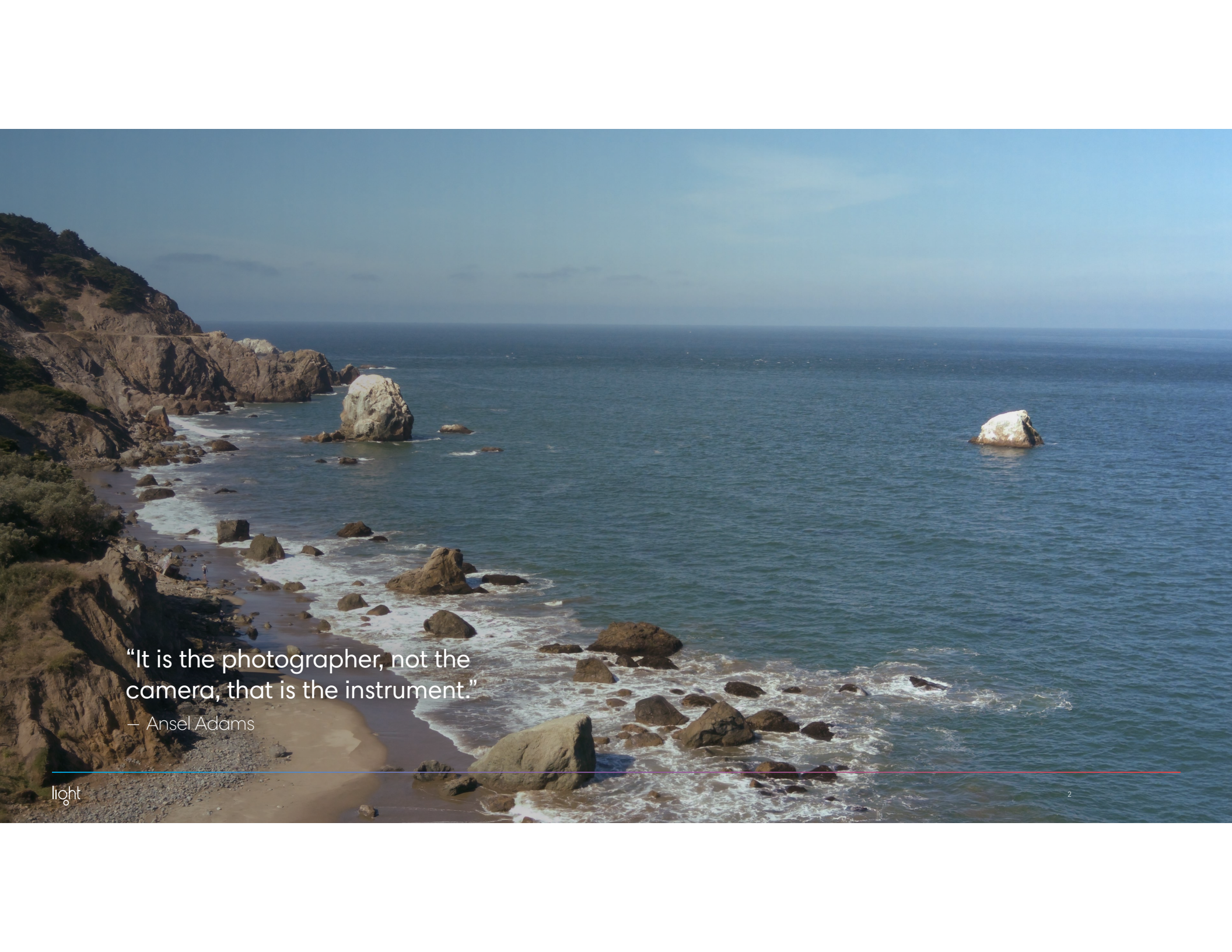


light

Gathering Light  
Rajiv Laroia, Co-founder & CTO

October 16, 2015

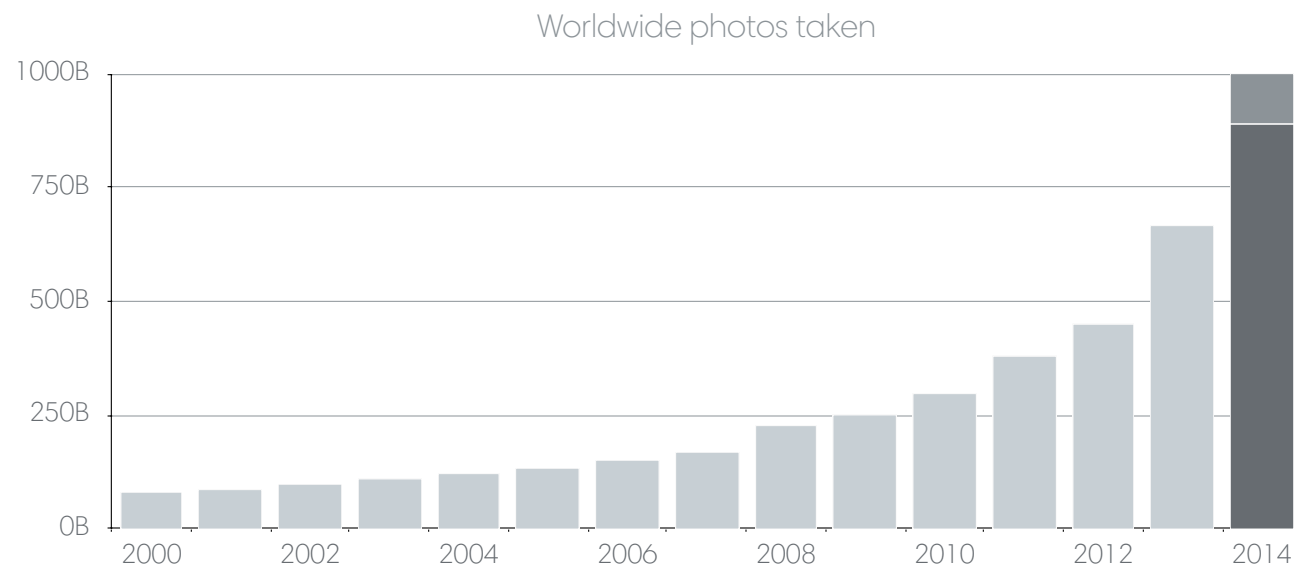
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“It is the photographer, not the camera, that is the instrument.”

— Ansel Adams

# Photos are now **the** communication medium



Source: CIPA, Tomi Ahonen Phone Book '14, 1000memories, Mylio

## The problem we solve

High-quality optics are big and bulky



Radically miniaturized



## The Light L16 Camera



- 16 individual camera modules
- Three different focal lengths
  - 5x35mm; 5x70mm and 6x150mm
- Smartphone size sensors
- All f/2.4 P5 lenses

## The big picture

- Developed system technology
- Capitalize on cell phone camera-fueled element-level innovation
  - High resolution sensors
  - Molded plastic lenses
  - Android operating system
    - Intuitive user interface
    - Social media integration

## Molded plastic lenses – a silent revolution

- Smartphones today use no glass in their lens – only plastic
  - Canon and Nikon use exotic optical materials
- Perfection of molded plastic lens technology over last five years
  - Why are plastic lenses better than glass?
  - Today's plastic lenses are diffraction limited!

A diffraction limited  $f/2.4$ , P5 smartphone lens is about \$1 in volume  
A 13 MPix smartphone sensor is about \$3 in volume

## What is the diffraction limit?

- An ideal lens - light (energy) from a point source converges to a single point image
- Light is a wave and the image energy spreads to a region (disk)
- Size of the disk (point spread) proportional to the f-number
- Diffraction limit is like the AMT (alternate minimum tax)
- Lens performance depends upon aberrations and diffraction
- A diffraction limited lens is as good as physics will allow it to be



## Why are smart phone cameras not good enough?

- Three main issues
  - Grainy picture
    - Small opening for light capture
    - Limited dynamic range
    - Poor low light performance
  - No control over depth-of-field
  - No optical zoom

## Dynamic range of small sensors

- Pixel is like a bucket (cup) that collects photons
- Capacity of a modern phone sensor pixel is about 5k photons
  - Very little light energy used to take pictures
- With a 10 bit quantizer, each level corresponds to about 5 photons
- At that level flow of energy is not continuous (particle nature of light)
  - Photons follow a Poisson arrival process
  - Injects noise into the image captured
  - Limits dynamic range

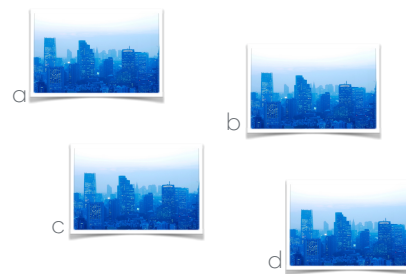


1000 levels

## Use multiple small camera modules to solve for these problems

- Increases effective pixel area (bucket size)
  - Better dynamic range
- Sensors with no color filters
  - Better low light performance
- Capture multiple perspectives
  - Depth-of-field control

# How does a camera take pictures?



## Focus and depth-of-field

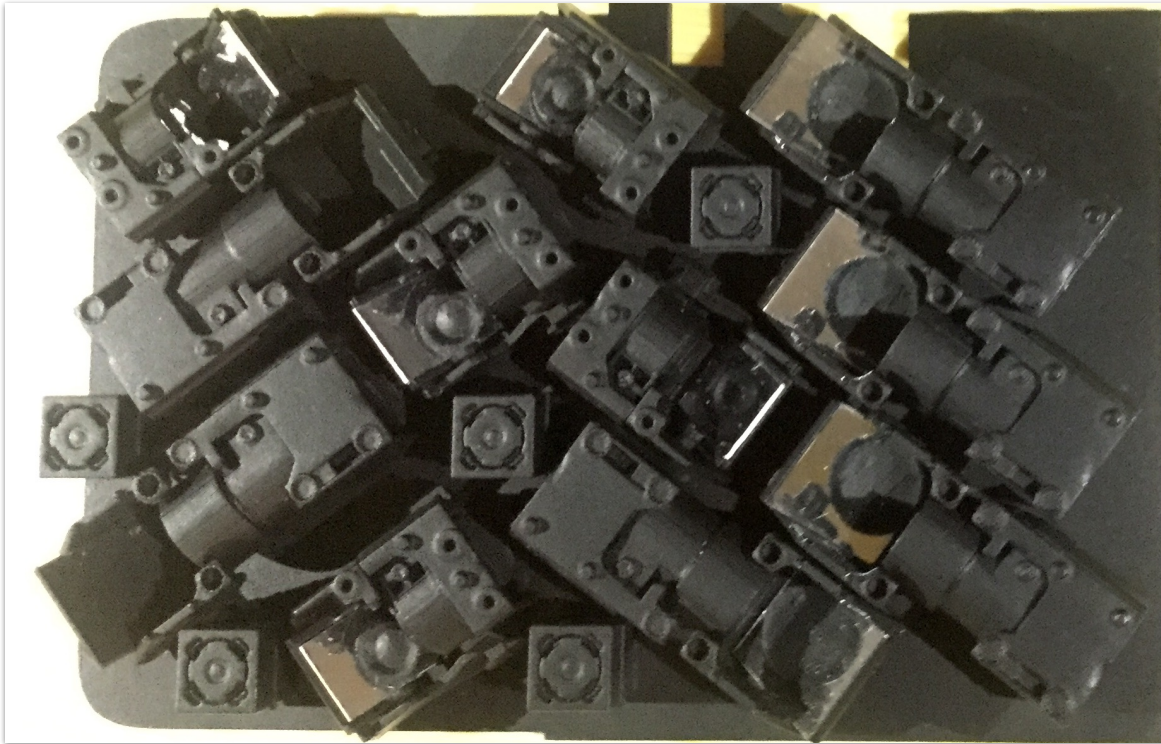
- Every piece of the lens (aperture) forms the entire picture on the sensor
- The lens analog adds (coherently) all these images
- The sensor digitizes the combined image
- Objects in the plane of focus are sharp
  - Their images from different parts of lens are rendered at the same location
- Objects not in the plane of focus are blurred
  - Their images from different parts of the lens are offset from each other
- Bigger aperture leads to shallower depth-of-field

# Emulating a big lens



- Put a small camera module at each hole
  - Small lens, small sensor but identical field-of-view
- Each module captures the image that the corresponding part of the lens renders on big sensor
- Digitally add these images to emulate big lens

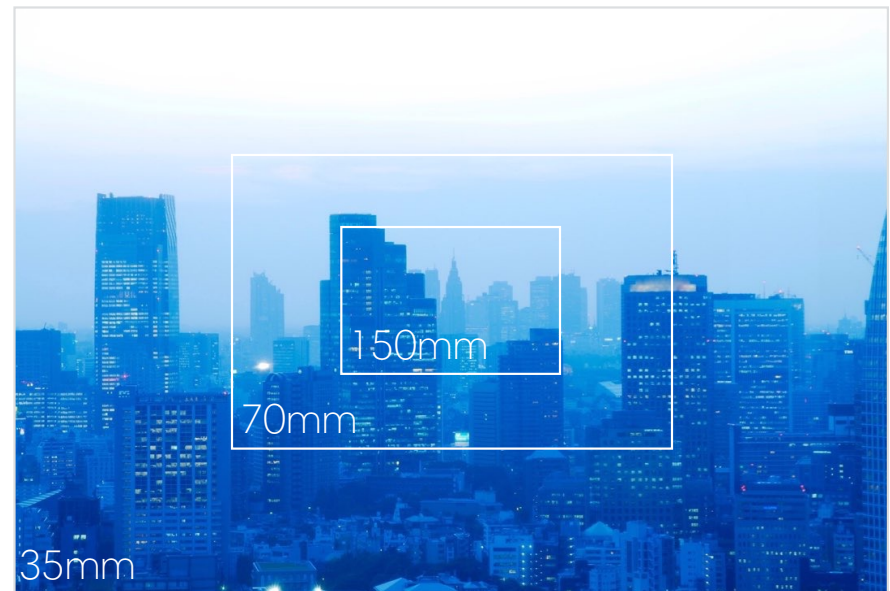
## Light systems technology



Total of 16 f/2.4 camera modules

- 35 mm (equivalent) x 5
- 70 mm x 5
- 150 mm x 6

# Field-of-view of three types of prime lenses





# Taking images at 35 mm



13MP cameras @ 35mm/70mm  
(10 shots per photo)



52MP photo at 35mm

# Taking images at 70mm



13MP cameras @ 70mm/150mm  
(10 shots per photo)



52MP photo at 70mm

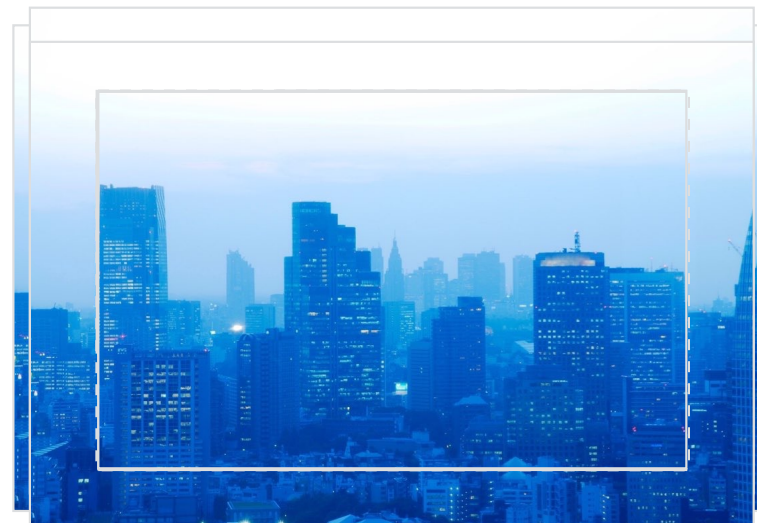
## Continuous zoom?

- Change focal length of camera modules
  - Compromised design
  - Mechanical precision too difficult
- Continuous zoom with fixed focal length lenses
  - Systems solution
  - No complex mechanical motion
  - Only tilt mirrors

# Taking images at 50mm



13MP cameras @ 35mm/70mm  
(10 shots per photo)



~40MP photo at 50mm

## Generating images - computational imaging

- Combine 10 images into a single image
  - Generate depth information
  - Control depth-of-field
  - Control bokeh
  - Control perspective
- Higher dynamic range
- Lower noise

## Aperture and shutter

- Aperture
  - No explicit aperture control
    - Diffraction limited lens - reduced sharpness
  - Aperture setting for depth-of-field control
  - Smooth waterfall long exposure time shots?
- Electronic rolling shutter - no mechanical shutter
  - Rapid motion could introduce distortion











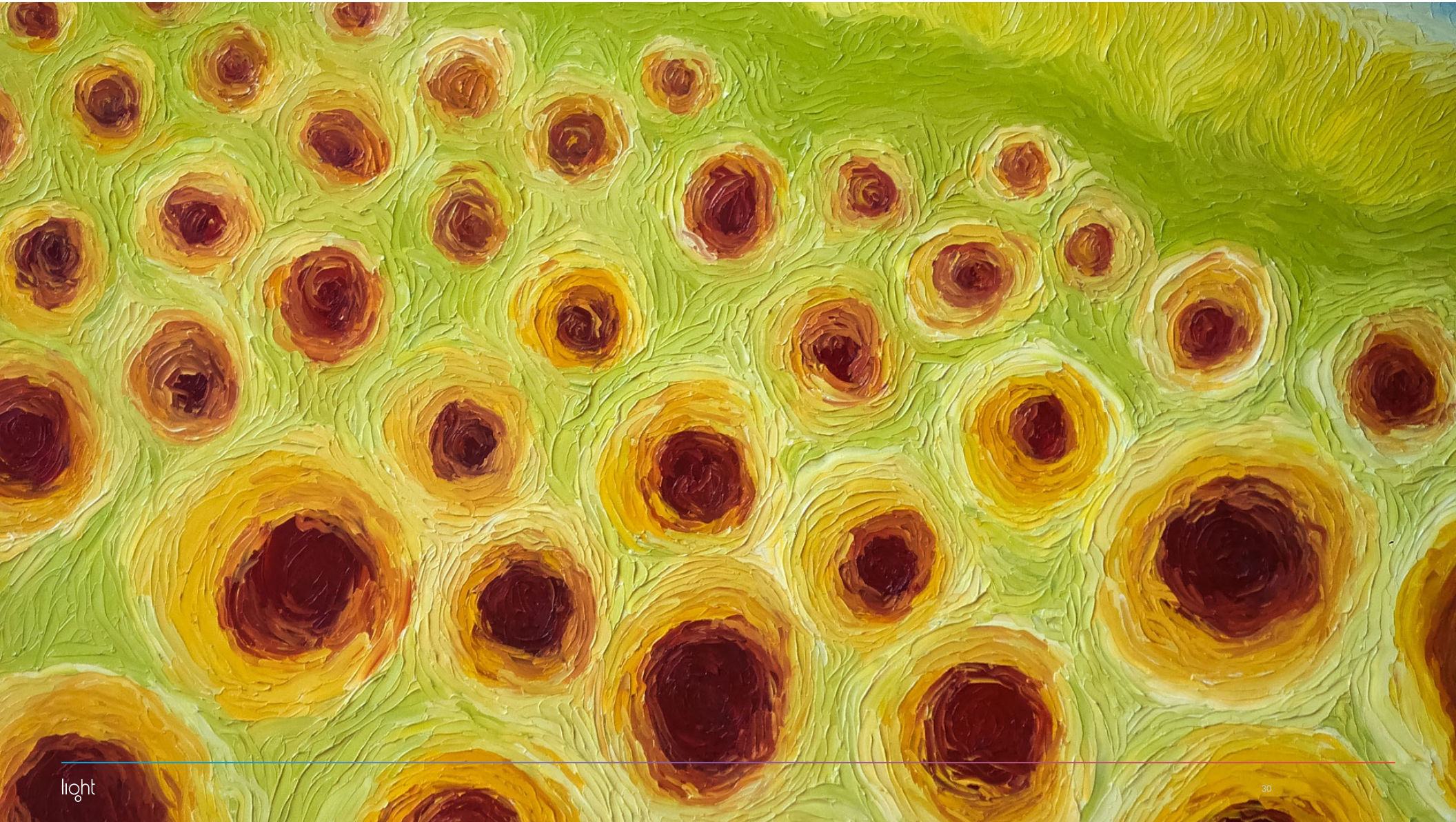




light



light

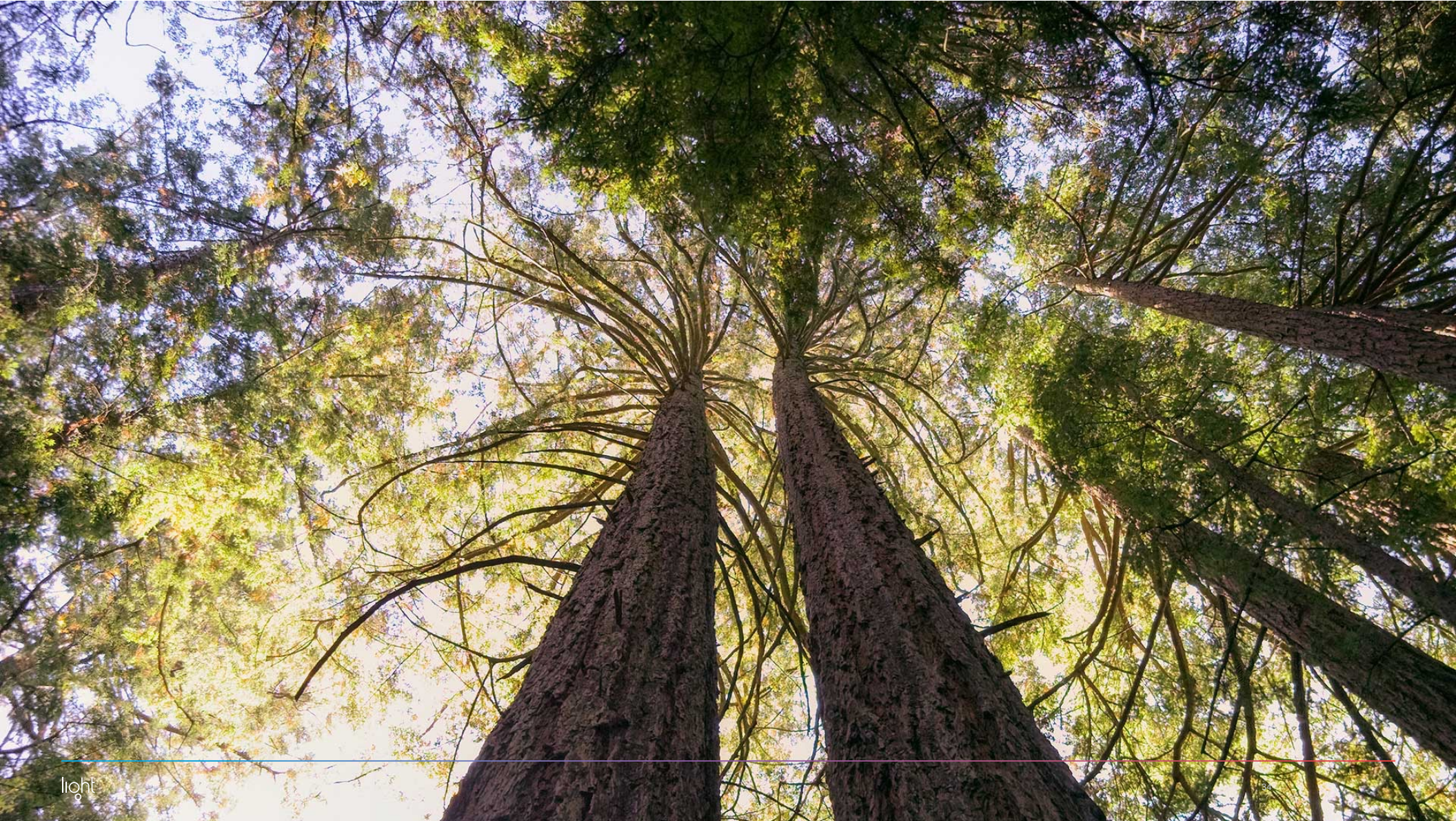










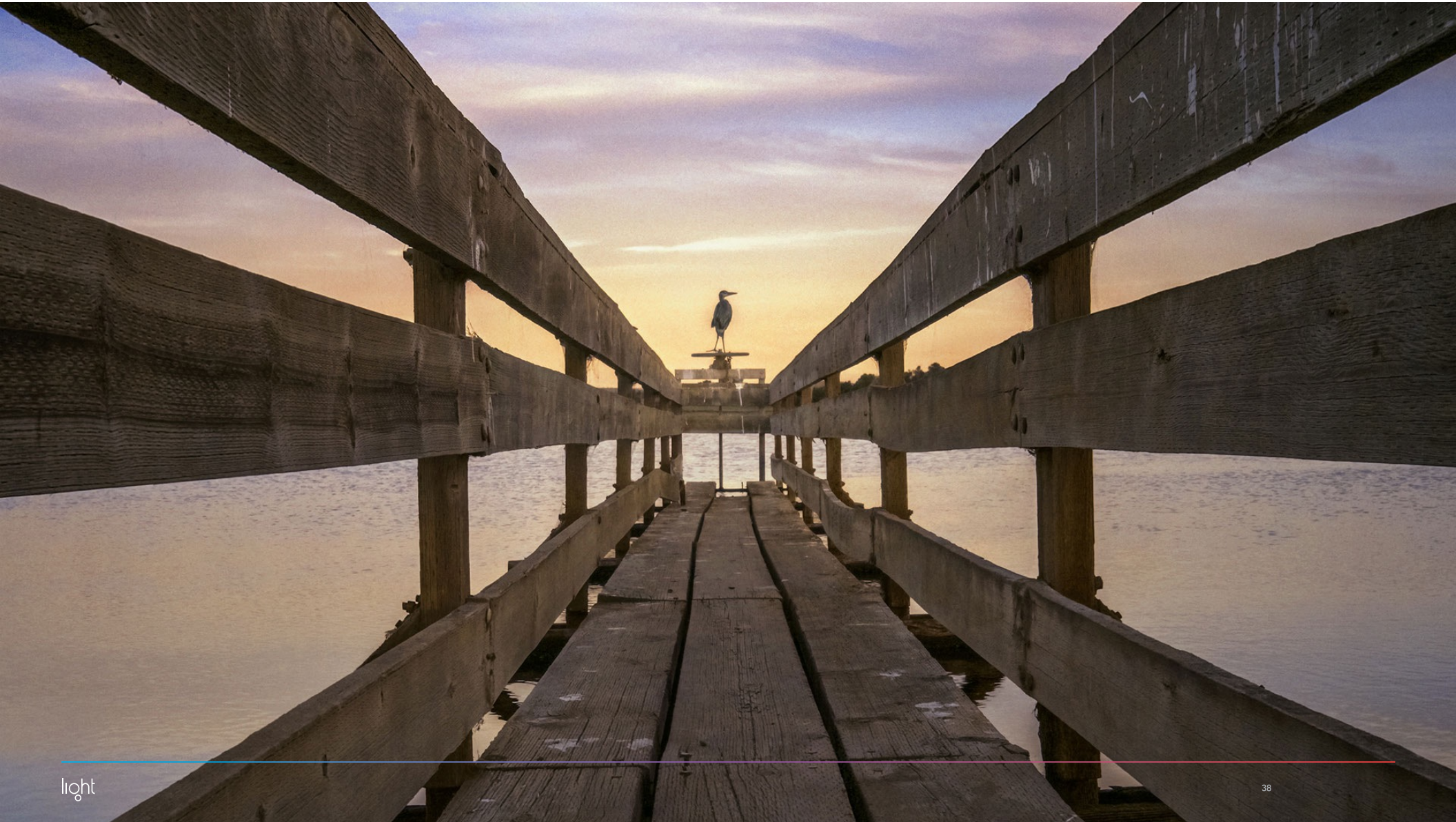


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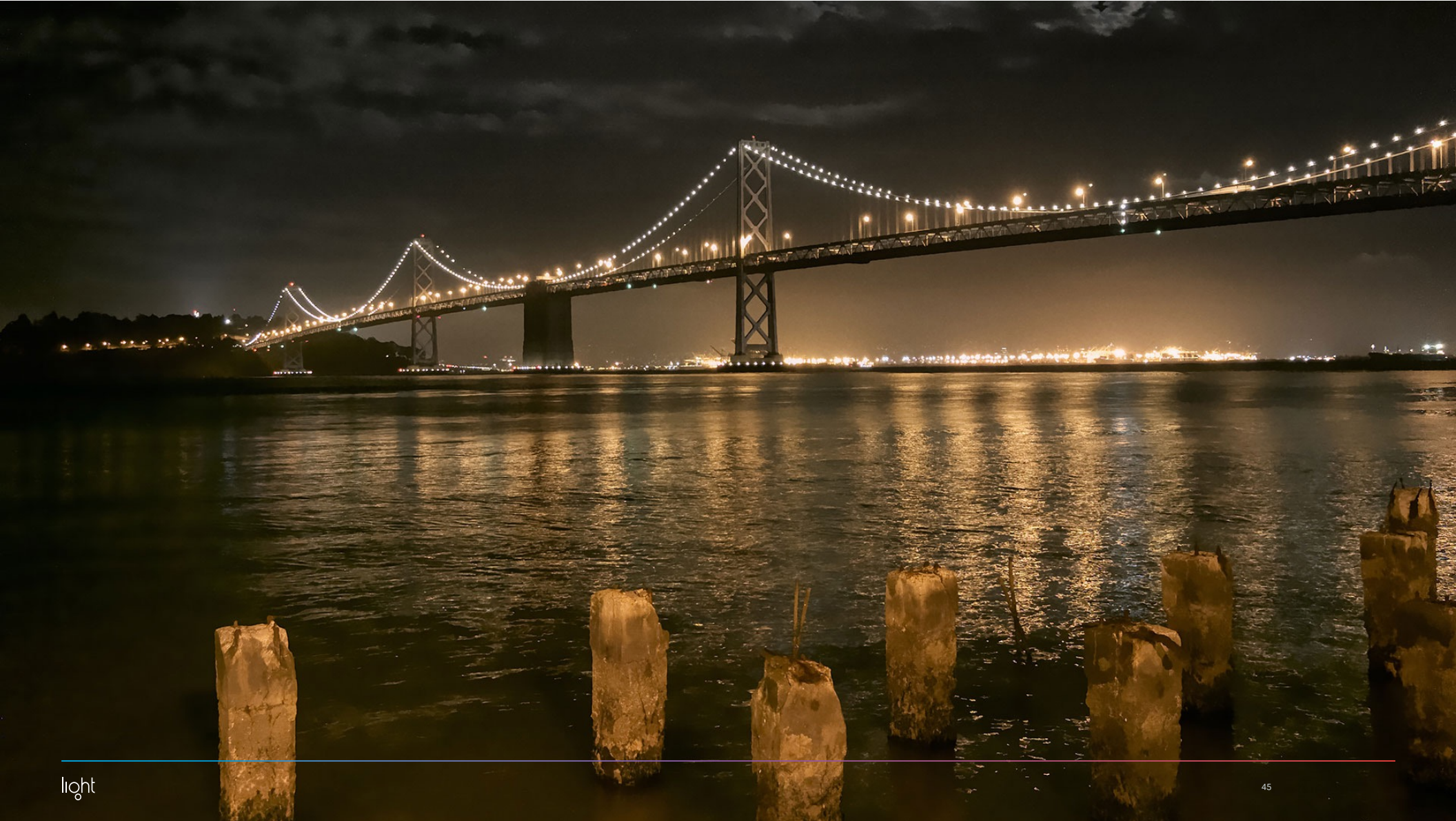














Thank you

# Contact

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