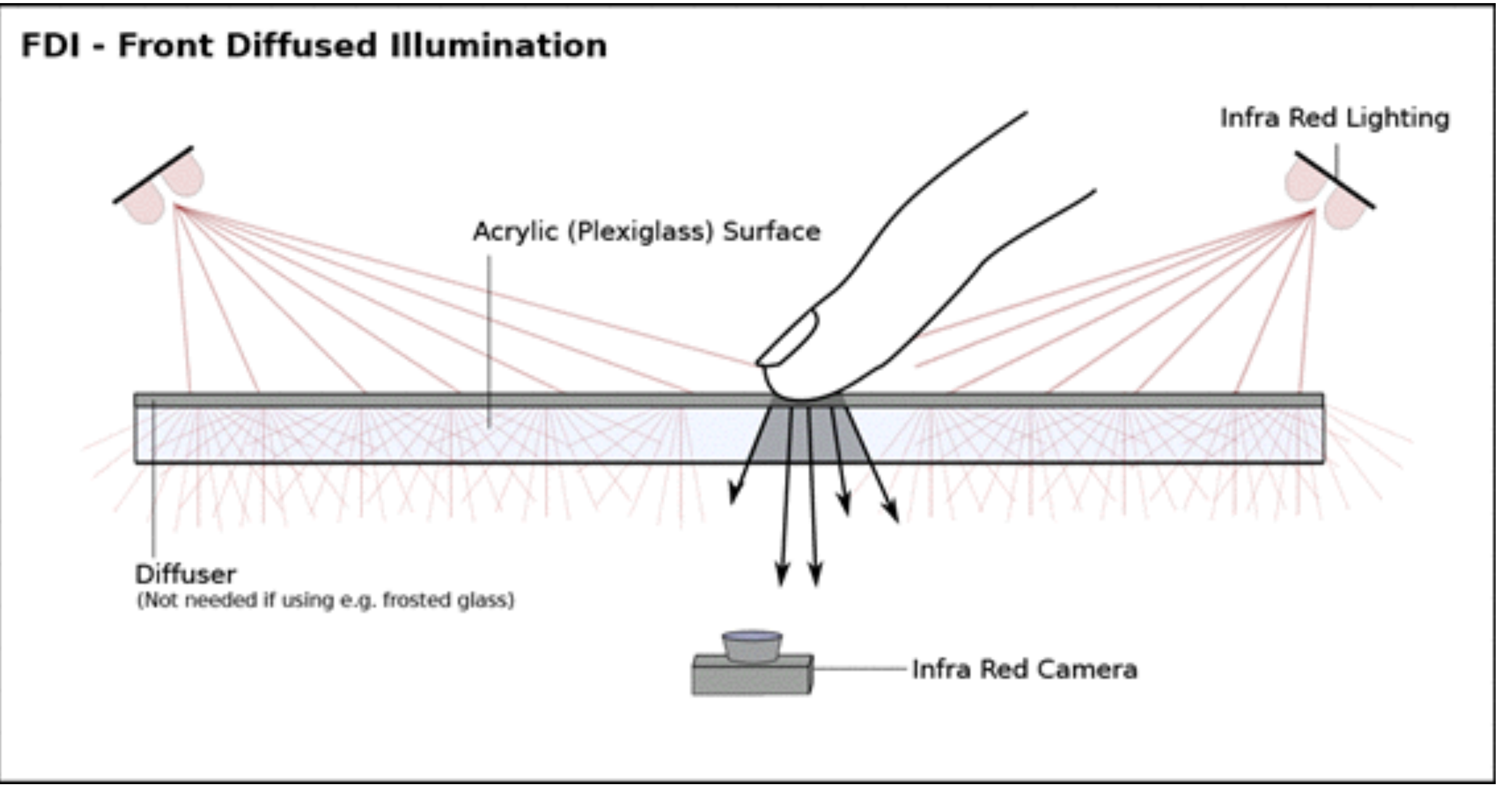
rear DI
light from below



front DI
light from above



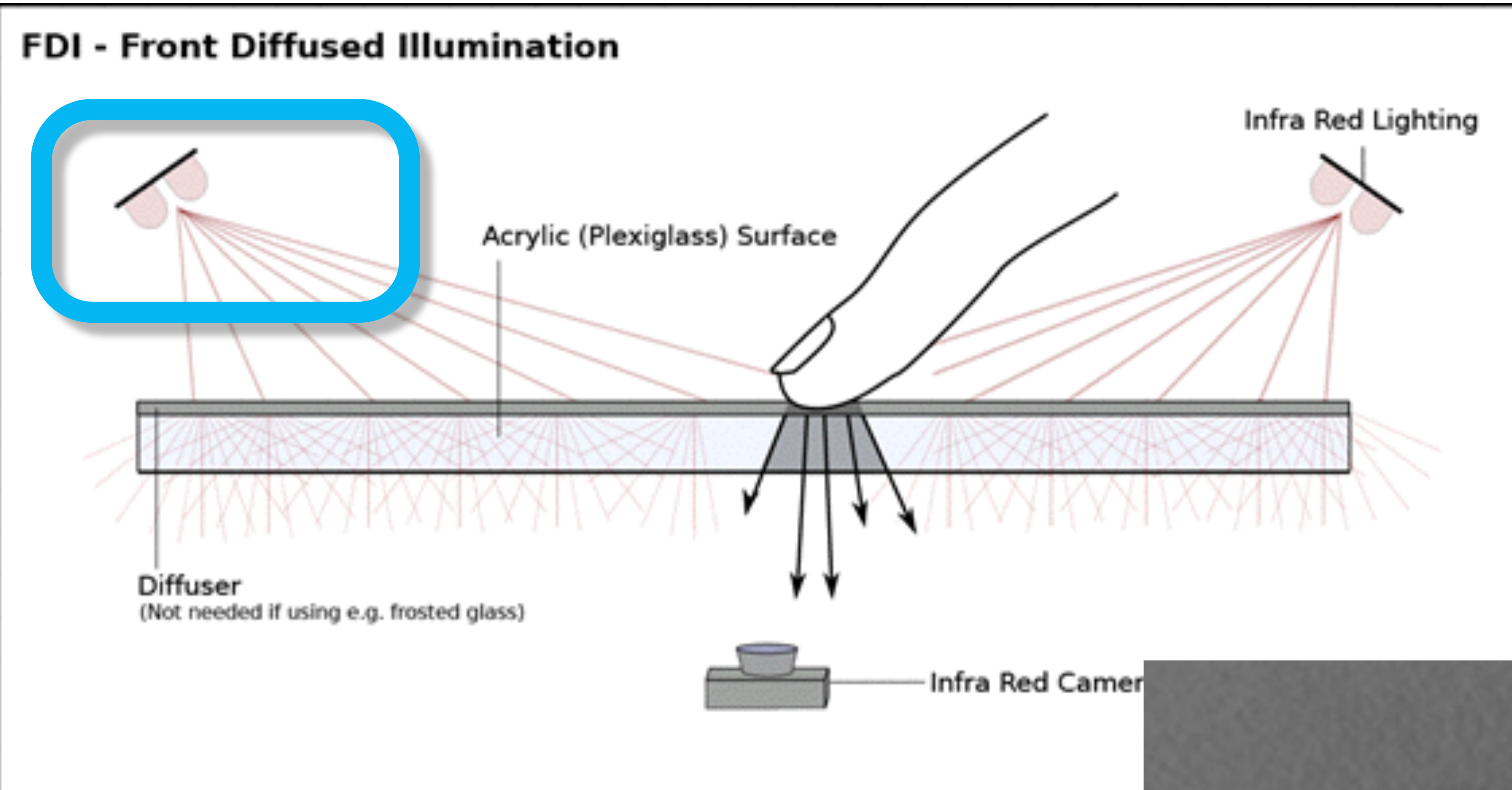
front DI

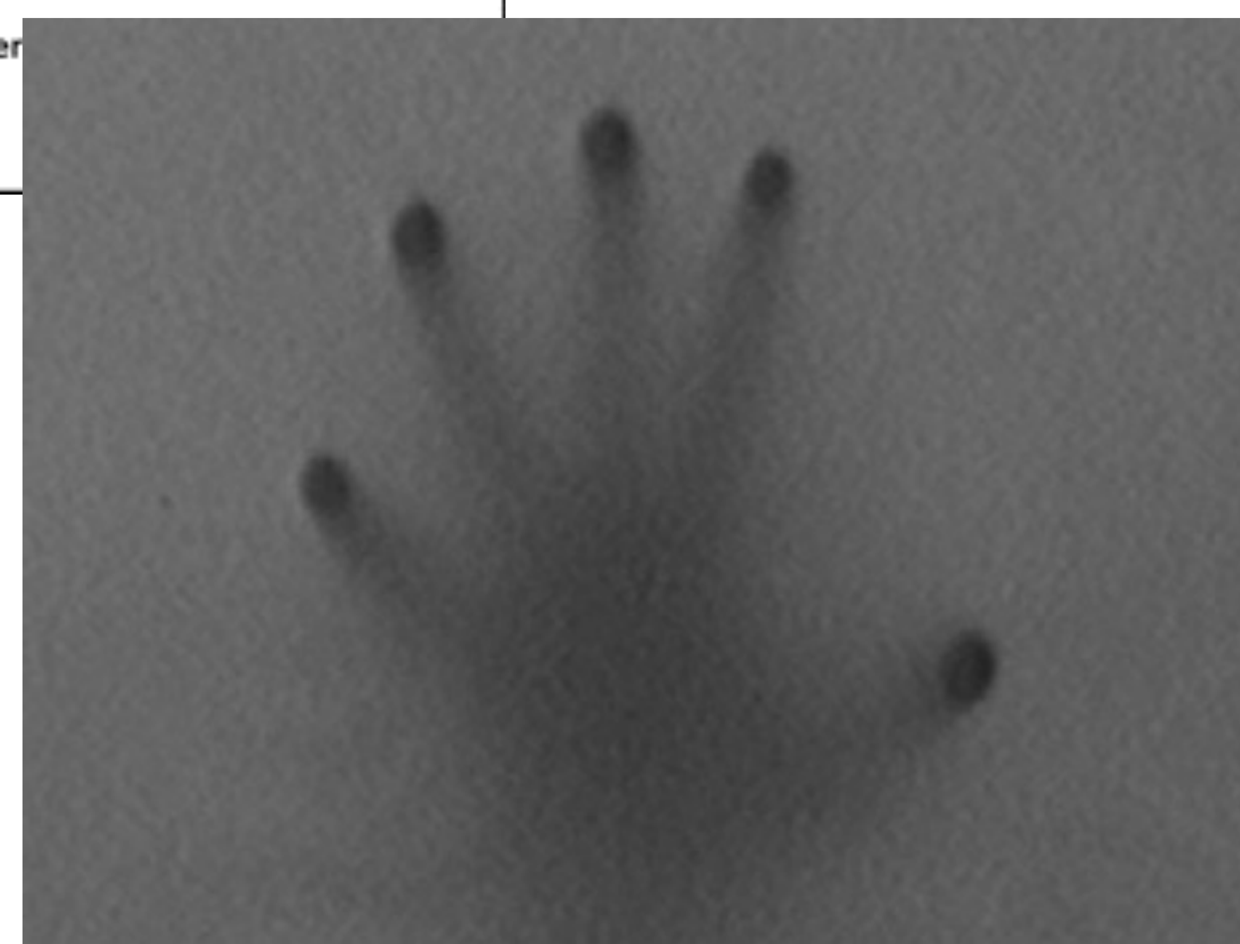


how do we expect the camera image to look like?

<raise hand>

front DI





finger **blocks** the light from the camera

= fingers are black

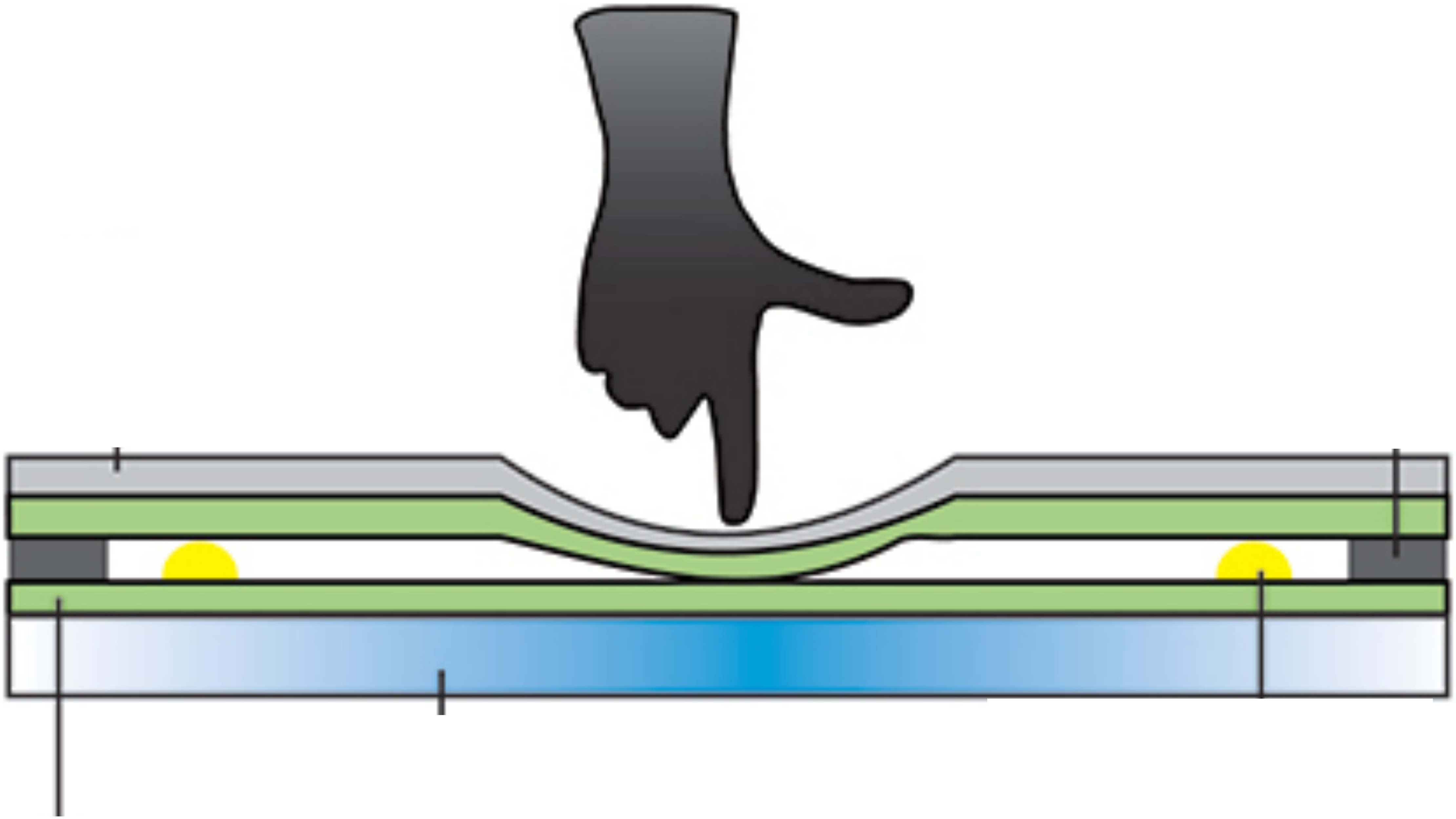
front diffused illumination (front DI)::

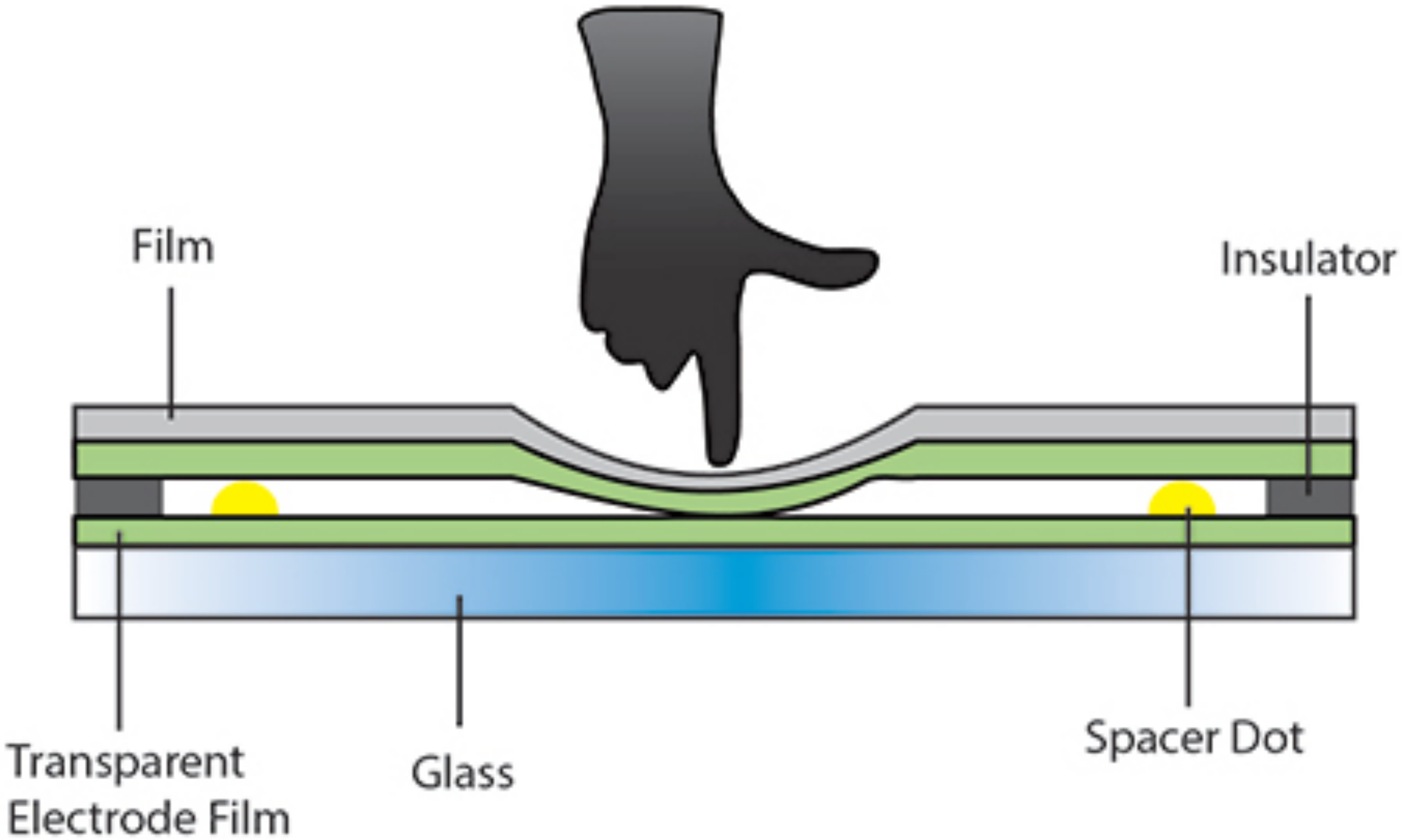
- light shined from **above** the touch surface
- when a finger touches, a **shadow** is created
- appears as **black blob** in the camera image

electric-based #1:

resistive touch panels (RTP)

Resistive Touch Panel

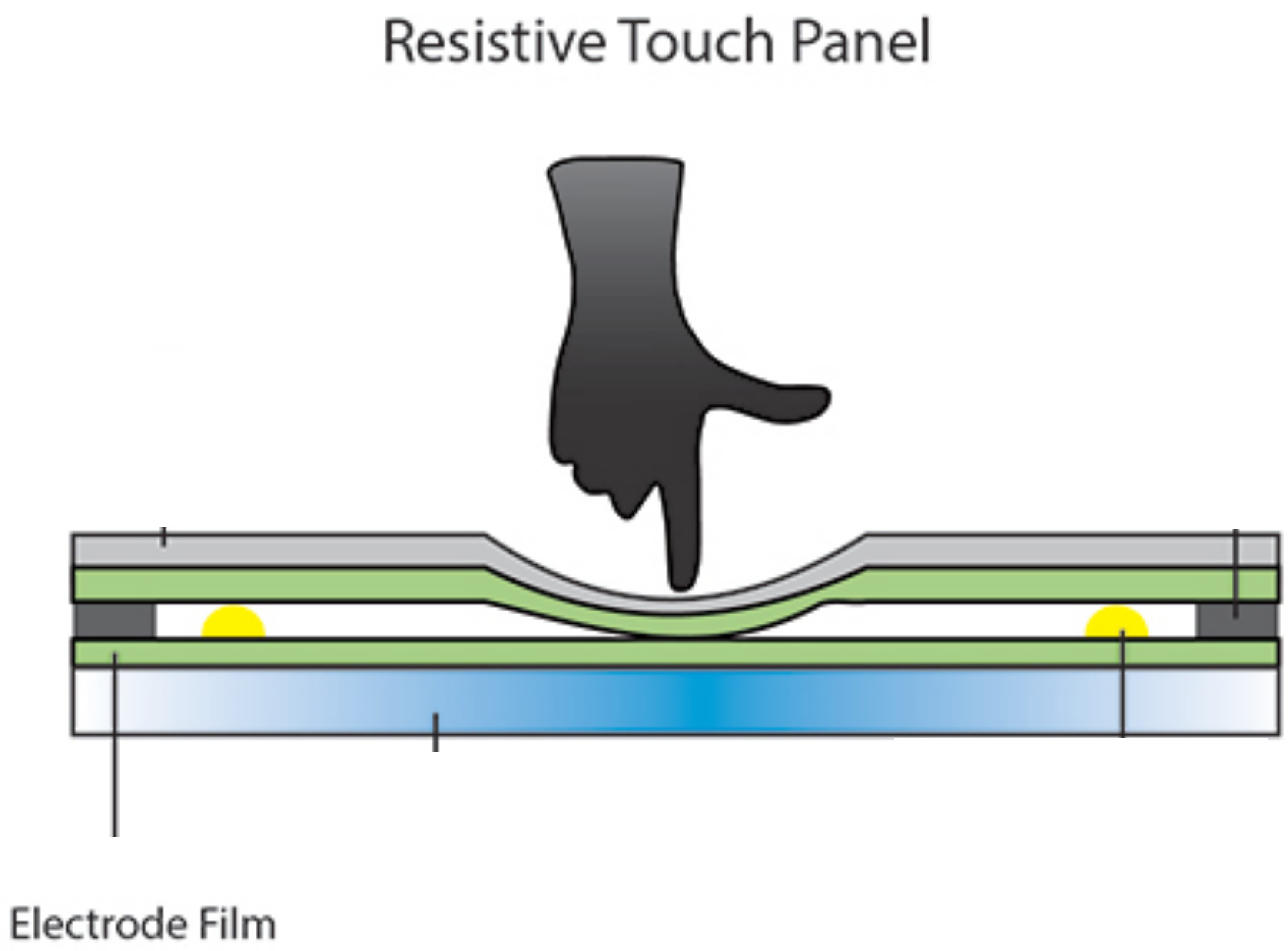




resistive touch panels (RTP):

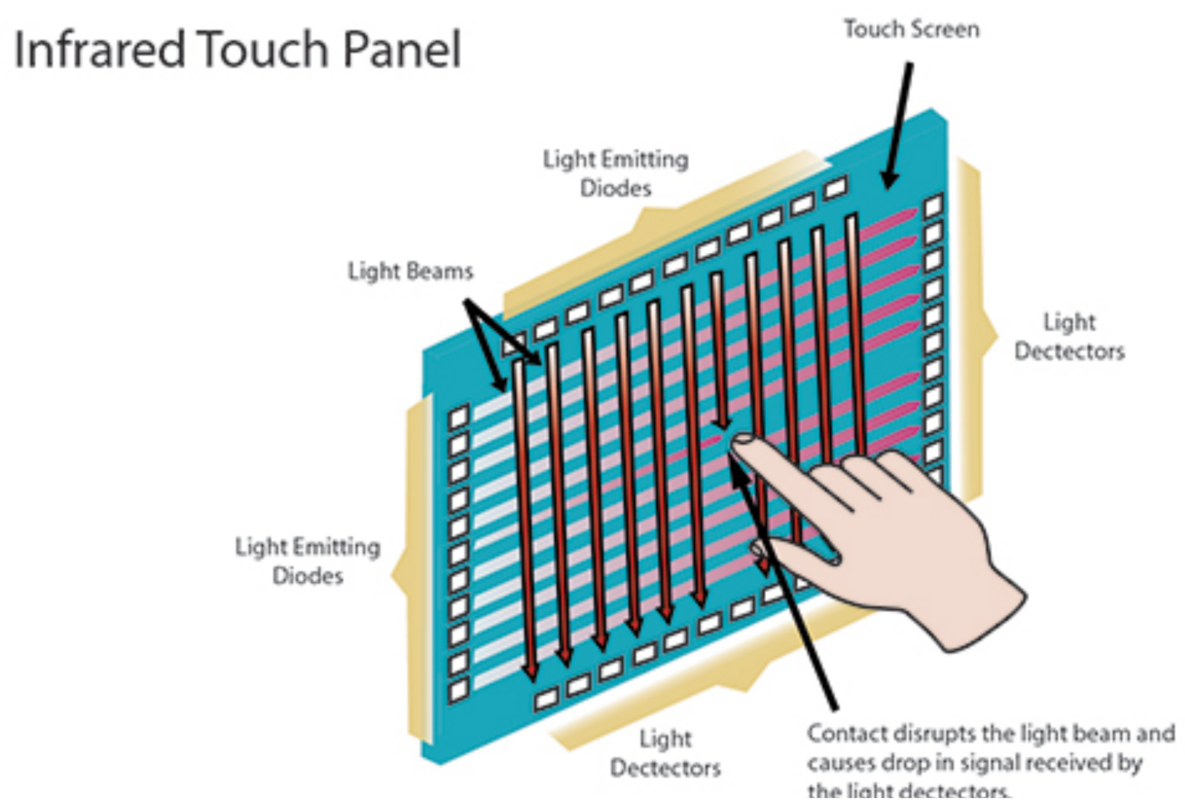
- the **top and bottom** sheet are **conductive**
- they have a **gap in-between,** no electricity flowing
- when the top sheet gets pressed by a finger, the pressed point **makes contact** with the bottom sheet
- **electricity now get conducted** at the contact point

this is why in airplanes
you have to **push so hard…**



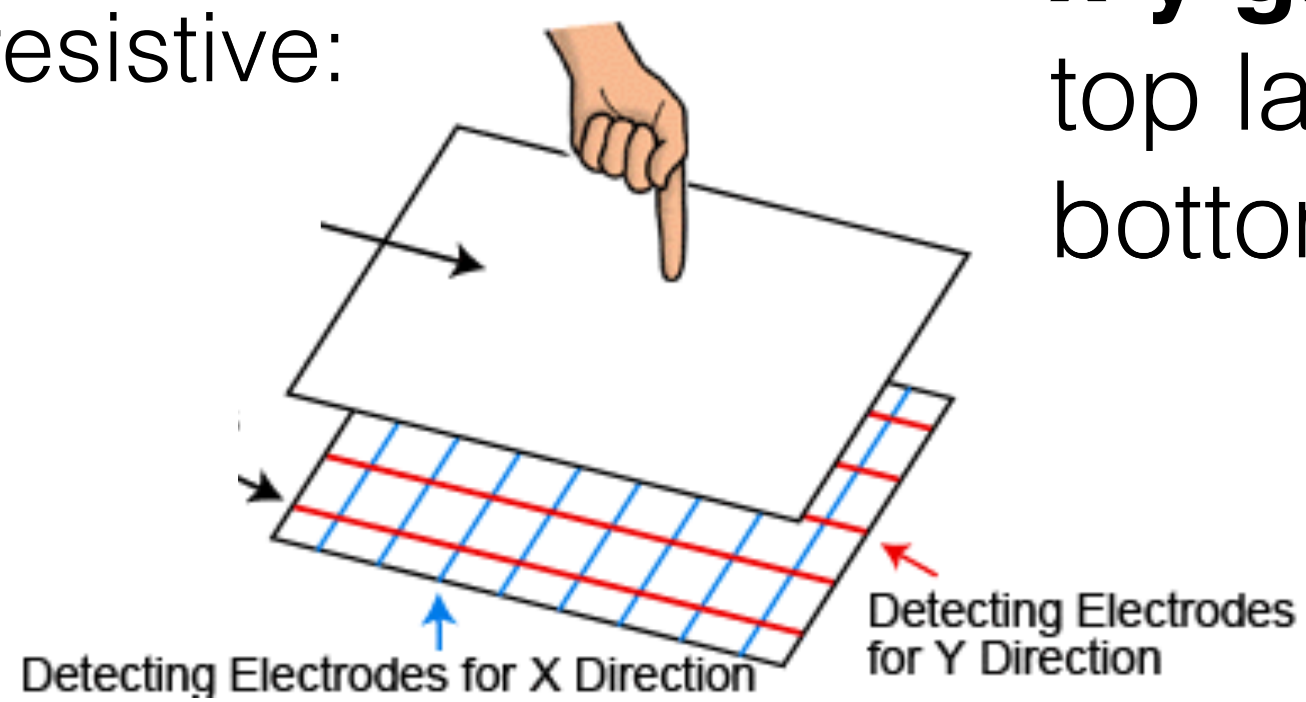
how do we know
where the user touches the screen?

<30 second brainstorming>



same principles
as infrared touch panel

resistive:



x-y grid

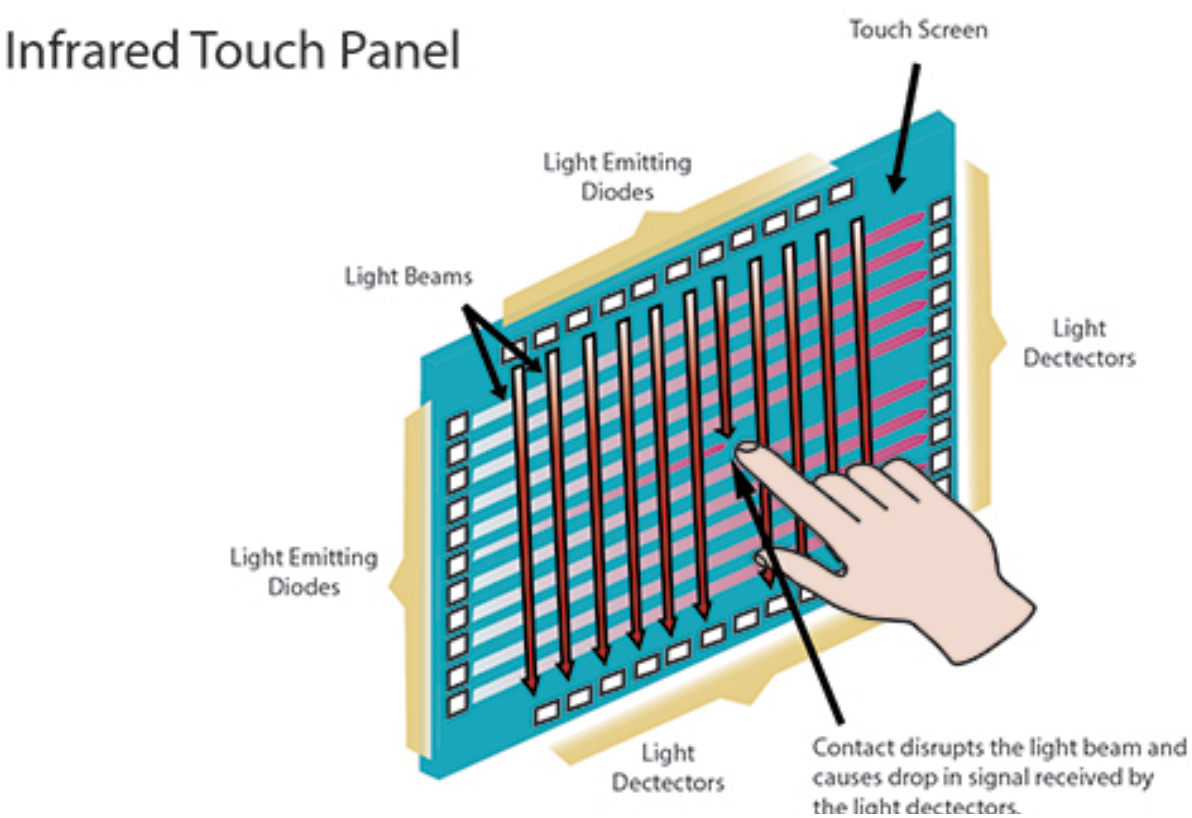
top layer: all horizontal lines (x)

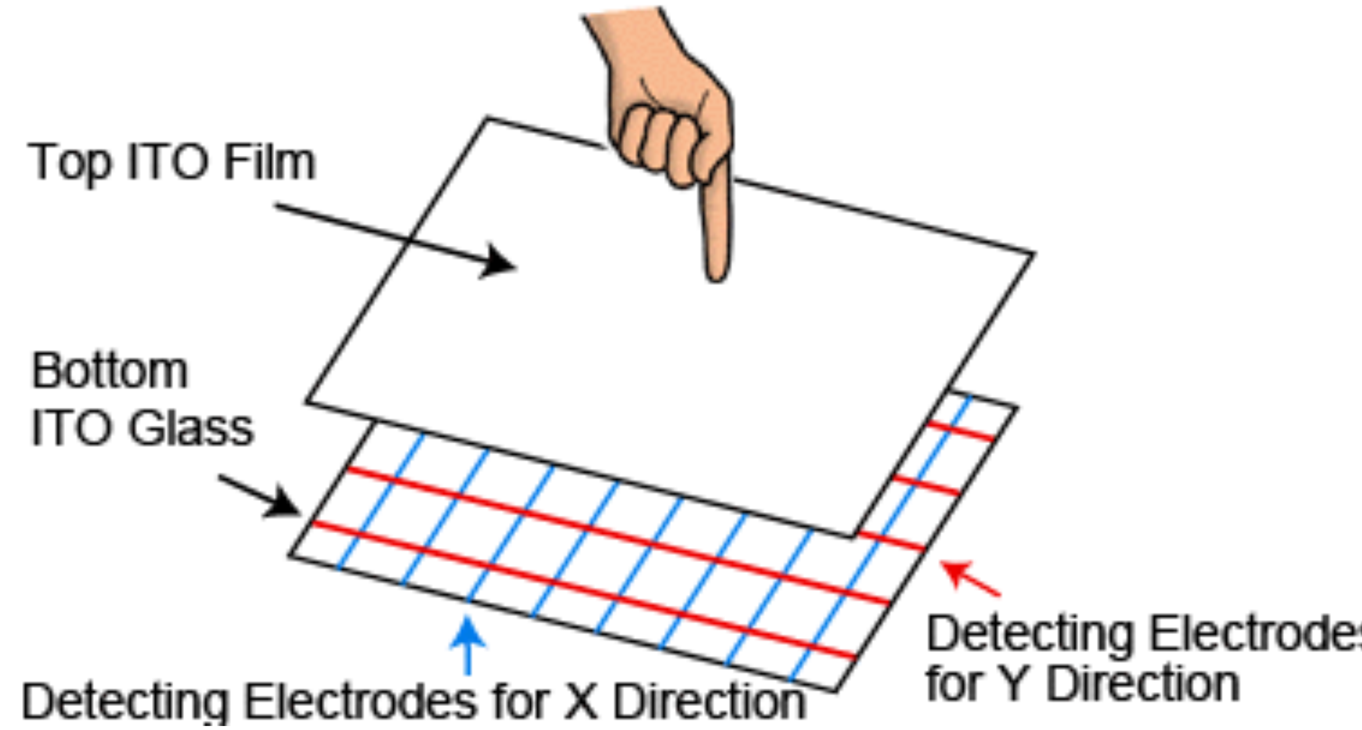
bottom layer: all vertical lines (y)

when contact is made

only these two line

conduct electricity (x,y)

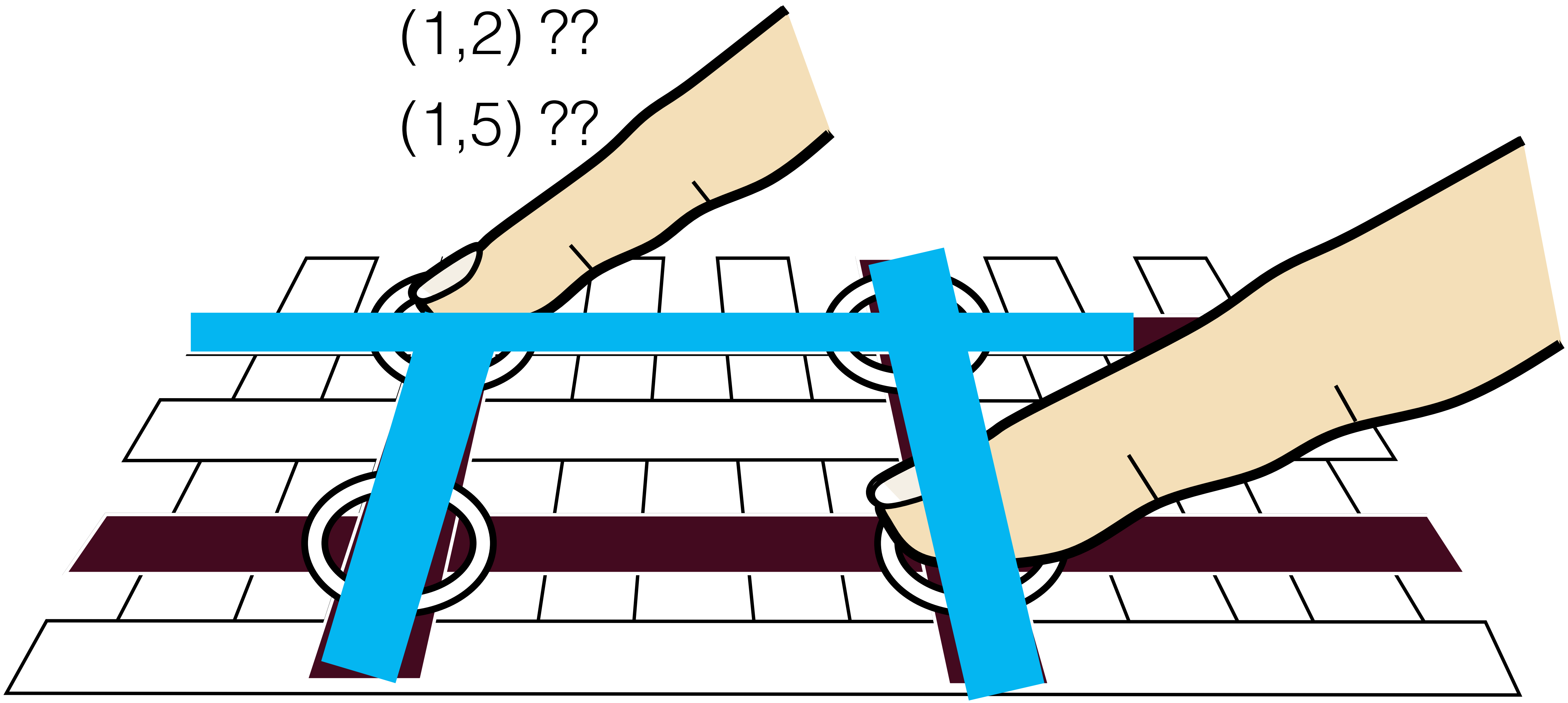




in multi-touch (more than 1 finger),
there are situations in which this approach
cannot correctly detect a finger's position.

how do you have to place **two fingers** to make it fail?

<30 second brainstorming>



these two finger positions lead to **ghosting!**

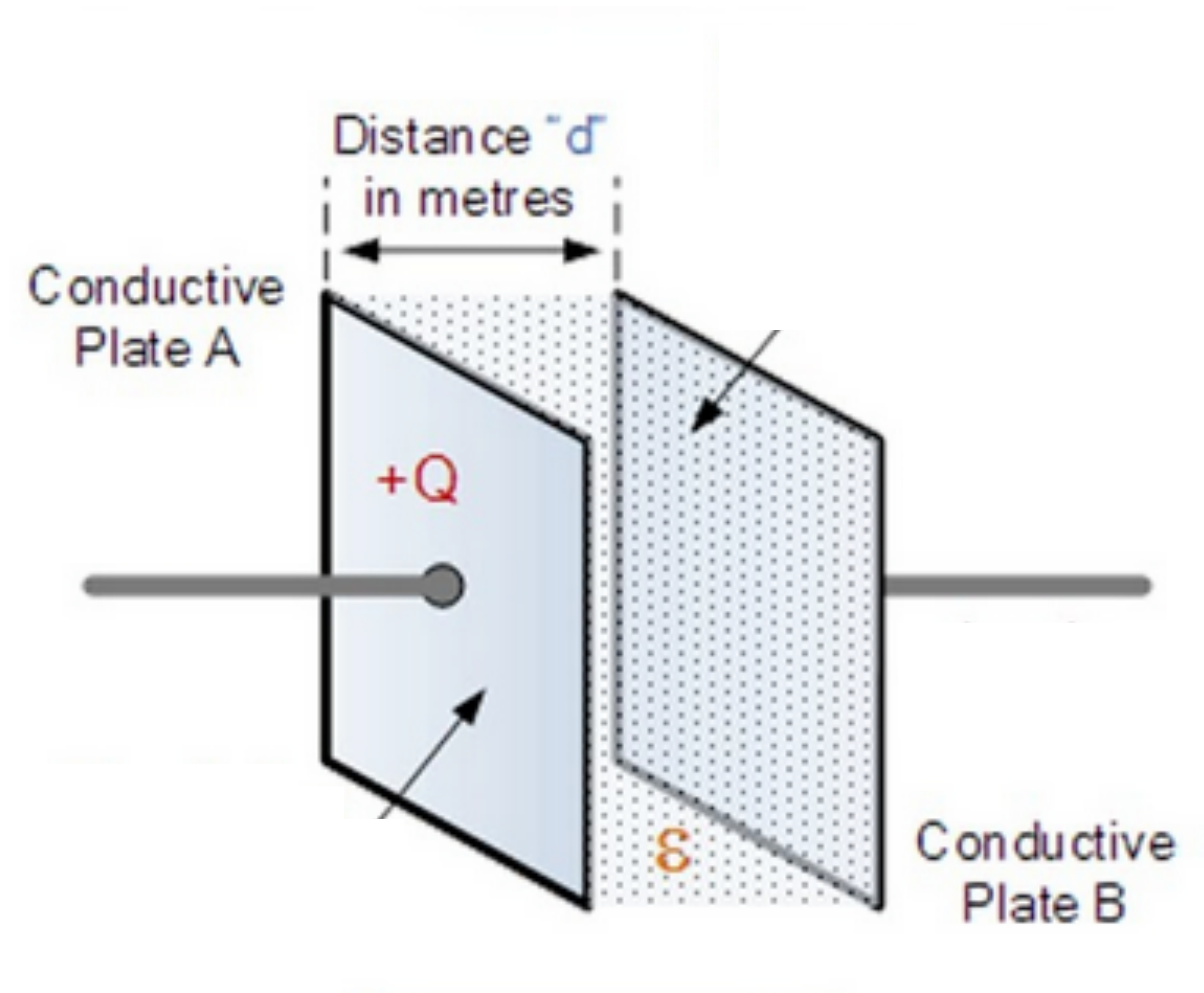
(camera-based setups don’t have this problem) electric-based #2:

capacitive touch screens

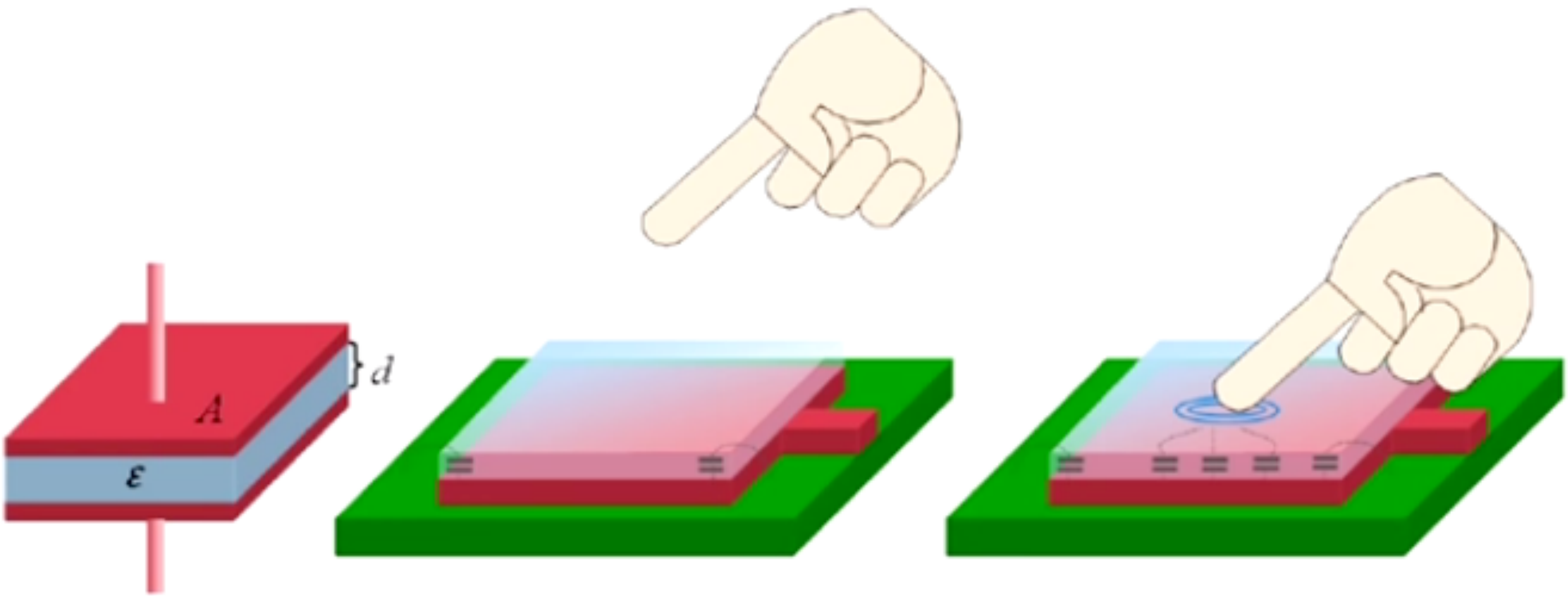
most commonly used today

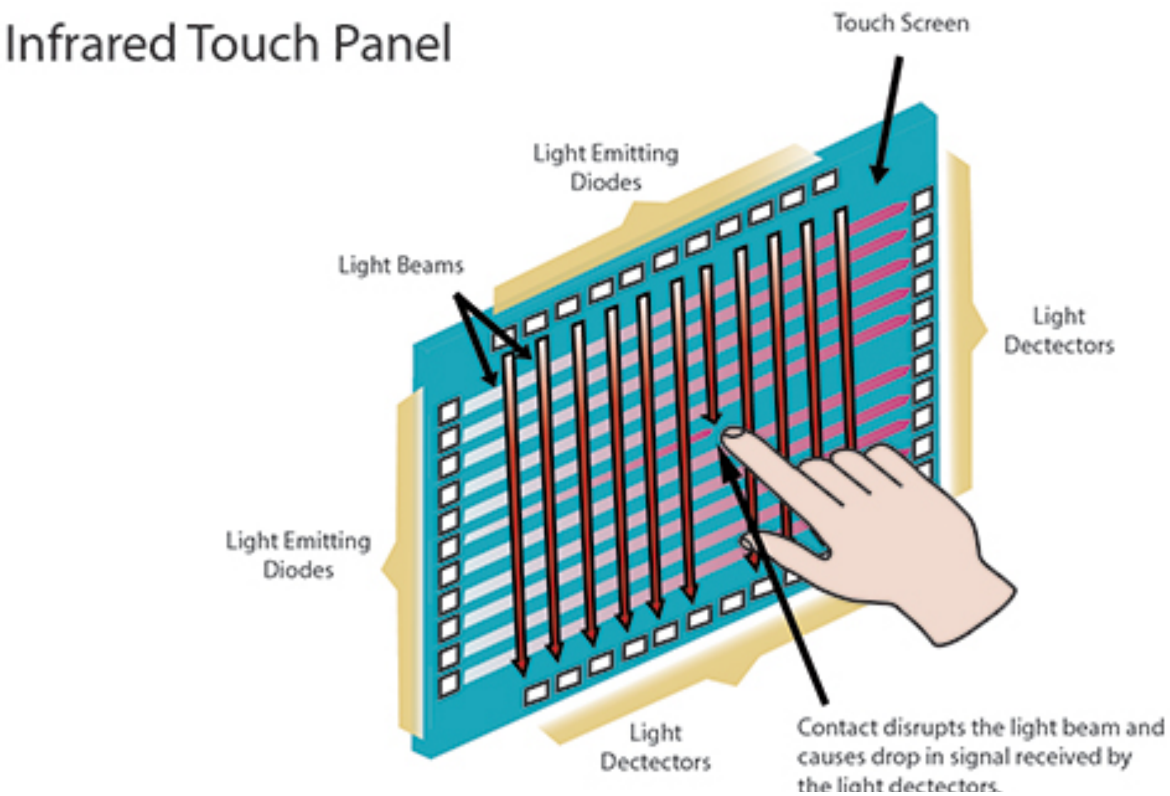
capacitance C = f(A/d)

function of area of electrodes
/ distance between electrodes)

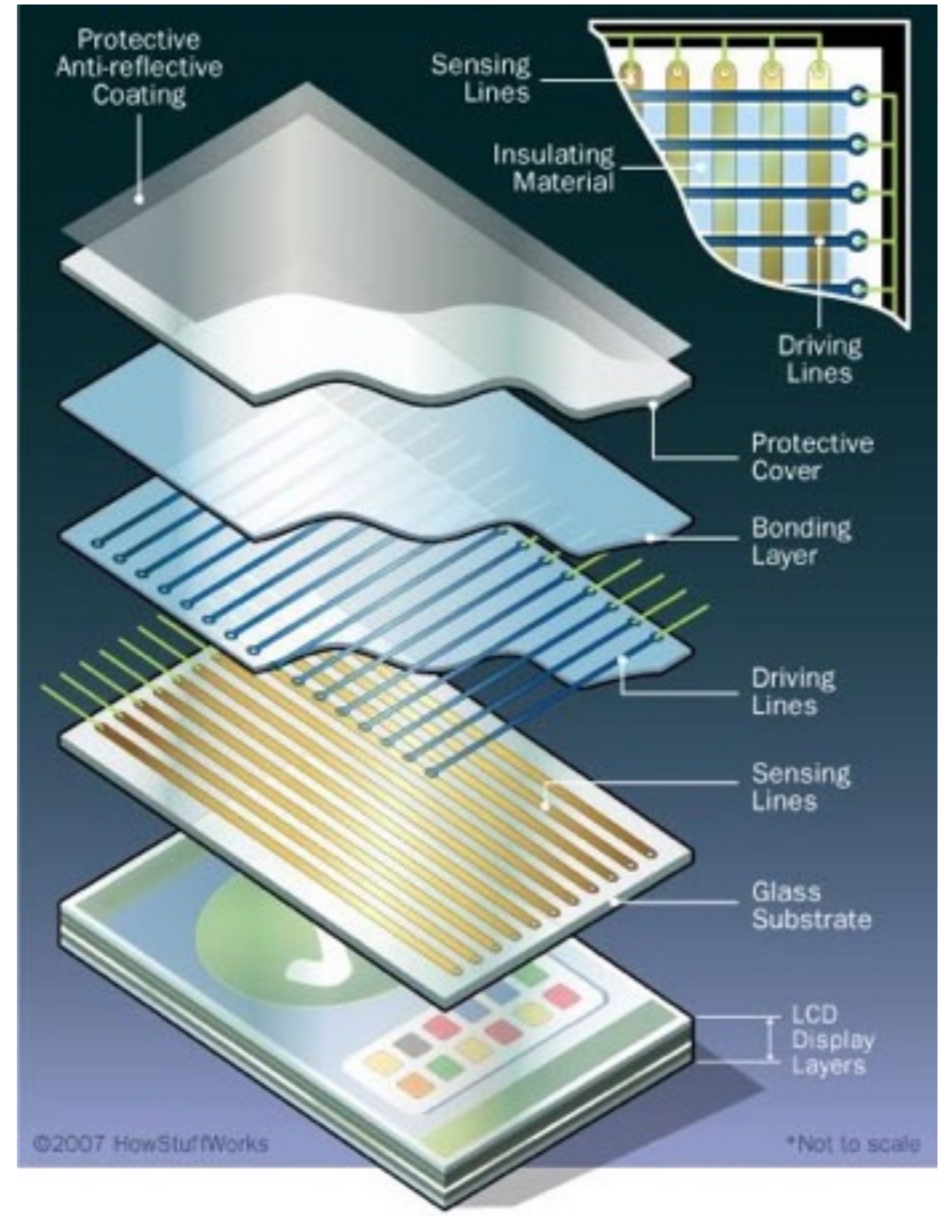


finger acts as the **second electrode!**
touching finger changes capacitance.

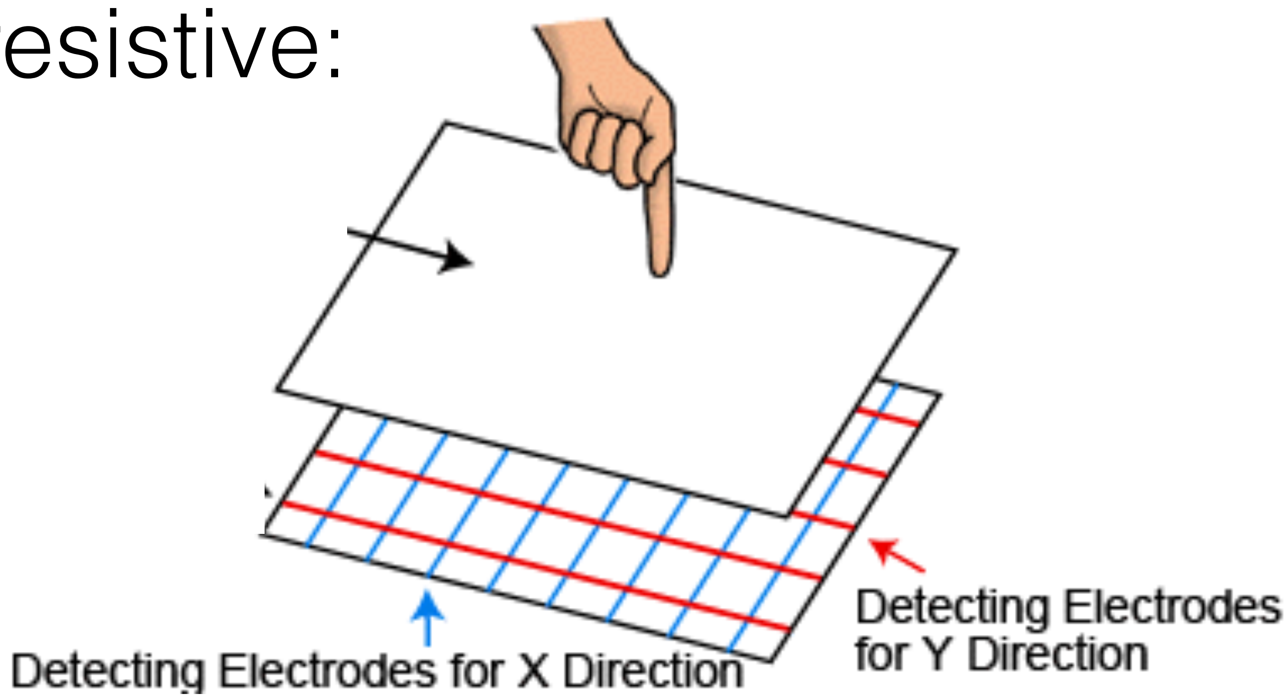




capacitive:



resistive:



again
same principle

projected capacitance (PCAP)

- 2 parallel conductive layers with grid lines
- **continues scanning** of x/y grid lines **(‘always on’)**
- grid lines create **electro static field**
- when finger touches, the **change in the electrodes** can be detected

this is what your iphone uses…

2007: ‘we invented a new technology’

DiamondTouch: A Multi-User Touch Technology

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ABSTRACT
A technique for creating a touch-sensitive input device is proposed which allows multiple, simultaneous users to interact in an intuitive fashion. Touch location information is determined independently for each user, allowing each touch on a common surface to be associated with a particular user. The surface generates location dependent, modulated electric fields which are capacitively coupled through the users to receivers installed in the work environment. We describe the design of these systems and their applications. Finally, we present results we have obtained with a small prototype device.

KEYWORDS: DiamondTouch, multi-user, touch, collaborative input, single display groupware

INTRODUCTION
DiamondTouch is a multi-user touch technology for tabletop front-projected displays. It enables several different people to use the same touch-surface simultaneously without interfering with each other, or being affected by foreign objects. It also allows the computer to identify which person is touch-

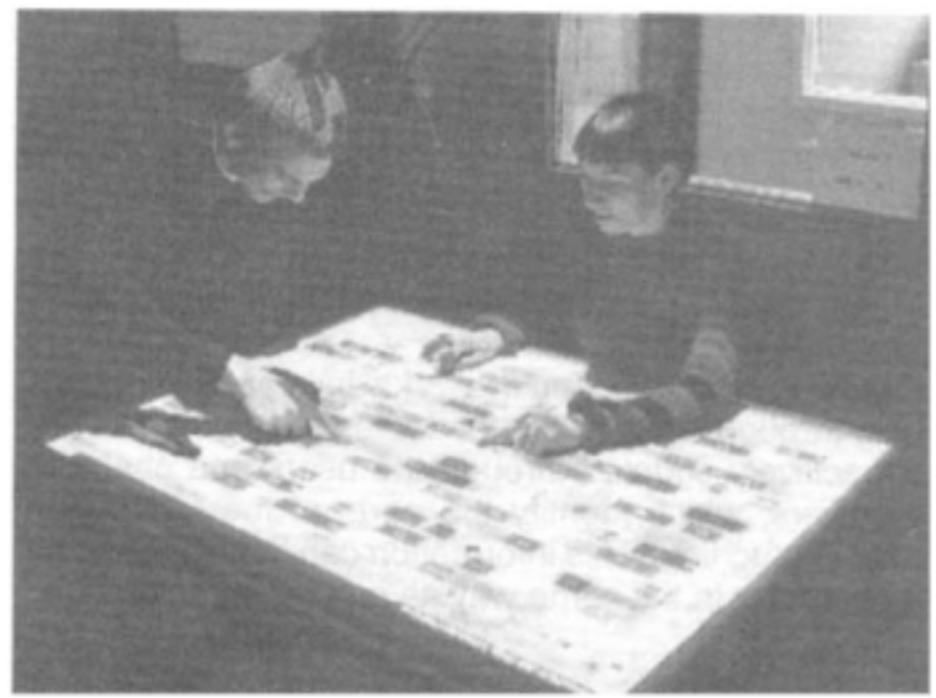
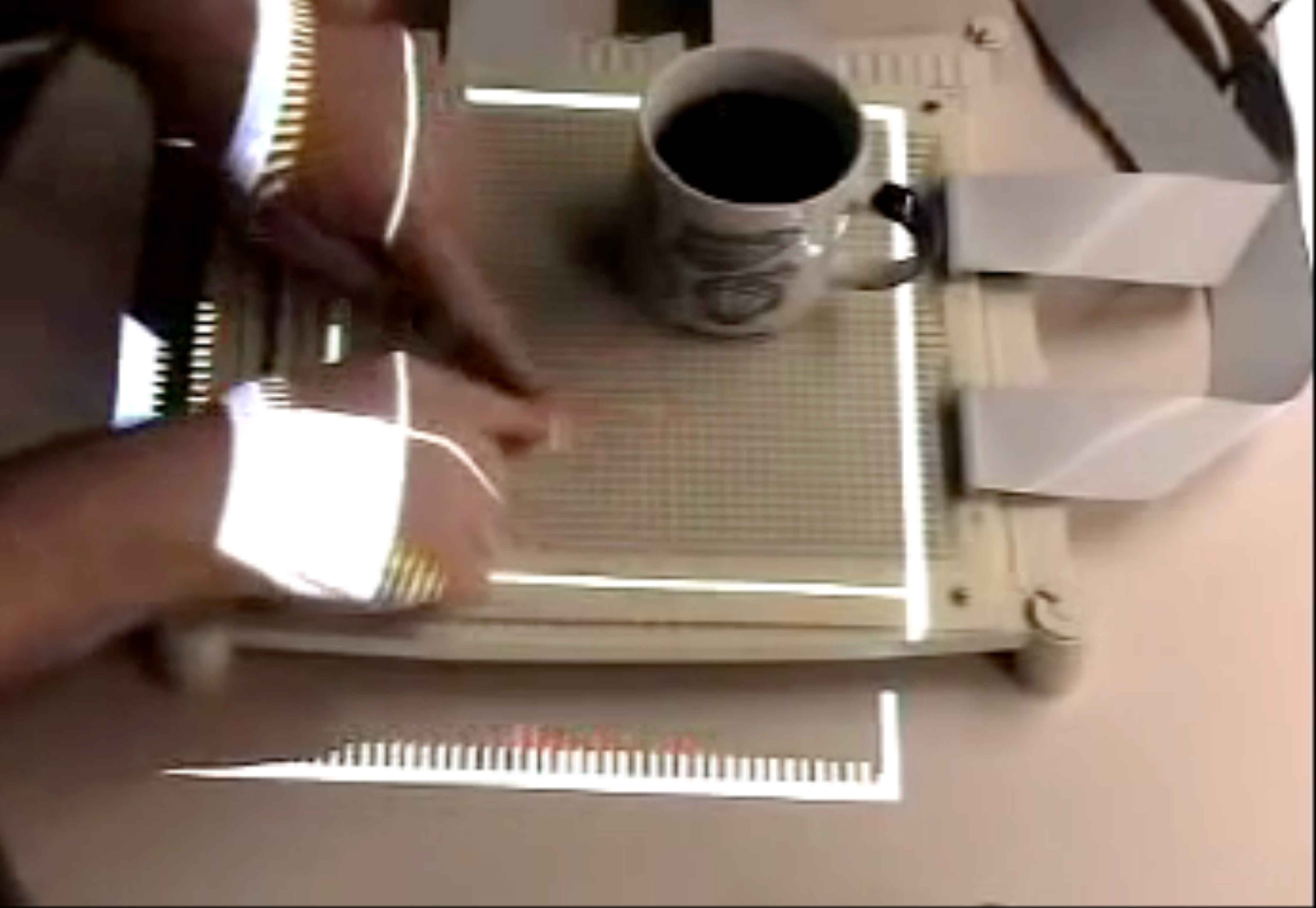


Figure 1: The collaborative work environment for Human-Guided Simple Search.

ity. Keeping track of many mice is nearly impossible. This leaves users physically pointing at their virtual pointers to

UIST 2001

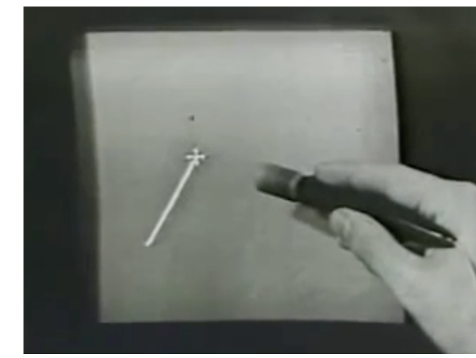


UIST 2001 Diamond Touch — super robust!

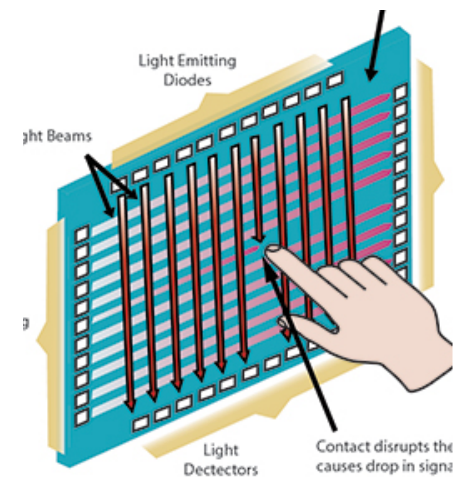
let’s zoom out

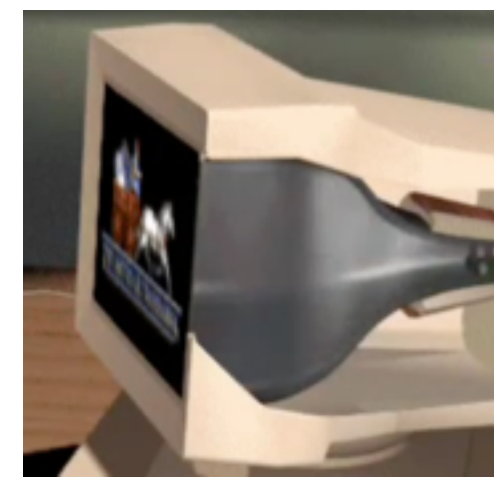
6.810 Engineering Interactive Technology

- learn about **history** of interactive technologies

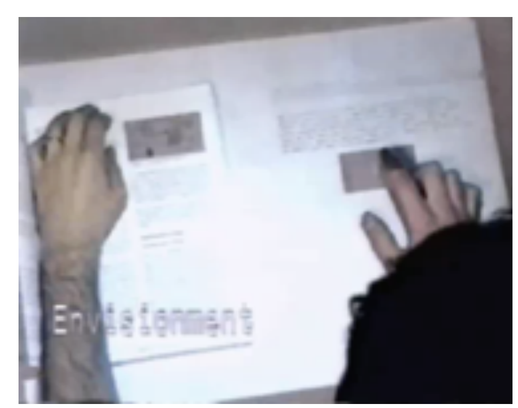


- understand the **underlying technology**



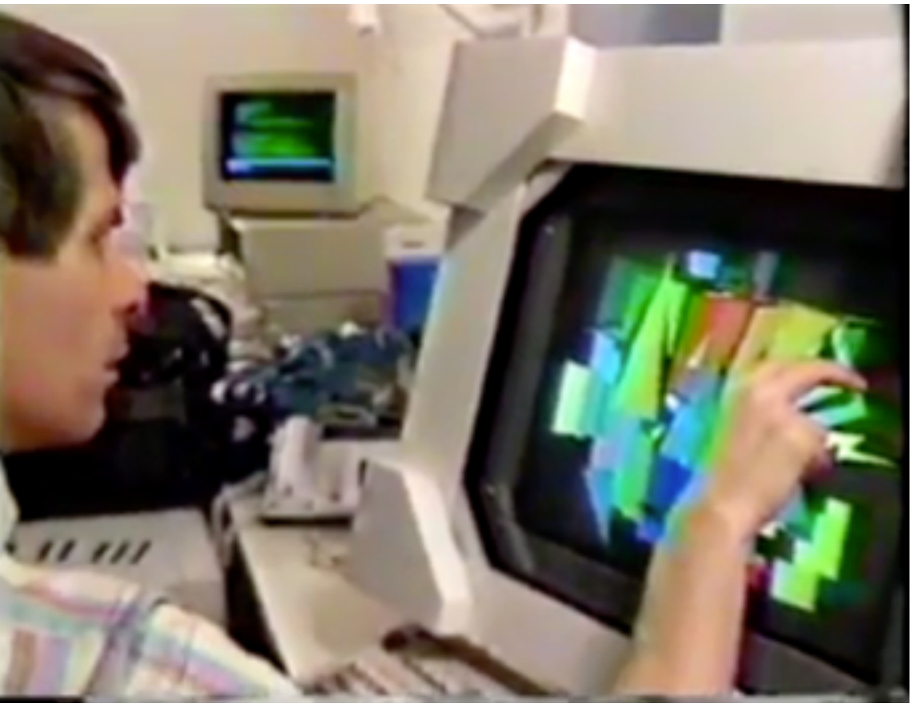


- **invent future** interactive technologies



towards more natural user interaction!
use **your hands to interact.**

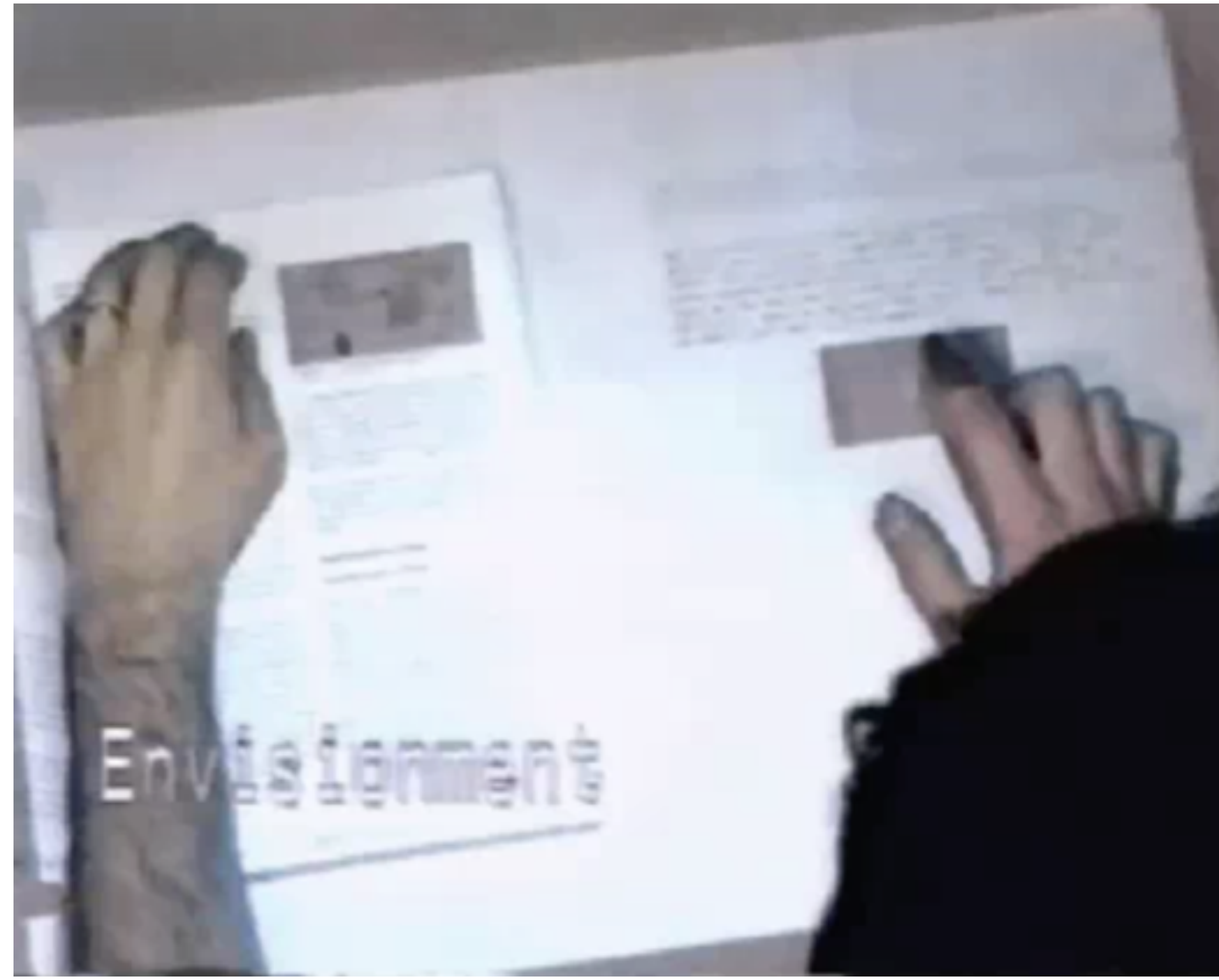
1963



1986

2007

help invent the future of interactive tech!



20XX?

reaching the consumer market when?
(typically ca. 30-50 years after invention)

20XX?

5 min break
(then we continue with class orga stuff + sign up)

end.