Privacy Preserving Optics for Miniature Vision Sensors

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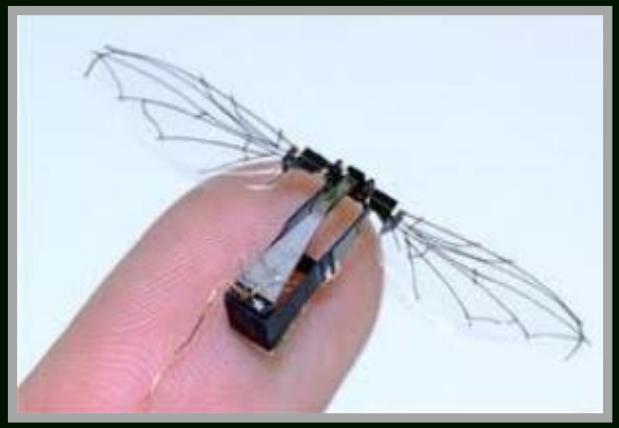
The next wave of small devices



Microrobots

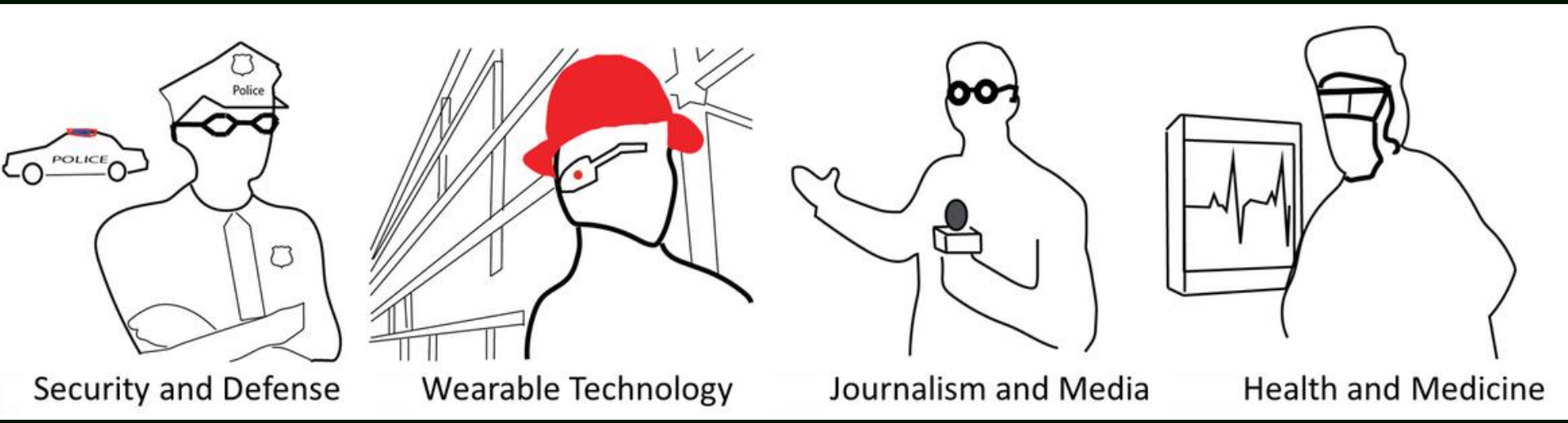
Medical devices

Remote sensor nodes

Shoham et al. 07, Wood 08, Enikov et al. 09, Agrihouse 15

In the future, there will be trillions of networked miniature cameras.

Privacy in the Face of Trillions of Eyes



Some groups are particularly vulnerable

Our ideas

1) Pre-Capture Privacy
   - Privacy *before* capture

2) Miniaturizing Algorithms
   - High performance
   - Smallest mass and volume

We show mobile scale prototypes

Motivating Example

Group of People

We want to:

1) Track/Photograph everyone
2) Prevent face recognition

Quantitative: accurate people tracking and low recognition rate

Block Diagram

Group of People

Light

1. Tracking people with privacy

Modulating Optics

Light

Camera

2. Photographing people with privacy

Block Diagram

Group of People

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1. Tracking people with privacy

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Ray Diagram

Group of People

Light

Display

Displayed light

Beam splitter

Camera

Ray Diagram

Group of People

Light

Display

Displayed light

Beam splitter

Camera

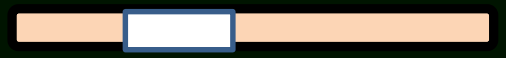
Displayed light
+
Scene radiance

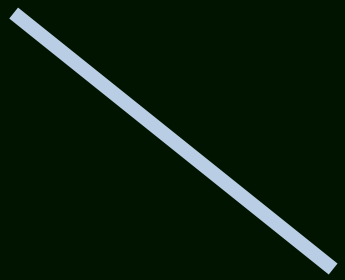
Pre-Capture White-Out

Group of People

Light

Some overexposed pixels





Beam splitter

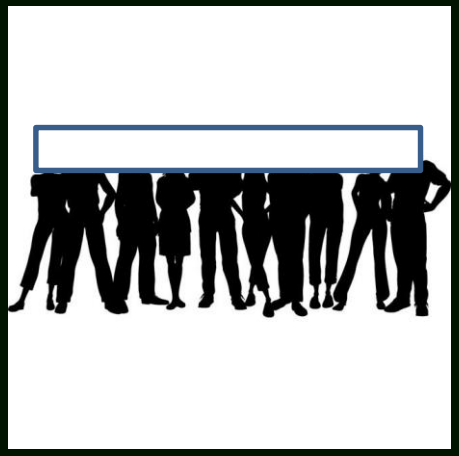


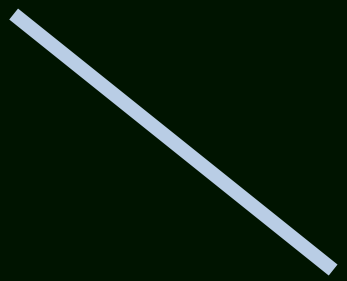
Image Captured

Optical K-Anonymity

Group of People

Light

Optically superimpose face



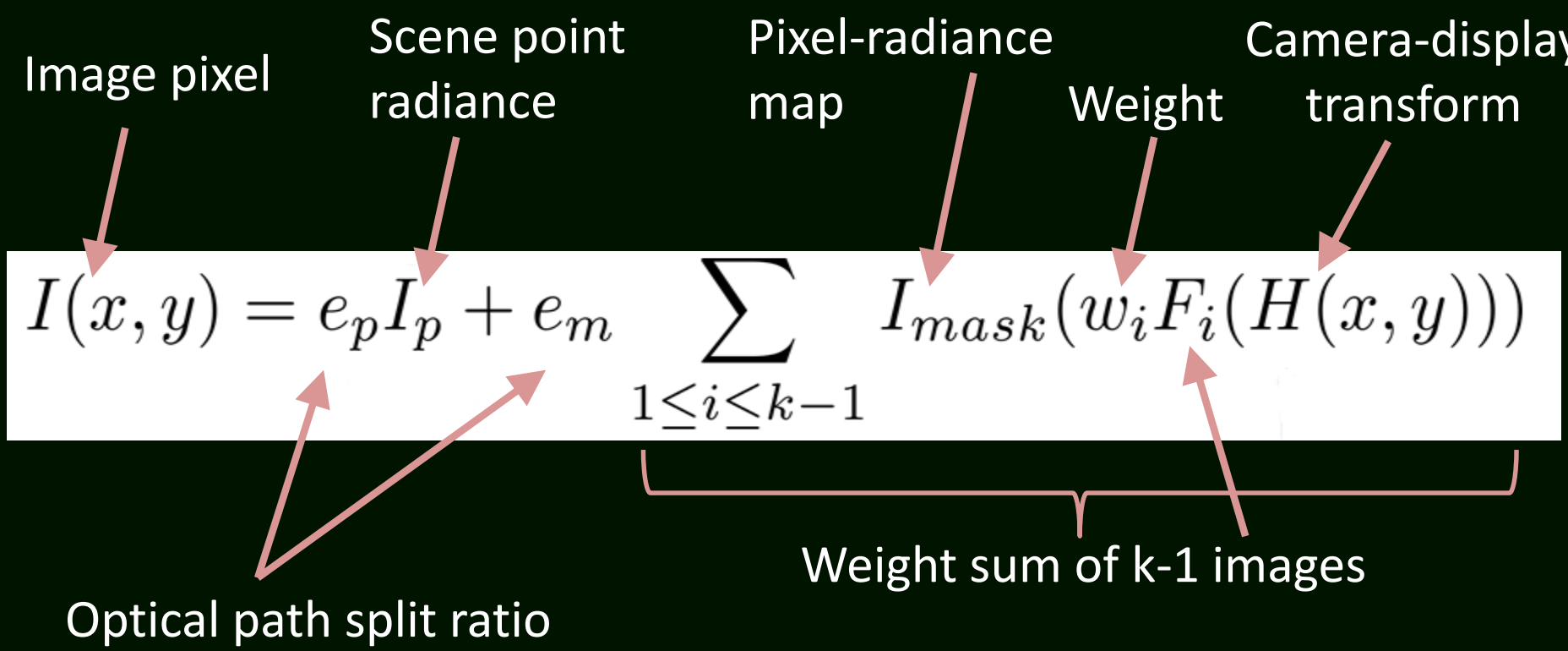
Beam splitter

Sweeney 2002

Optical K-anonymity

Scene Displayed Image Sensor output

Image Formation Model



Miniaturization (Orthographic)

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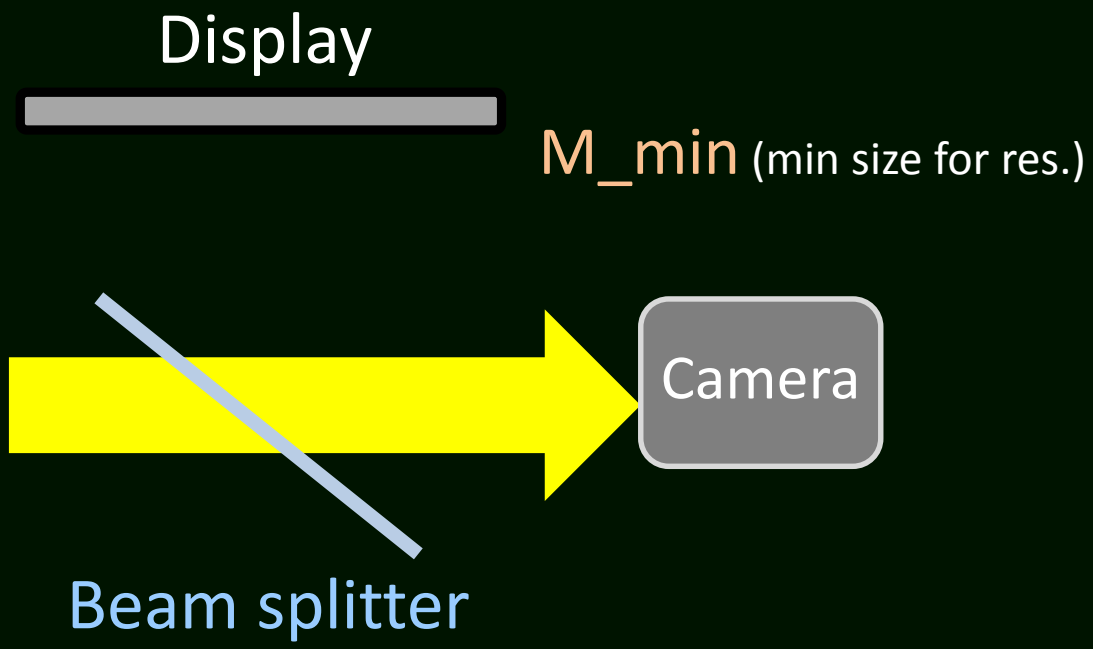

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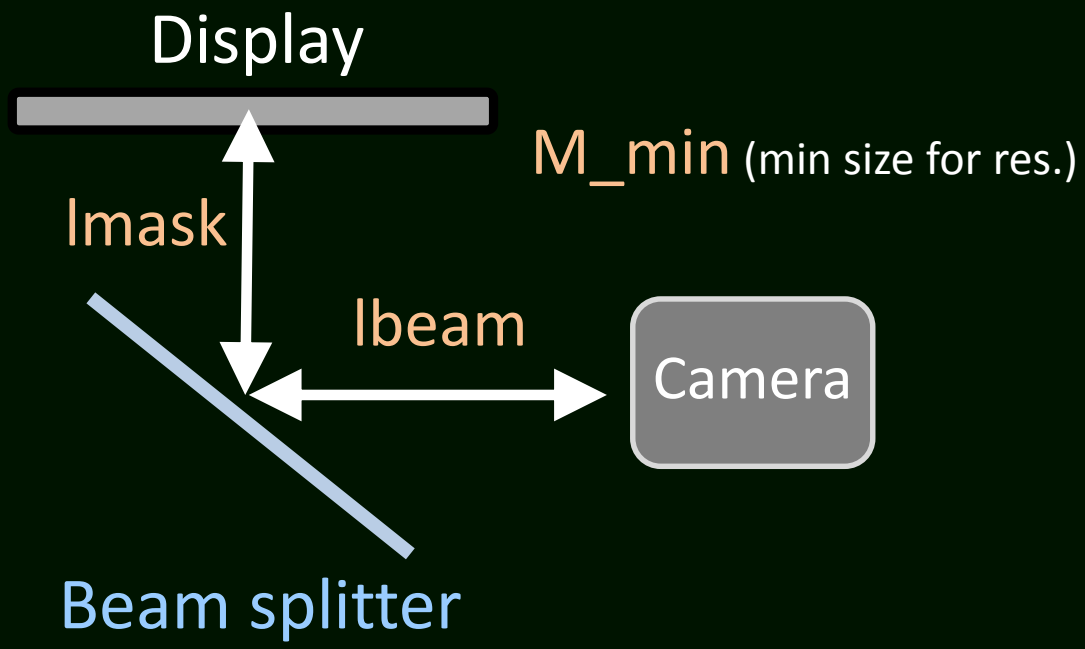
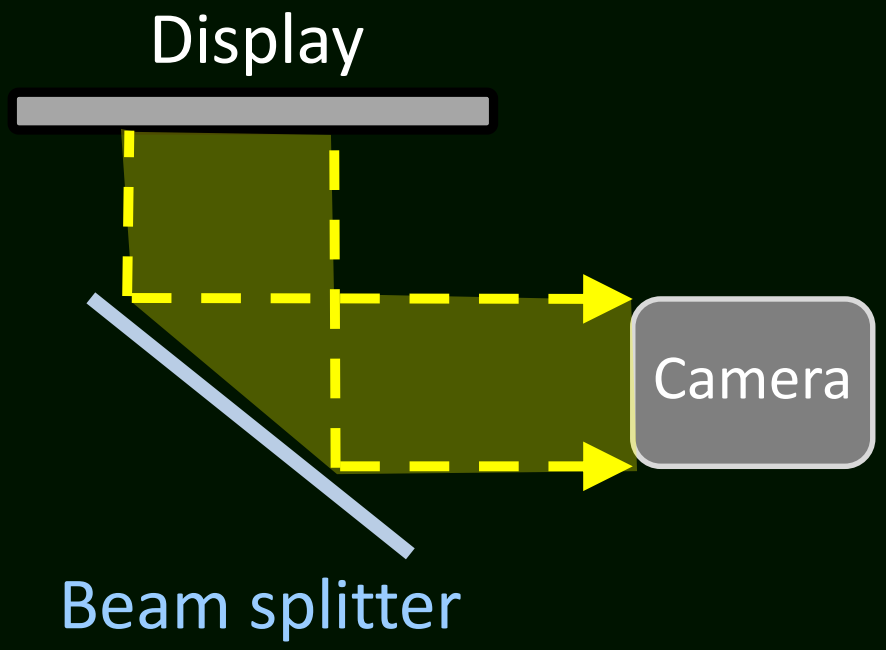
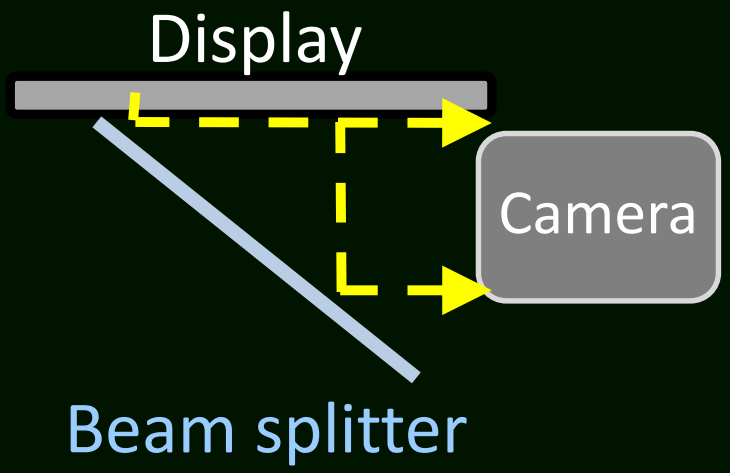


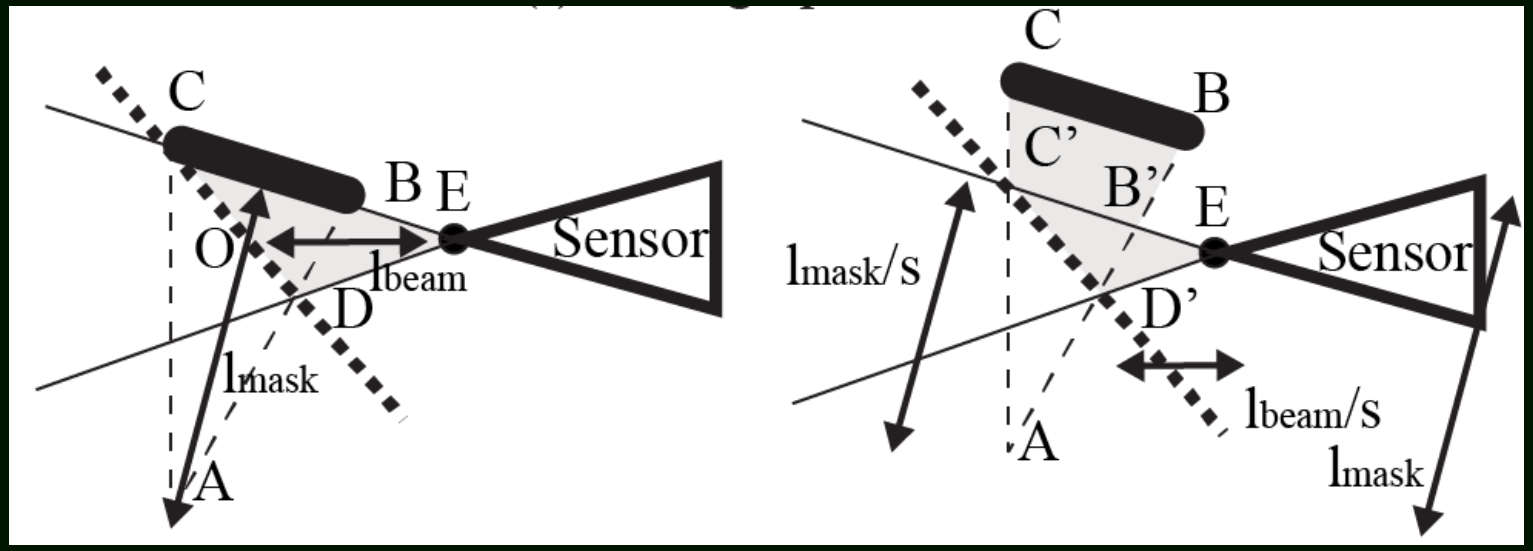
Volume occupied



Miniaturization by translation



Miniaturization (Perspective)



$$C_1 = \frac{\sin\frac{\theta}{2}\ \sin\phi}{2\ \sin(\frac{\theta}{2}-\phi)} + \frac{\sin\frac{\theta}{2}\ \sin\phi}{2\ \sin(\frac{\theta}{2}+\phi)}$$

$$s = \frac{M_{min} l_{mask}}{2C_1 l_{beam}^2 - M_{min} l_{mask}}$$

Please see details in the paper

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2. Photographing people with privacy

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Our key ideas

- Defocus in time-of-flight (TOF) and thermal domains preserve utility and provide privacy

- Multiple defocus apertures allow privacy and utility even in visible domains

Not effective in RGB for small blur Neustaedter 2006

Privacy Vision Sensor 1 of 3

Group of People

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1. Tracking people with privacy

Modulating Optics

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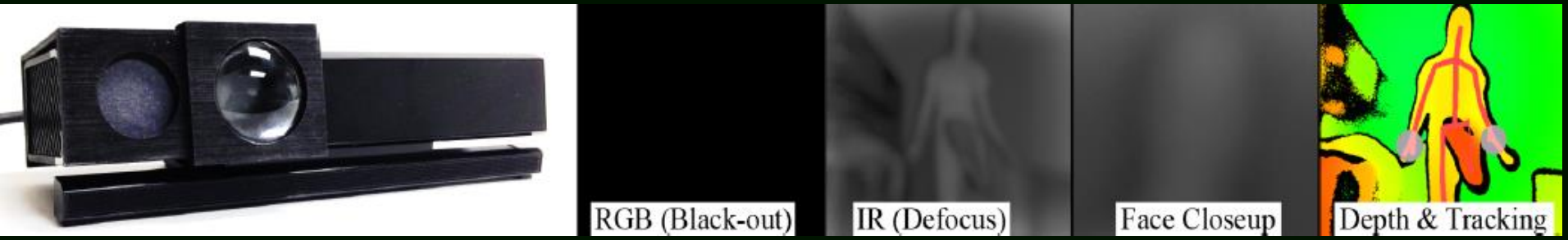
2. Photographing people with privacy

Defocused time-of-flight camera

Conventional usage



With Defocus

Defocused time-of-flight camera

Conventional usage

With Defocus

Privacy Vision Sensor 2 of 3

Group of People

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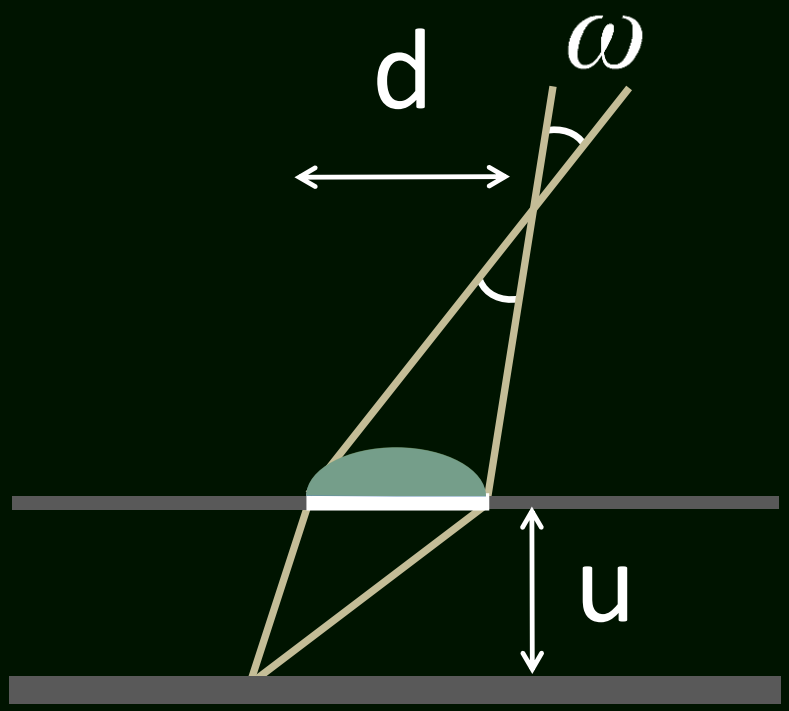
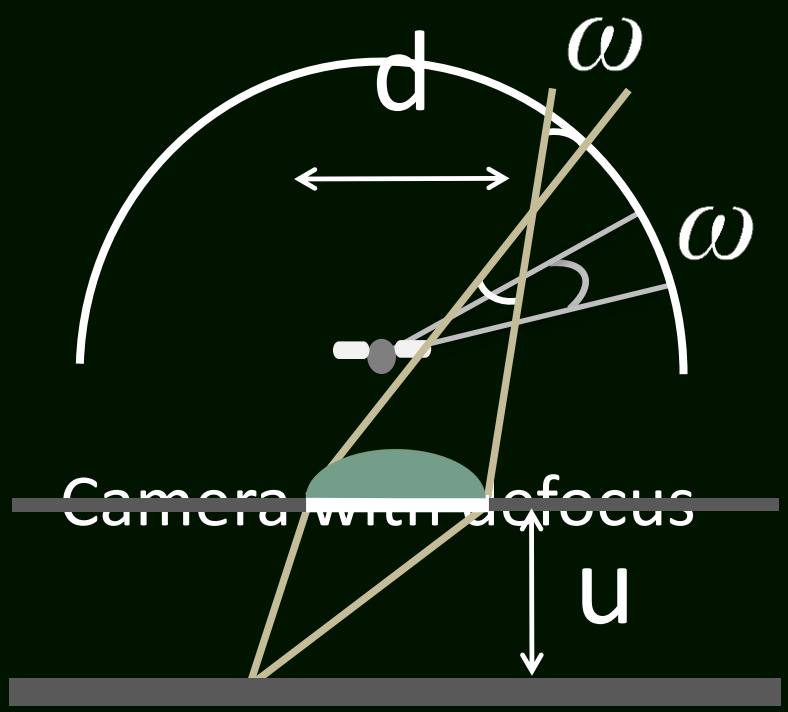
Defocused thermal camera

FLIR One with defocus lens

Miniaturization of defocus



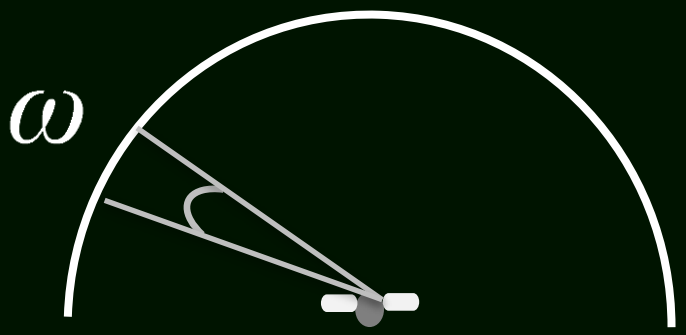
Miniaturization of defocus



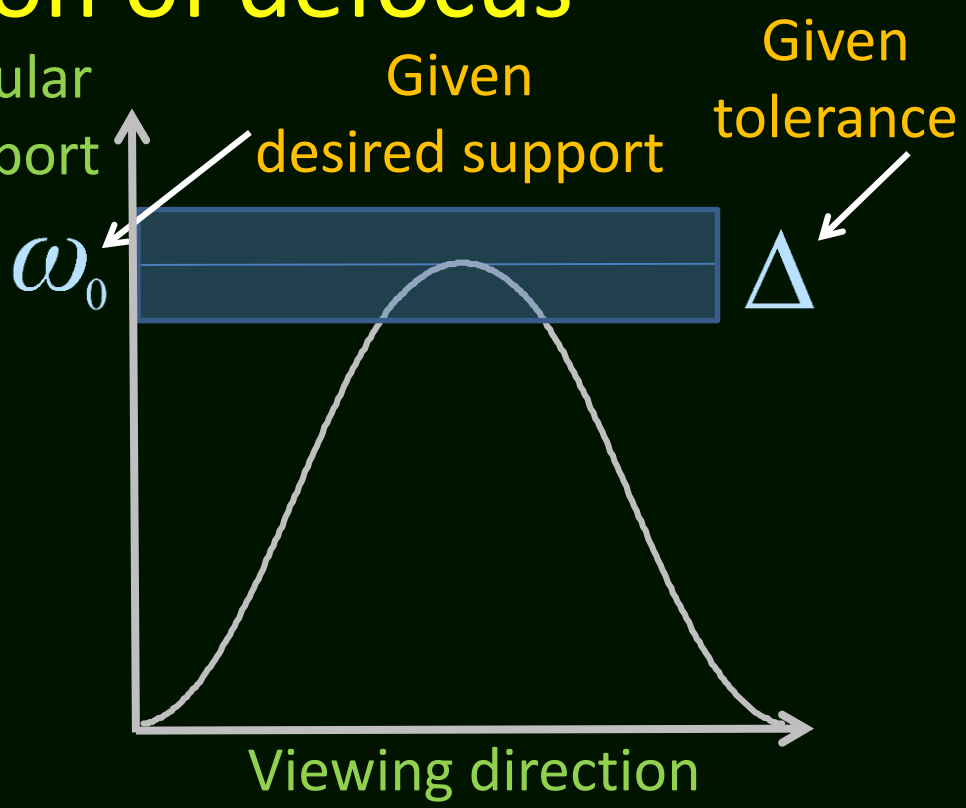
Miniaturization of defocus

Camera with defocus

Miniaturization of defocus



Camera with defocus



Koppal 2013

Miniaturization of defocus

$\omega_0 \; \Delta$

Given

u , d

Output

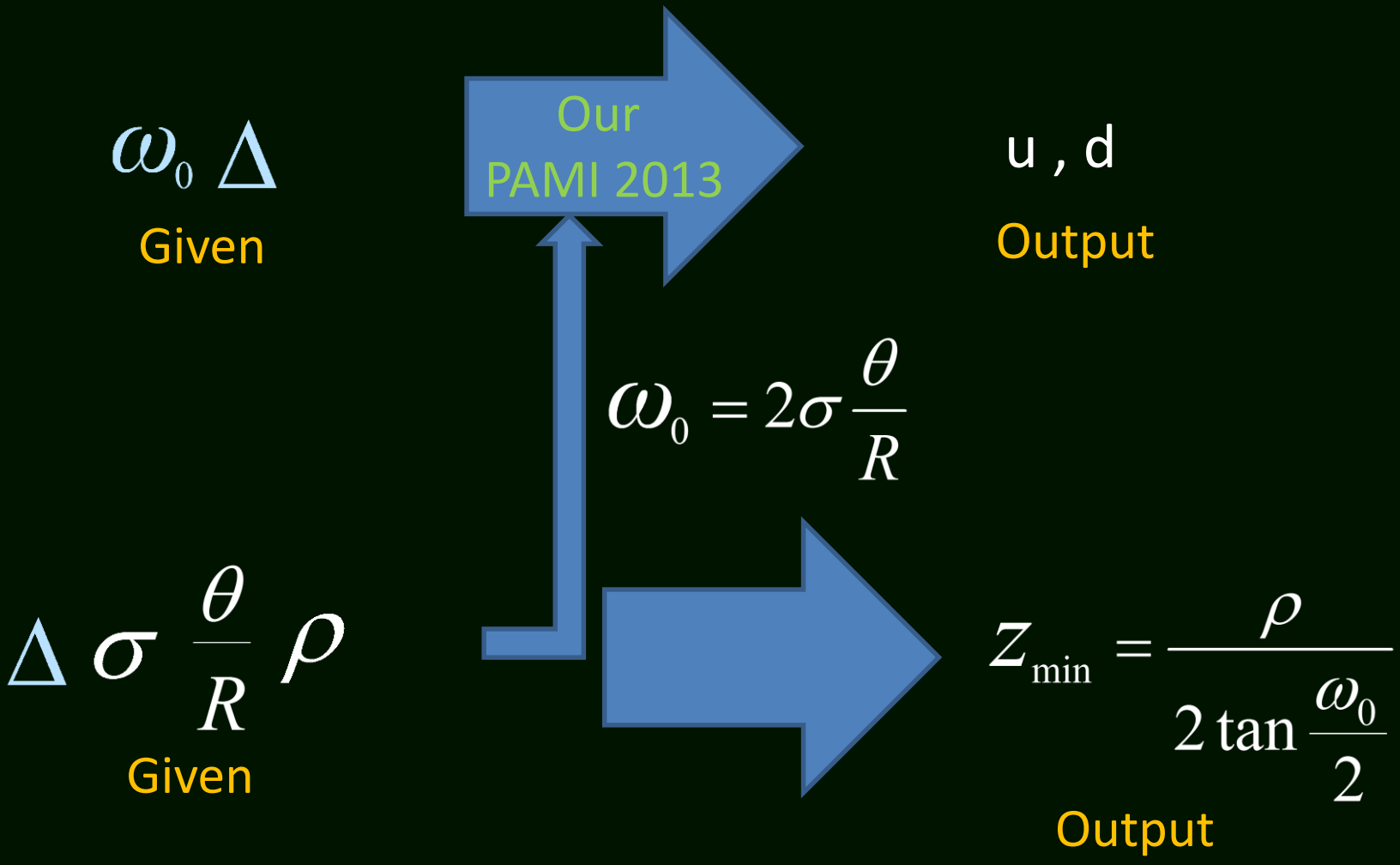
Defocus parameter and angular res.

Biggest feature to anonymize

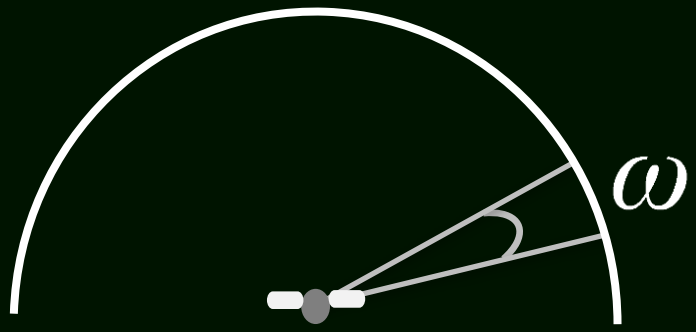
$\Delta \; \sigma \; \frac{\theta}{R} \; \rho$

Given

Miniaturization of defocus



Miniaturization of defocus



$$z_{\min} = \frac{\rho}{2 \tan \frac{\omega_0}{2}}$$

Camera with defocus

Miniaturization of defocus

Camera with defocus

Privacy Vision Sensor 3 of 3

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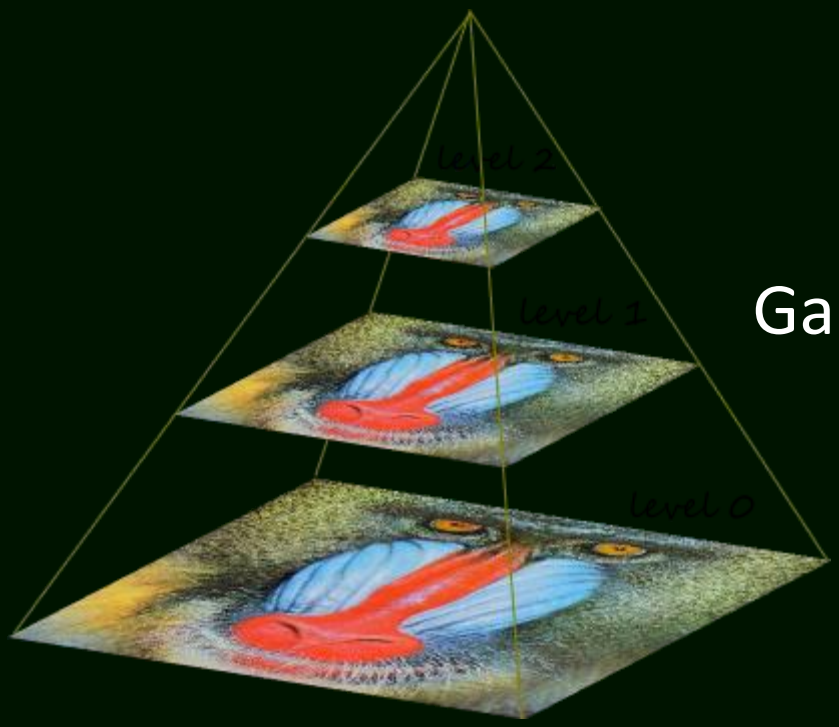
Scale space analysis

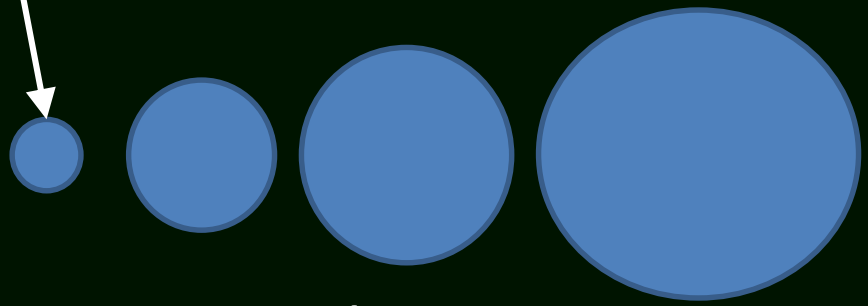


Gaussian pyramid

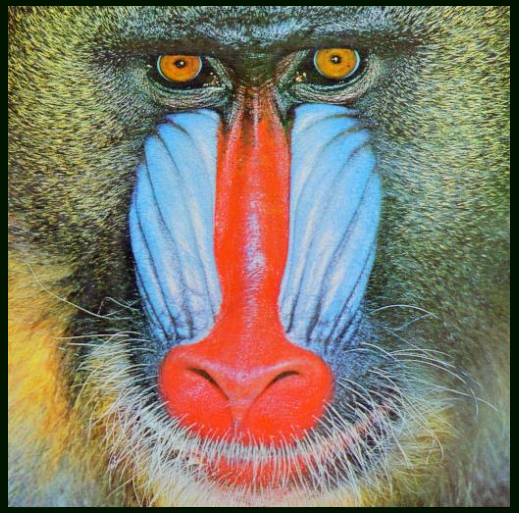
Lindeberg 1998

Scale space analysis with optical defocus

Worry about privacy here!

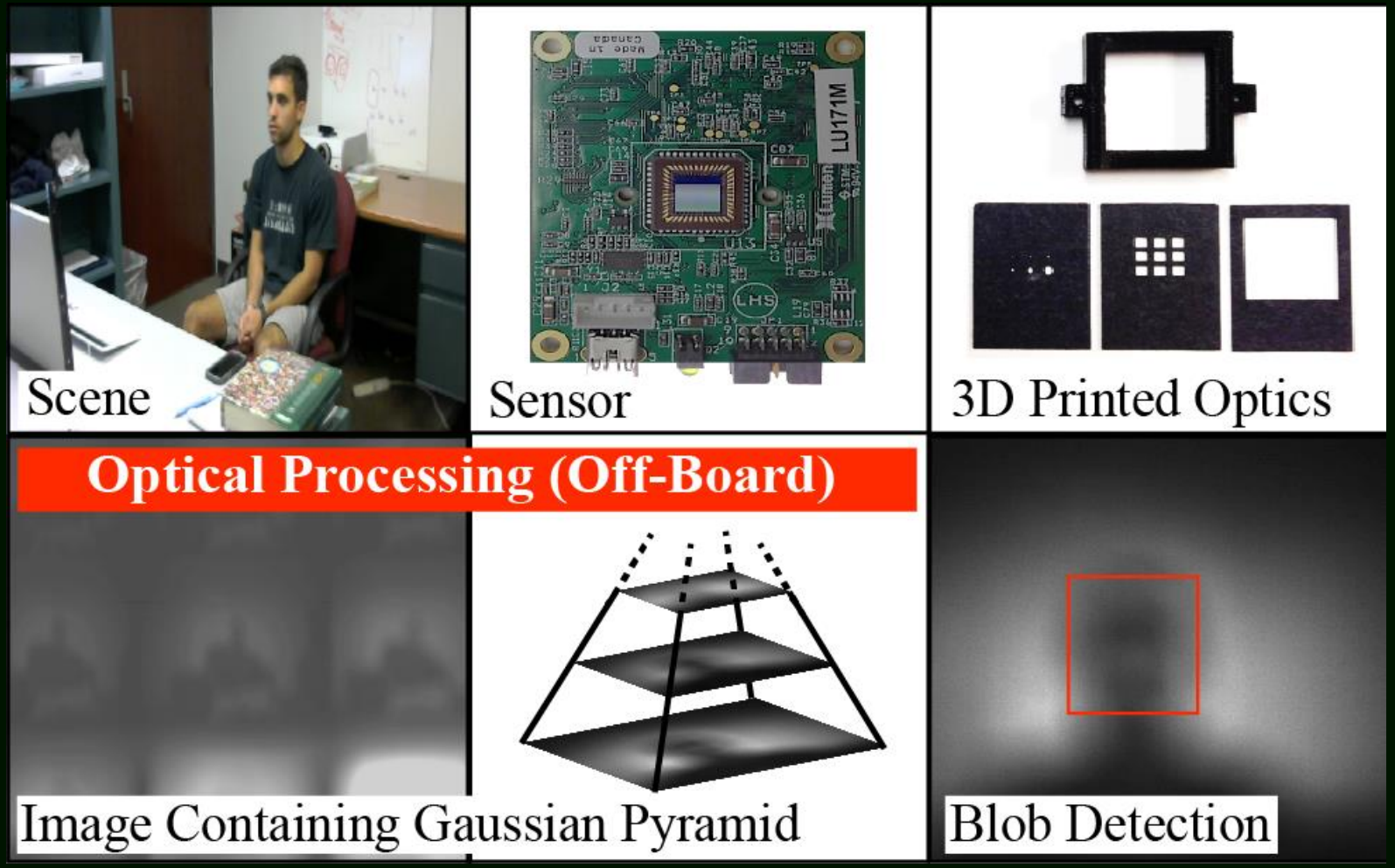


Optical apertures



Scene

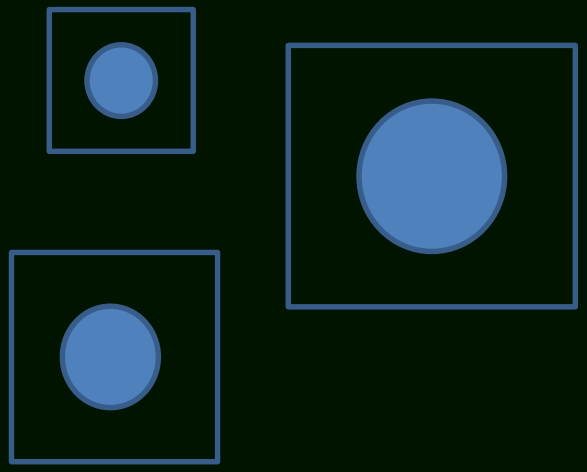
Scale space detection with optical defocus



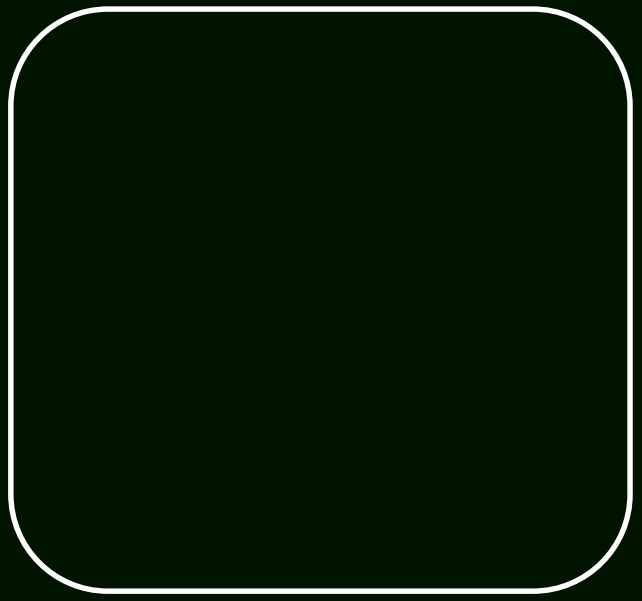
A classifier is trained on the blobs

Optical Array Miniaturization

Optical Array Miniaturization

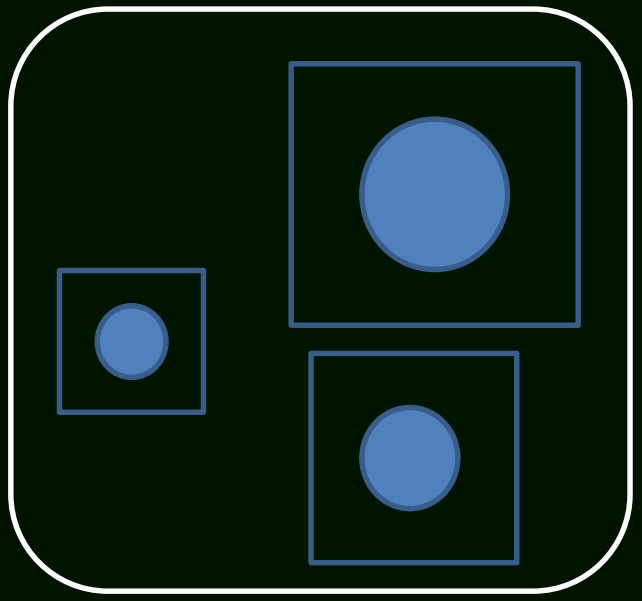


Optical elements with mass/volume/FOV



Physical device has size limits

Optical Array Miniaturization



Optical elements with mass/volume/FOV

Physical device has size limits

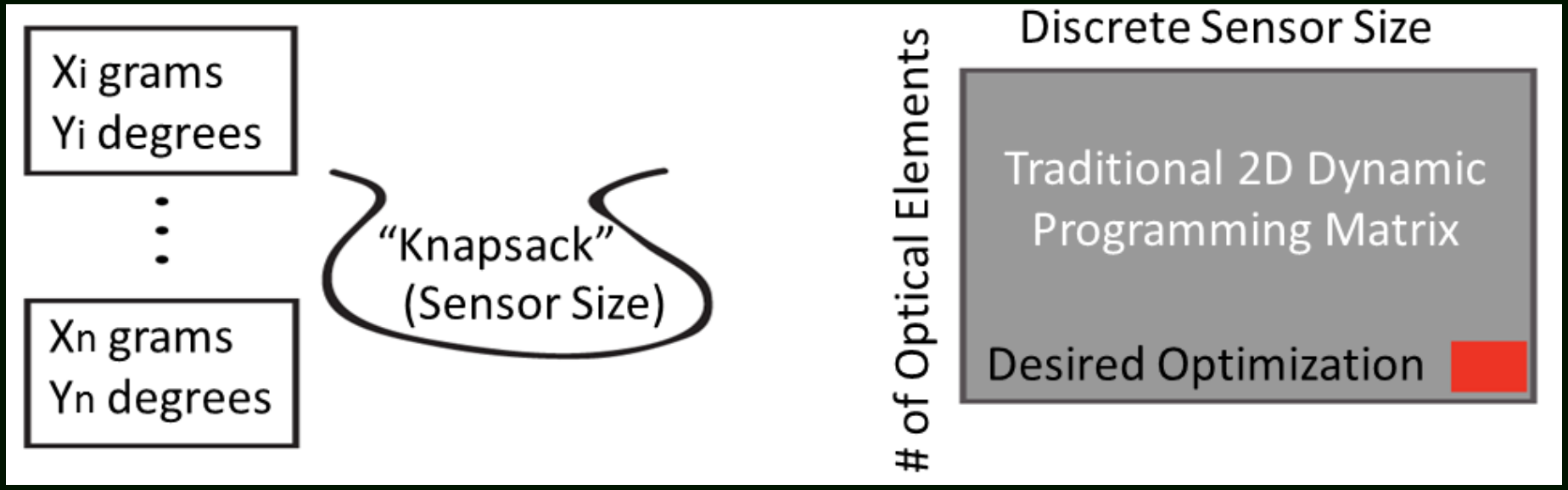
Optical Array Miniaturization

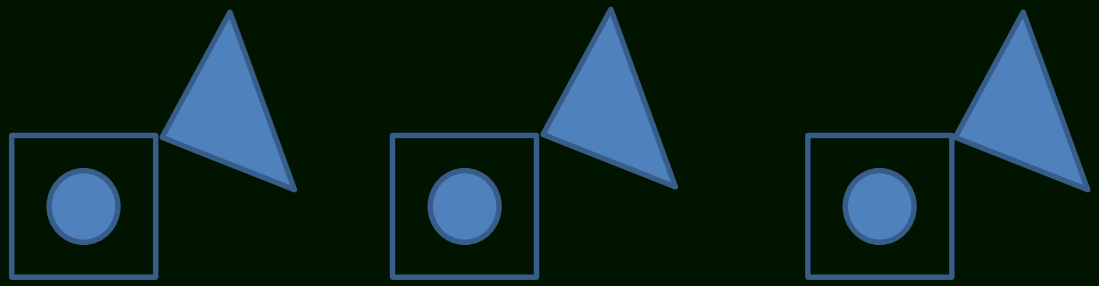
- Has two parts
  - Selection
  - Packing

We focus on selection

Korf et al. 2010

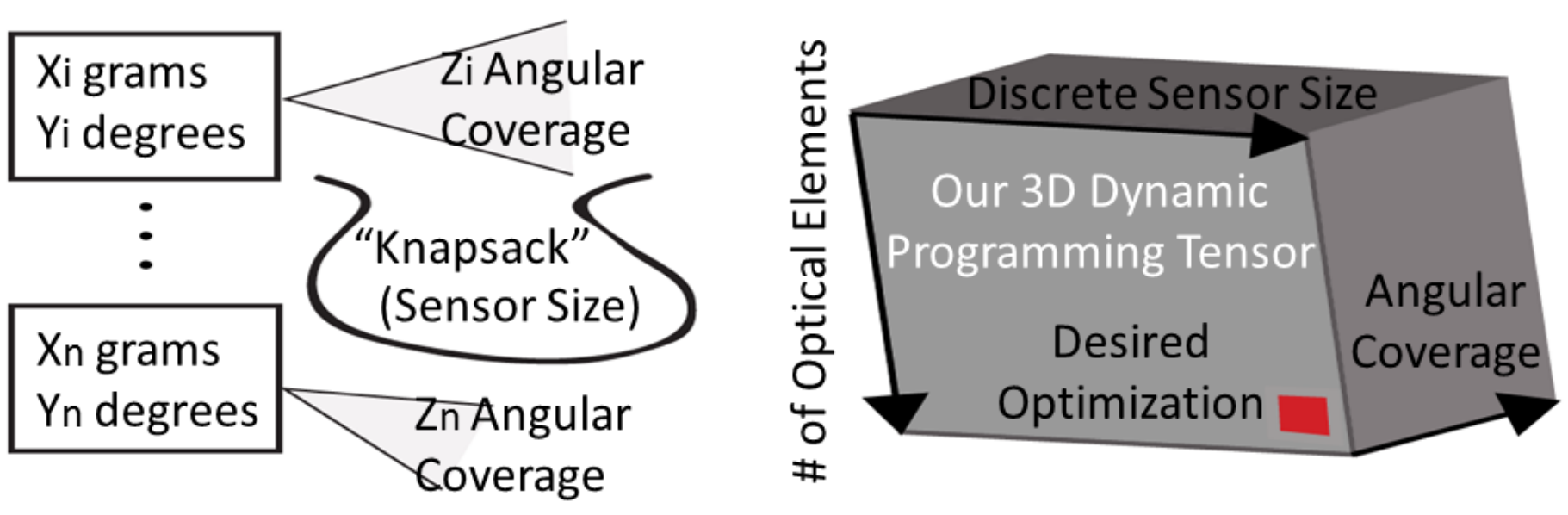
Knapsack Problem





These could get added into the design

Optical Knapsack Problem



Optical Knapsack Problem

Angular discretization

$M[i,a,b] = 0$, if $0 \le a \le A$, $0 \le i \le n$ and $0 \le b \le \beta$

and is recursively updated as

If $a < 0$ $\quad M[i,a,0] = -\infty$

For any other a, **for any** i

If

$M[i-1,a,0] <$

$f_i + M[i-1,a-a_i,0]$

and

$\sum_{1 \le b \le \beta} M[i-1,a,b] <$

$\sum_{1 \le b \le \beta} M[i-1,a-a_i,b] \vee K[i,b]$

$$\begin{cases} M[i,a,0] = \\ f_i + M[i-1,a-a_i,0] \end{cases}$$

$$\begin{cases} M[i,a,b] = \\ M[i-1,a-a_i,b] \vee \\ K[i,b],\ b \in (1,\beta) \end{cases}$$

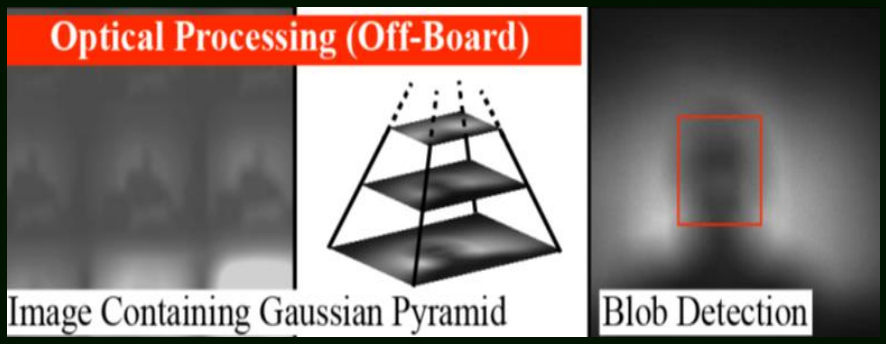
Otherwise $\forall b$ $\quad M[i,a,b] = M[i-1,a,b]$

No magic: Pseudo-polynomial approximation

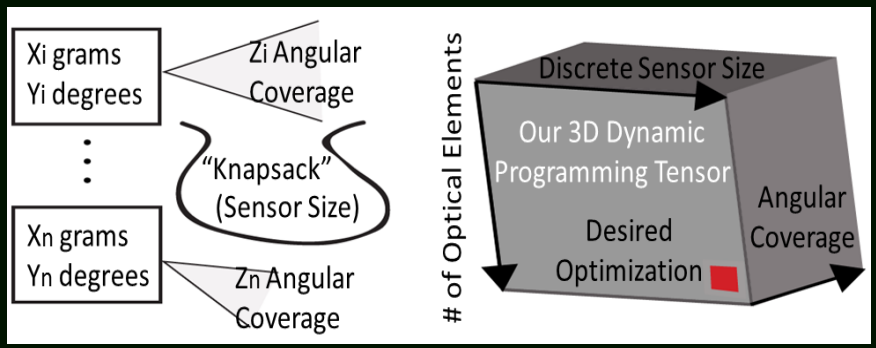
Summary

K-anonymity Camera

Defocus in thermal
and TOF preserves privacy



Optical scale space analysis



Optical knapsack solution

Future Work: Privacy in Image Formation

Materials

Geometry

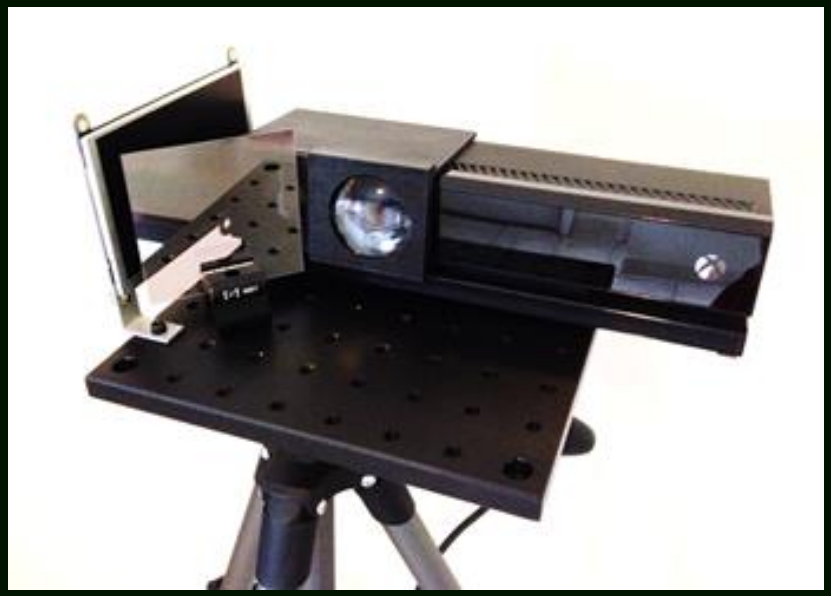
Image Formation

Camera

Acquired Image

Lighting

Demo at CVPR 2015



Sensor Setup

Pre-Capture White-Out