A Physics-based Approach to Removing Shadows and Shading in Real Time

TANDENT®

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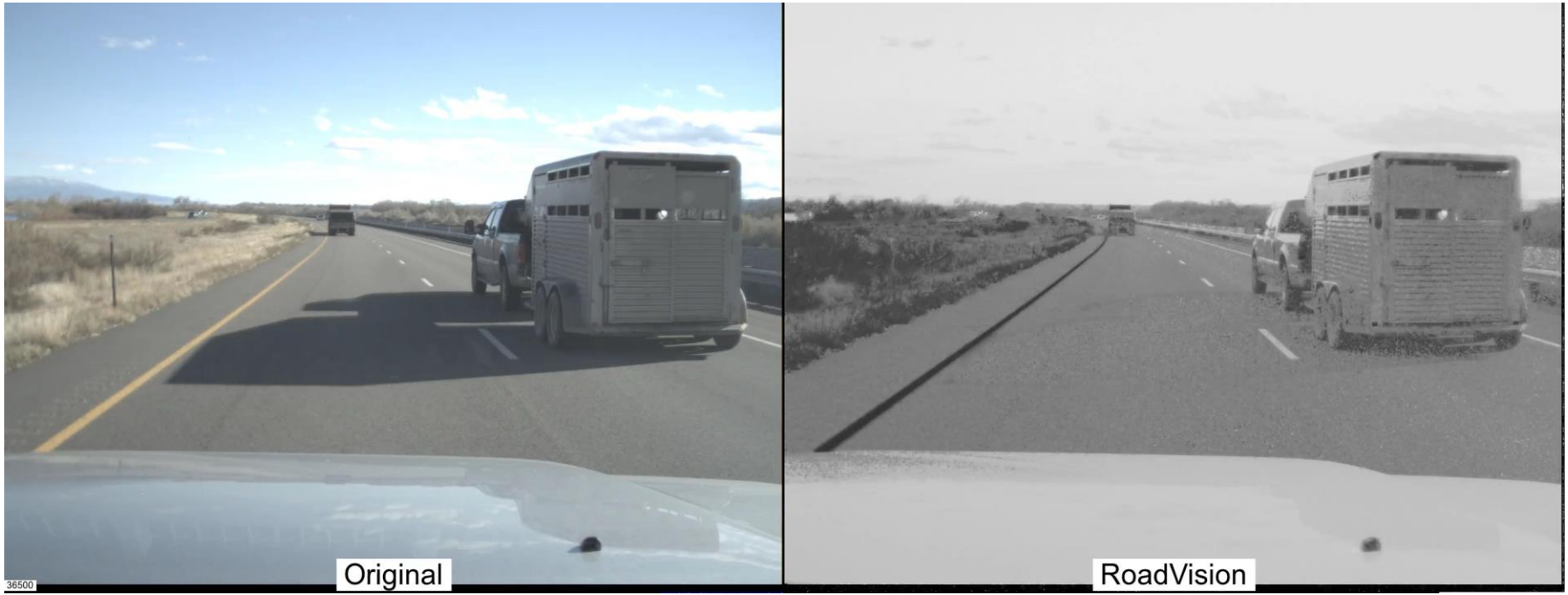
What is Possible?



How Do We Remove the Shadows?

- ~~We labeled a zillion images~~
- ~~We trained a really big convolutional network with a million parameters~~

Physics

11 operations per pixel

A Better Signal

A powerful strategy for simplifying computer vision

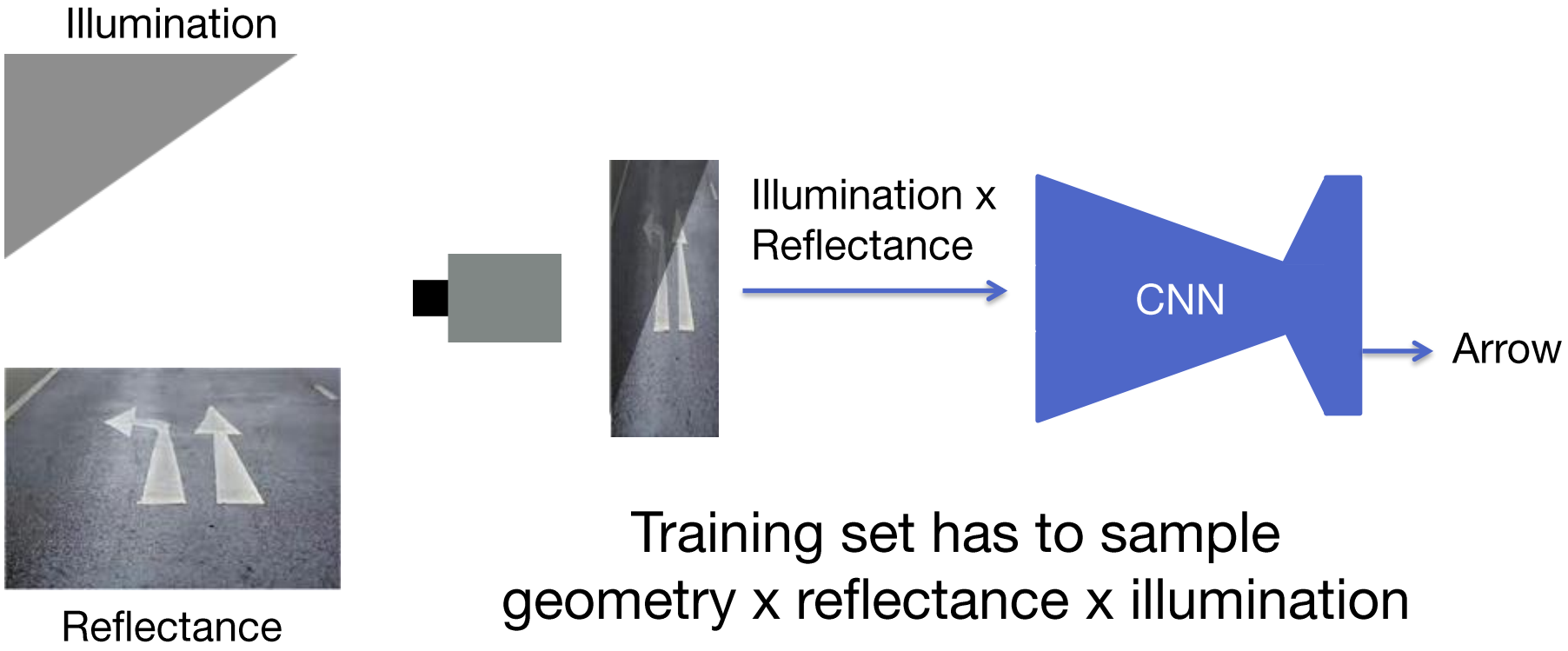
- Use physics to create an illumination independent signal
- Use simpler classifiers to accomplish the recognition tasks
- Use less computational power and achieve more robust performance

Illumination as a Confounding Signal

Looking for paint on the road

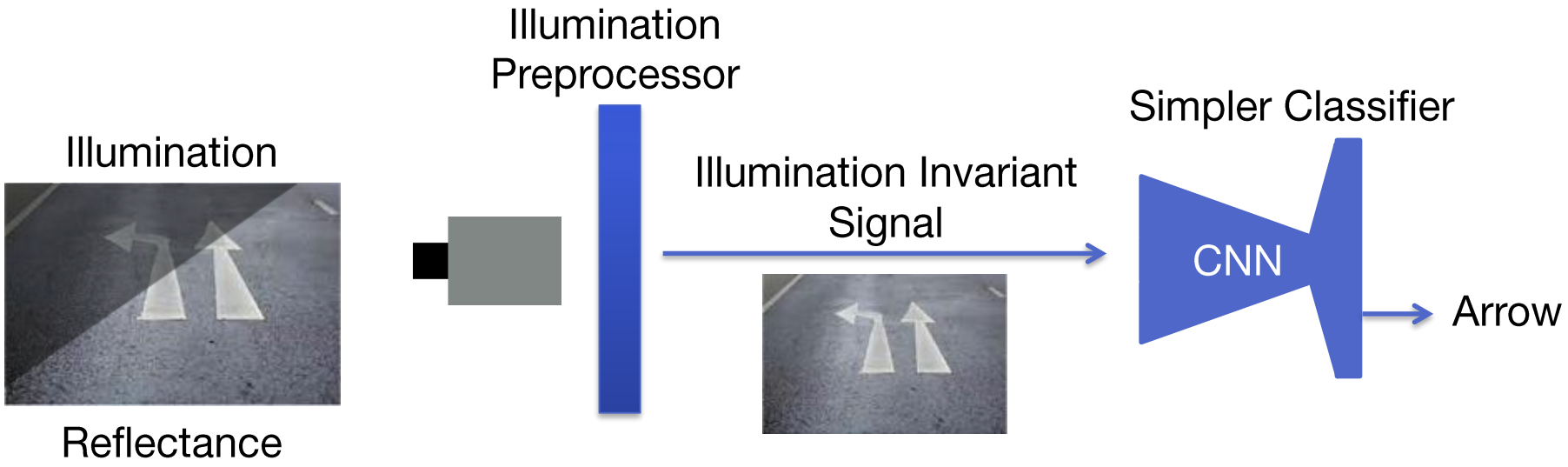
- Intensity is not discriminative
- Color is not discriminative
- Shape is not discriminative

Using Standard Images to Understand the World



Training set has to sample
geometry x reflectance x illumination

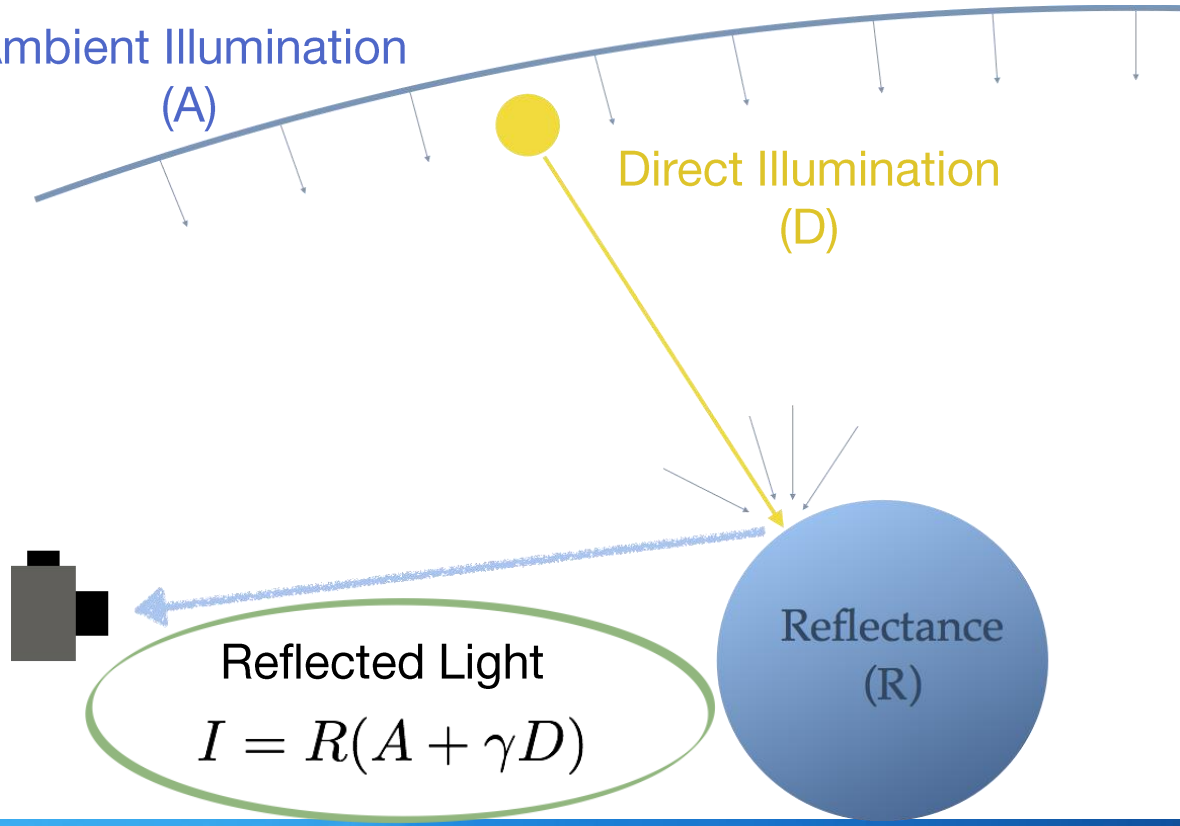
A Better Visual Signal



Training set has to sample geometry x reflectance ~~x illumination~~

Bi-illuminant Scene Model

- Light
- Surfaces
- Geometry
- Reflected light
- Sensor (linear)

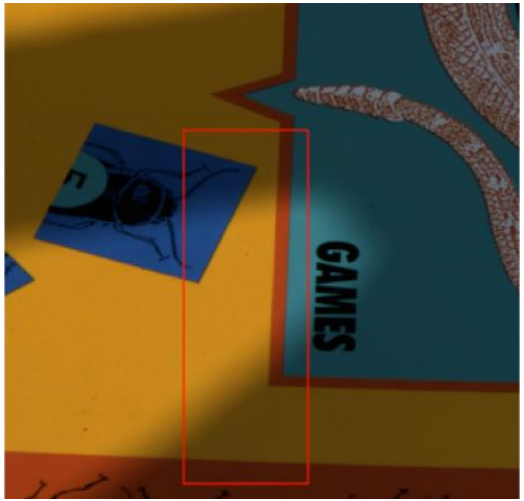


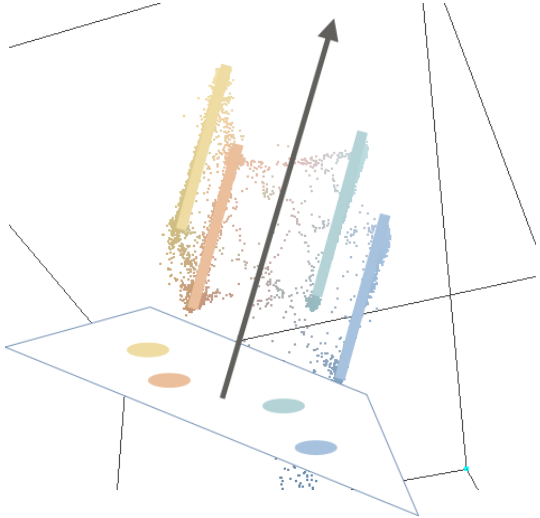
Tandent Log Space Chromaticity

$$\log I = \log R + \log(A + \gamma D)$$

Reflectance term
Constant for a material

Illumination term
Constant shape for an A, D pair





Illumination
Spectral
Direction
[ISD]

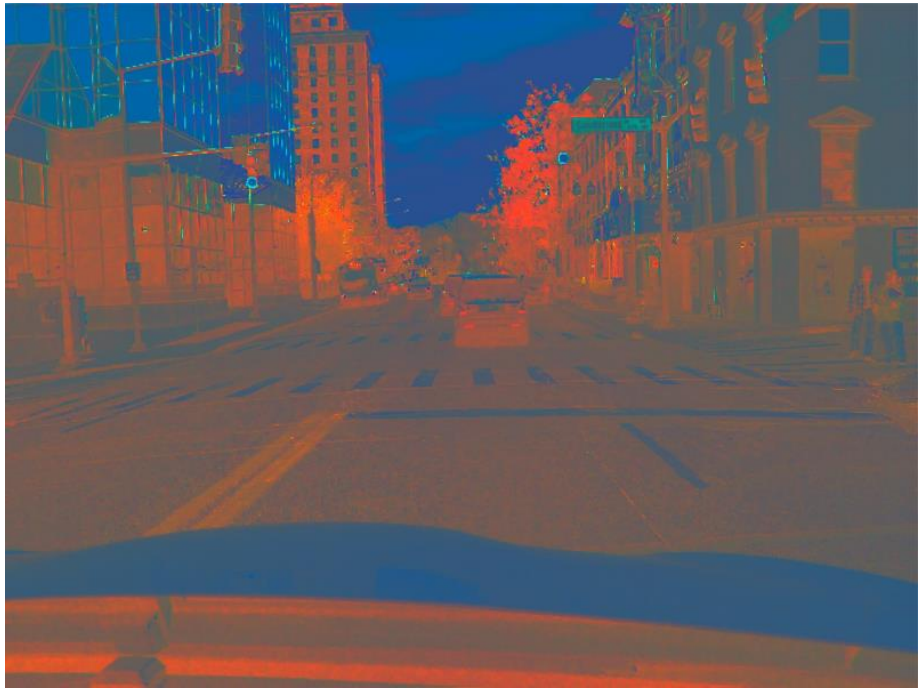
Chromaticity
Plane

Standard Chromaticity v. Log Space Chromaticity

Original Image

Standard Chromaticity

Standard Chromaticity v. Log Space Chromaticity



Tandent Log Space Chromaticity

Standard Chromaticity

Identifying the Illumination Spectral Direction

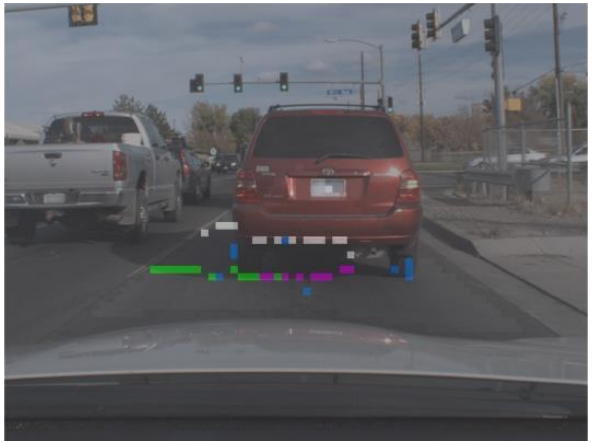
Goal: identify a shadow boundary and stable measurements of lit and shadowed pixels on road surfaces within a ROI

1. Down-sample and compute stable pixels
2. Identify potential lit and shadowed pixels
3. Dilate the lit and shadow masks
4. Find proposed ISDs
5. Identify the dominant ISD
6. Return the ISD and its confidence

More Examples of ISD detection

500 fps on an NVidia Jetson

Confidence is 0.999



Confidence is 0.119

Confidence is 0.0

Overall Process

Original Image → ISD → Tandent Log Space Chromaticity

Potential Output: Road Vision

Tandent Log Space Chromaticity → Road Vision

Potential Output: Road Vision

Original Image → Road Vision

Real Time Illumination Invariant Imaging

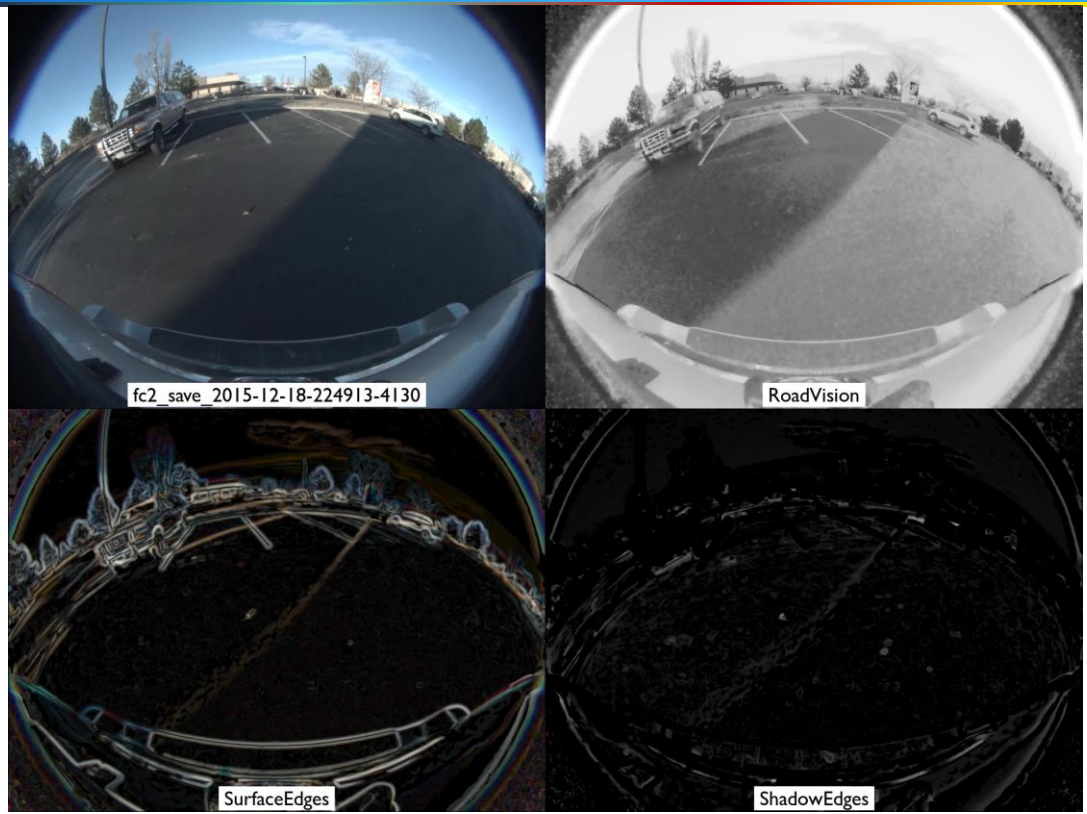
Other Possible Outputs

Original Image

Color Road Vision

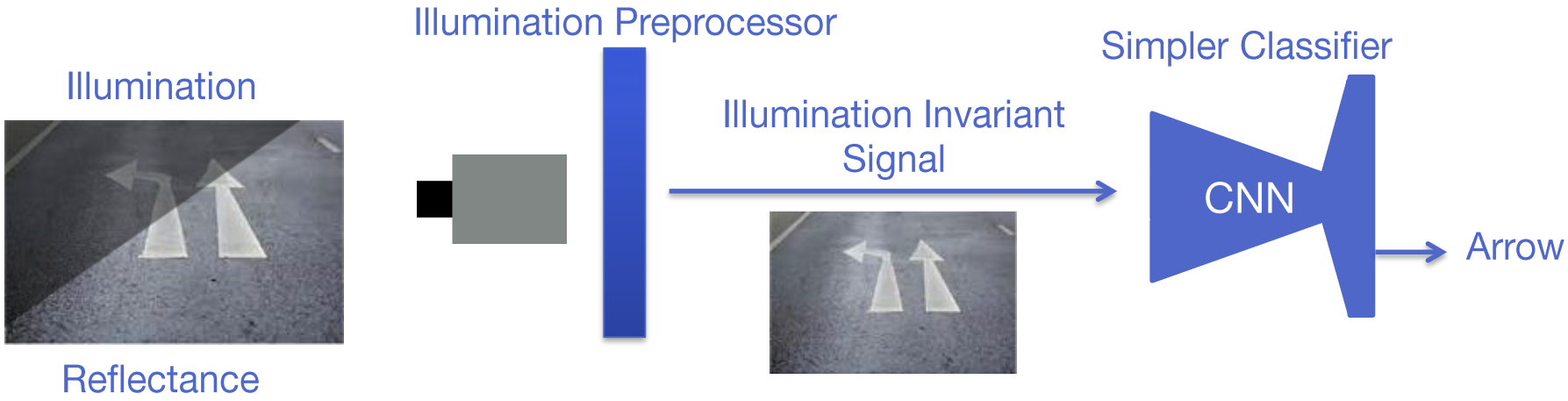
Greyscale and Color Road Vision

Shadow Edges and Material Edges



Is This Useful?

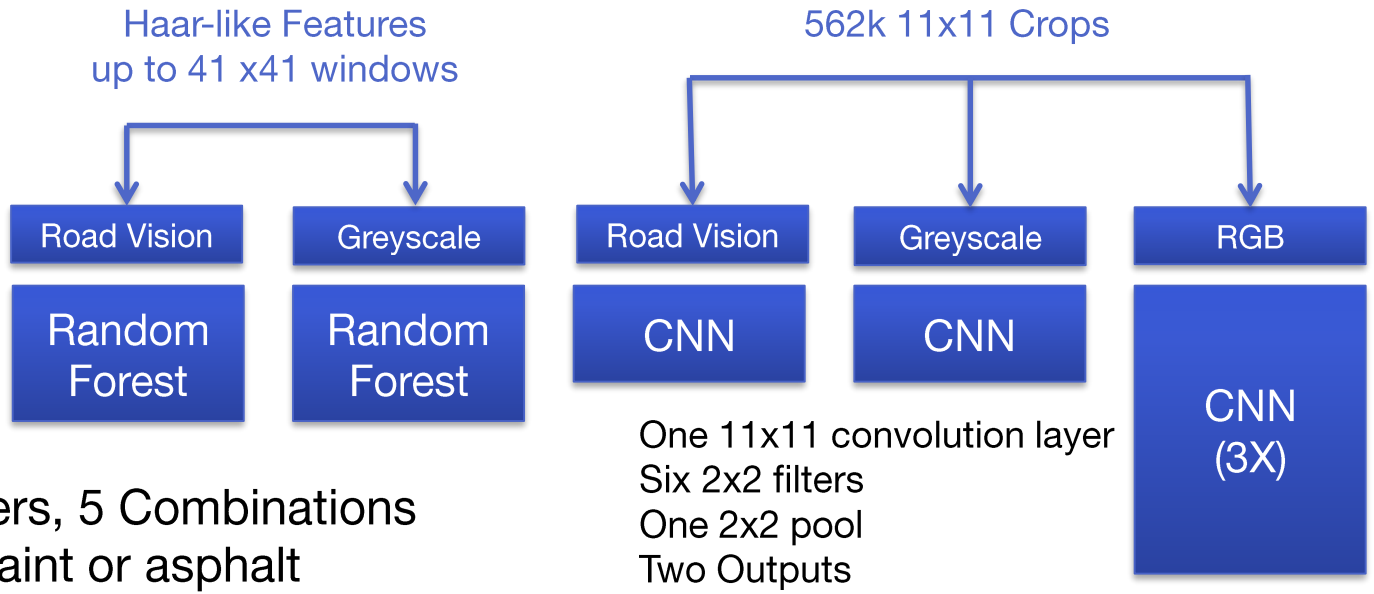
- Illumination is a confounding signal in many applications with no relevance to the problem
- Illumination can be an arbitrary signal and mimic features of the problem of interest
- Hypothesis: removing illumination first makes it easier for ML to solve the problem



Evaluation

Training set: 304 labeled images from 62 video sequences

- Different times of day, varying cloud/sun conditions
- Three camera sensors
- Four lenses,
- Three cities
- Four seasons

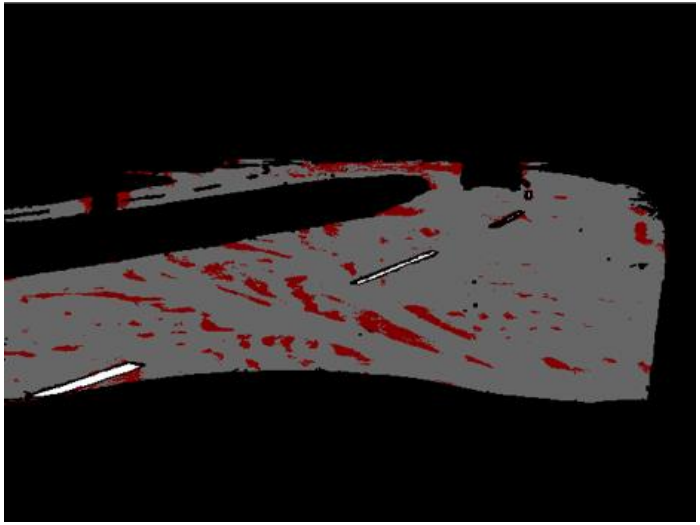


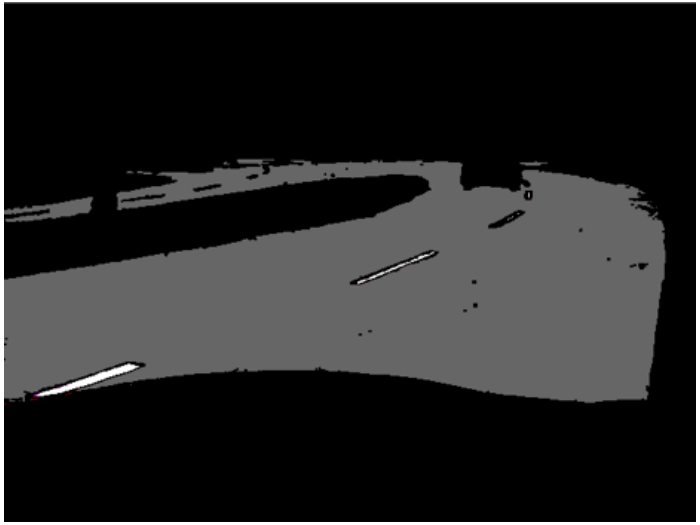
2 Different Classifiers, 5 Combinations
Classify as white paint or asphalt

Qualitative Results: Random Forest

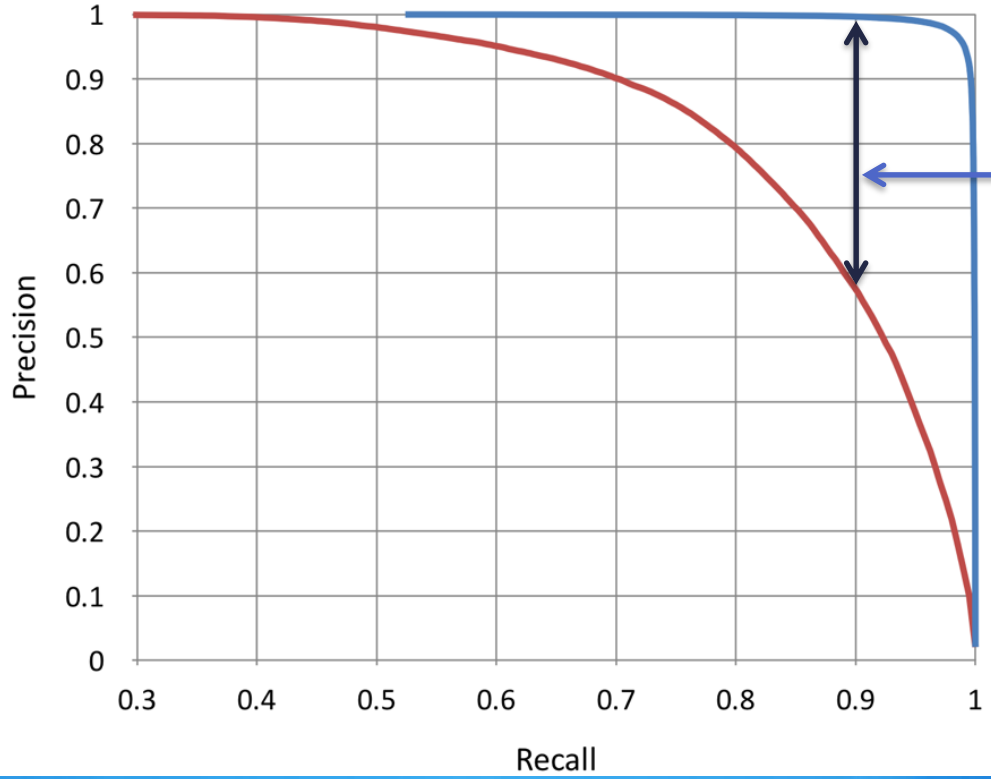
Trained/Run on
Original Images

Trained/Run on
Greyscale Projection





Random Forest Precision/Recall Plot

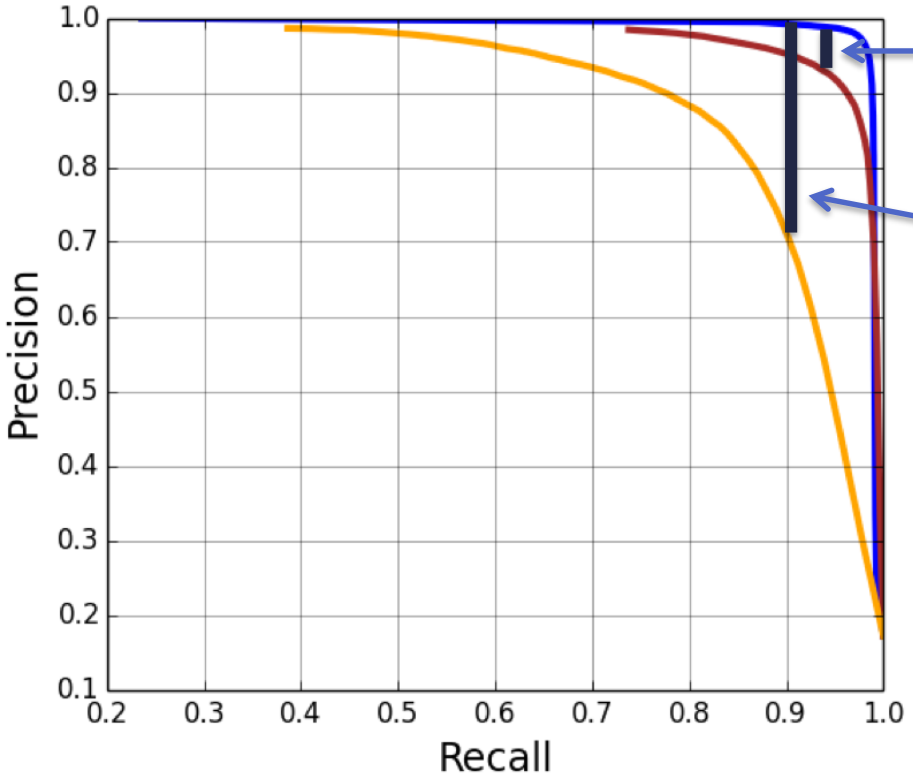


At 90% recall, accuracy goes from 58% to 99.6%

Grey Proj

Original Grey

CNN Precision/Recall Plot

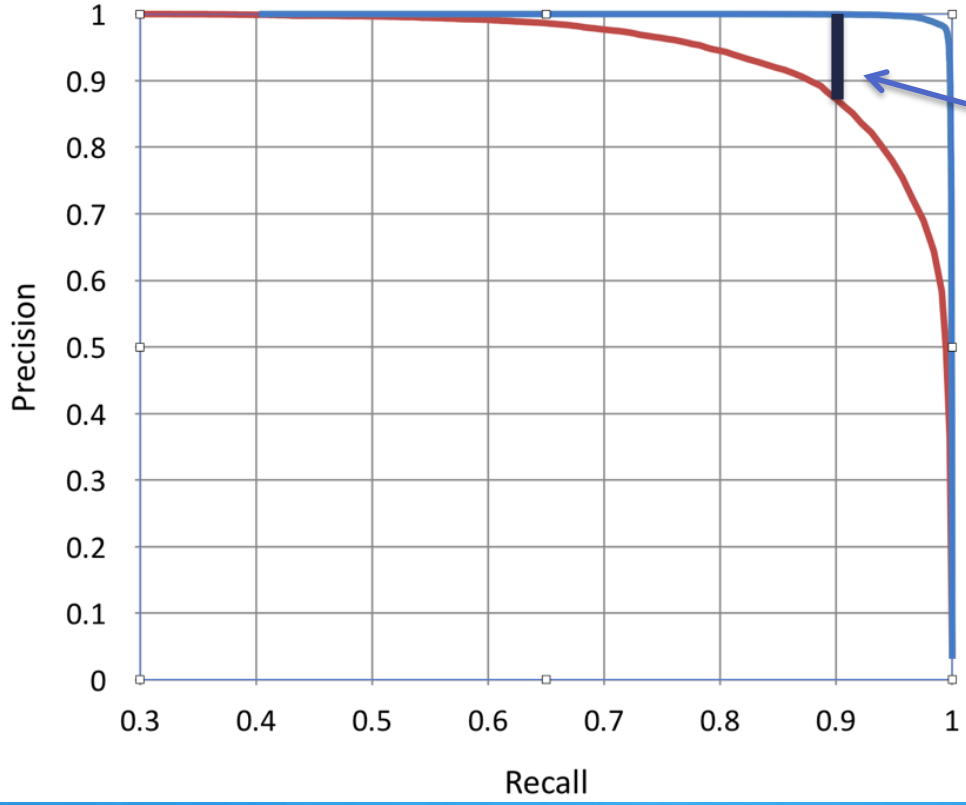


At 95% recall, RV + Grey CNN outperforms RGB CNN 99% v. 92% with 1/3 of the computation

At 90% recall, RV + Grey CNN outperforms Grey CNN 99% to 71%

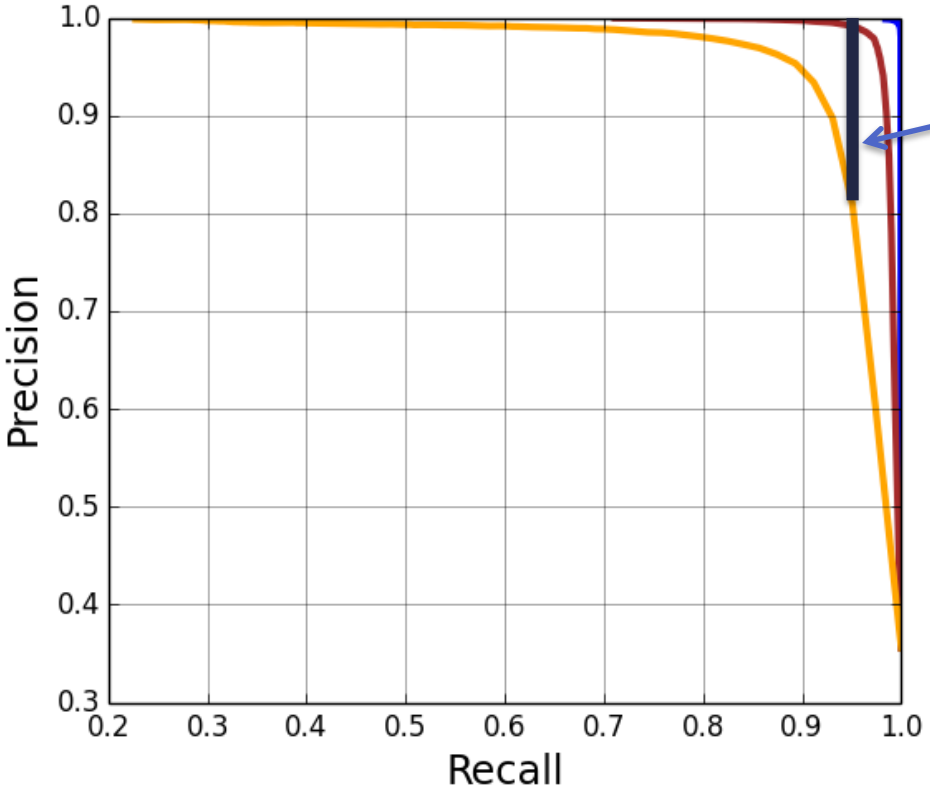
3 X Computational Cost

Random Forest on Images with No Shadows



At 90% recall, accuracy improves from 87% to 99.9%

CNN on Images with No Shadows



At 95% recall, accuracy improves from 81% to 100%

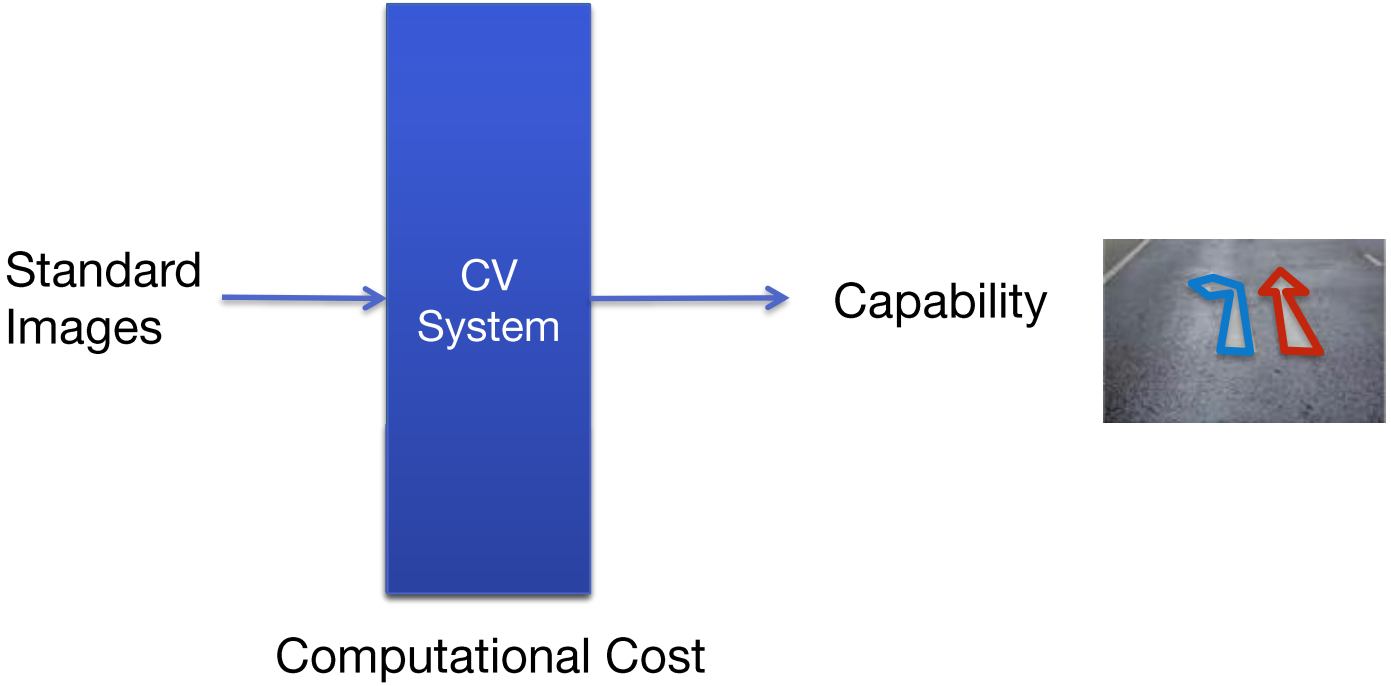
Even RGB CNN doesn't do as well (99.1%)

Why?

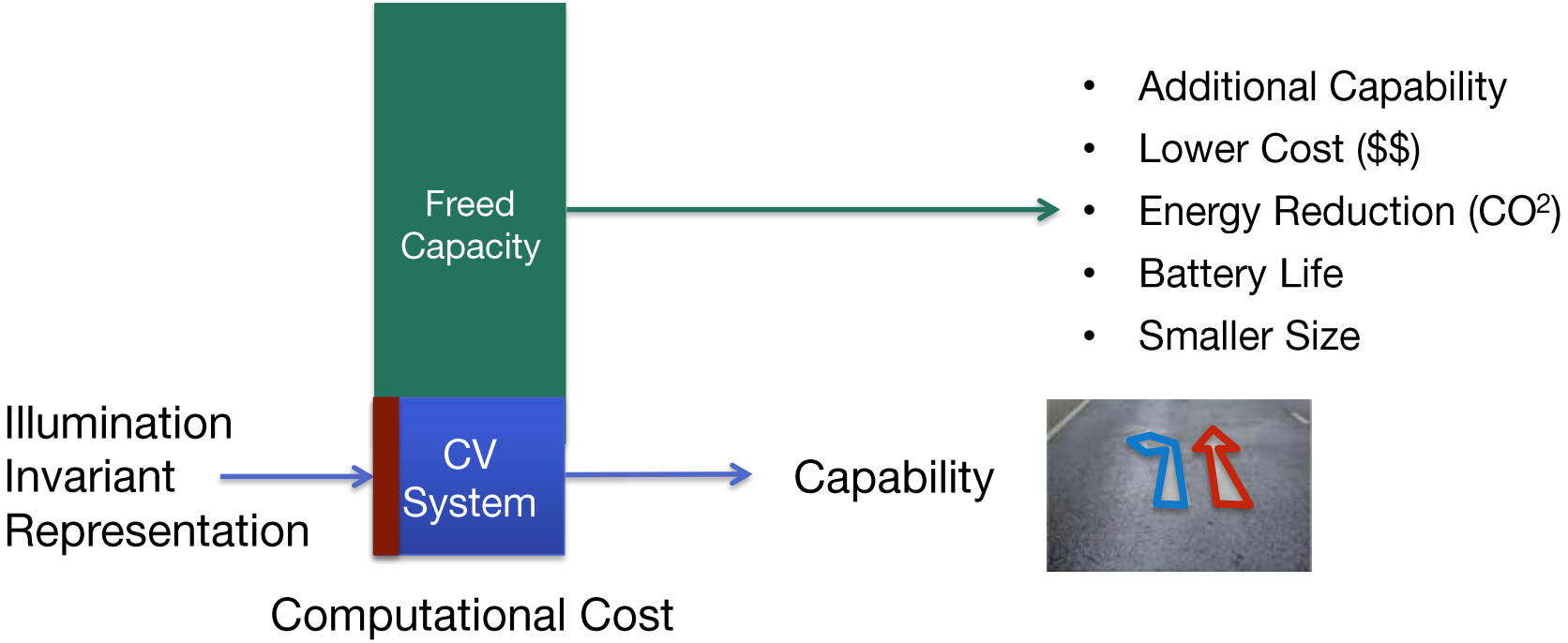
Illumination mimics the signal of interest

- Intensity Patterns
- Spectral Patterns
- Spatial Patterns

Value of a Physics-Based Approach

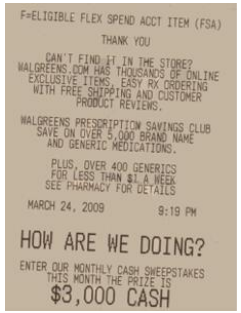


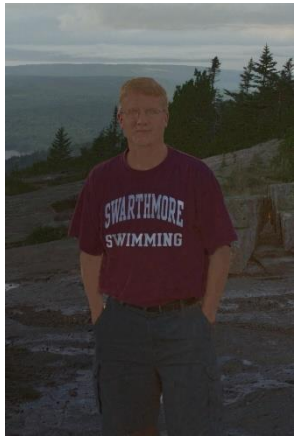
Value of a Physics-Based Approach

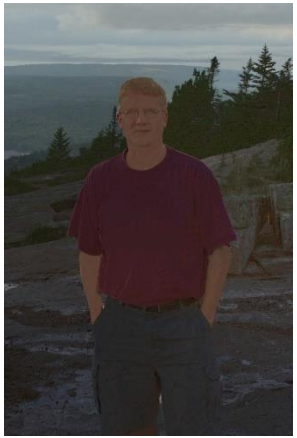


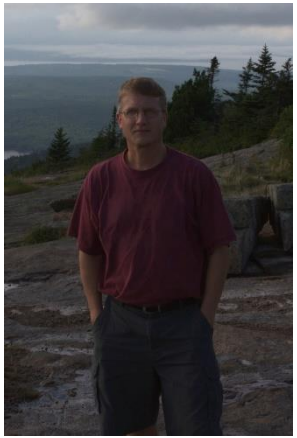
- Additional Capability
- Lower Cost ($$)
- Energy Reduction (CO^2)
- Battery Life
- Smaller Size

Diverse Applications









Find Out More

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Log Space Chromaticity: https://ieeexplore.ieee.org/document/4587491/?tp=&arnumber=4587491

Video Sequences

https://vimeo.com/256140601/e72e927f93
https://vimeo.com/257804616/c73f4e5642
https://vimeo.com/256141155/b07d502d65
https://vimeo.com/256141223/85b320a60c
https://vimeo.com/257804979/cdd4308664

Contact Us!

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Road Vision in Action

Different Problems

Snow

Heavy Rain

Night Driving

Thank You