



OUSTER

DVN LIDAR Conference

November 2018

LIDAR - What Matters?

- Performance
 - Range
 - Angular Resolution (horizontal, vertical)
 - Field of View (horizontal, vertical)
 - Scan rate/frame rate (per second, in Hz)
 - Range repeatability (range “noise”)
 - Power consumption
 - Spatial resolution
 - Spatial accuracy - any “blooming”, artifacts, etc (How accurately you measure the location you think the LIDAR is pointing in)
 - Environmental variability (e.g., over broad temperatures, in high humidity, peak sun, inclement weather)
 - Functionality amidst window obstruction
 - Other features (e.g., color, multiple returns, region of interest)
- LIEDAR: Beware of “Cherry Picking” and not reporting on performance on all dimensions at once
- Price
- Form Factor
 - Size
 - Mass
- Quality/Reliability
 - Automotive Spec
 - Ingress
 - Shock/Vibe/Jitter
 - Thermal Range & Cycling
 - Corrosion
- Scalability/Availability
 - Product or PowerPoint Slide?
 - Manufacturability

Lidar Landscape - Technology

		Advantages	Disadvantages
Multi-Beam Flash LIDAR	Ouster	<ul style="list-style-type: none"> Is a real product High range / res. Low-cost, compact 	<ul style="list-style-type: none"> Standard CMOS Power efficient Limited crosstalk True solid state sensor 2019
FMCW	Aeva Blackmore	<ul style="list-style-type: none"> Can read velocity without compute 	<ul style="list-style-type: none"> Power hungry & expensive lasers Low resolution / frame-rate INS required to compensate for system movement Velocity sensing is only at 0° incidence to target
MEMS 905nm or 1550nm	905 nm - Magna/Innoviz - Bosch - Velodyne 1550 nm - AEye	<ul style="list-style-type: none"> Some low-hanging fruit to make near-term semi-solid-state LIDAR with decent performance 	<ul style="list-style-type: none"> Need to combine many MEMS/laser modules to achieve reasonable FoV Aperture/mirror size/FoV tradeoffs Limited long-run avenues for improvement Crowded IP landscape, IP battle likely 1550nm limitations below Not truly solid state
Galvo or Prism 1550nm	Princeton Lightwave (flash) Luminar Innovusion	<ul style="list-style-type: none"> Long-range today – 200m+, Can be helpful for AV R&D 	<ul style="list-style-type: none"> Expensive: Getting to \$5-10,000 is likely limit Currently \$70-100K, will not be <\$10,000/unit in the next 10 years Large & power hungry Exotic semiconductor tech - InGaAs
Conventional Flash LIDAR	Continental (ASC) TetraVue Leddartech	<ul style="list-style-type: none"> High frame rate Cheap Truly solid state 	<ul style="list-style-type: none"> Extreme range / resolution tradeoff Large form factor Cross-talk
Other	Quanergy (OPA), Strobe (OPA) Blackmore (OPA) Oryx (LW IR antennae) Xenomatix Valeo Scala	<ul style="list-style-type: none"> No moving parts 	<ul style="list-style-type: none"> Exotic, challenging technology, 10+ yrs Limited field of view and range <hr/> <ul style="list-style-type: none"> Exotic, challenging technology; side lobes, range Product >5-10 yrs away Similar challenges as flash LIDAR

Corporate Overview

Our mission: Bring 3D sensing to the masses

Focused on delivering a compact, inexpensive, high-performance, and practical product from day-one

Developing both scanning and true solid state lidar

Shipping products, not promises

KEY FIGURES

3.5 years of development

7th generation custom ASIC

>\$70 million raised

46,000 ft² R&D & production facility

>20,000 units/yr run rate by Q2 '19

>60% of the lidar market as
as customers... and growing

The Same Technology in Smartphones

We customized the same type of semiconductor technology used in the iPhone X Face ID, added new 3D sensing algorithms, and integrated it on a compact spinning platform. The result is 360° field of view and long range performance in a compact form factor.



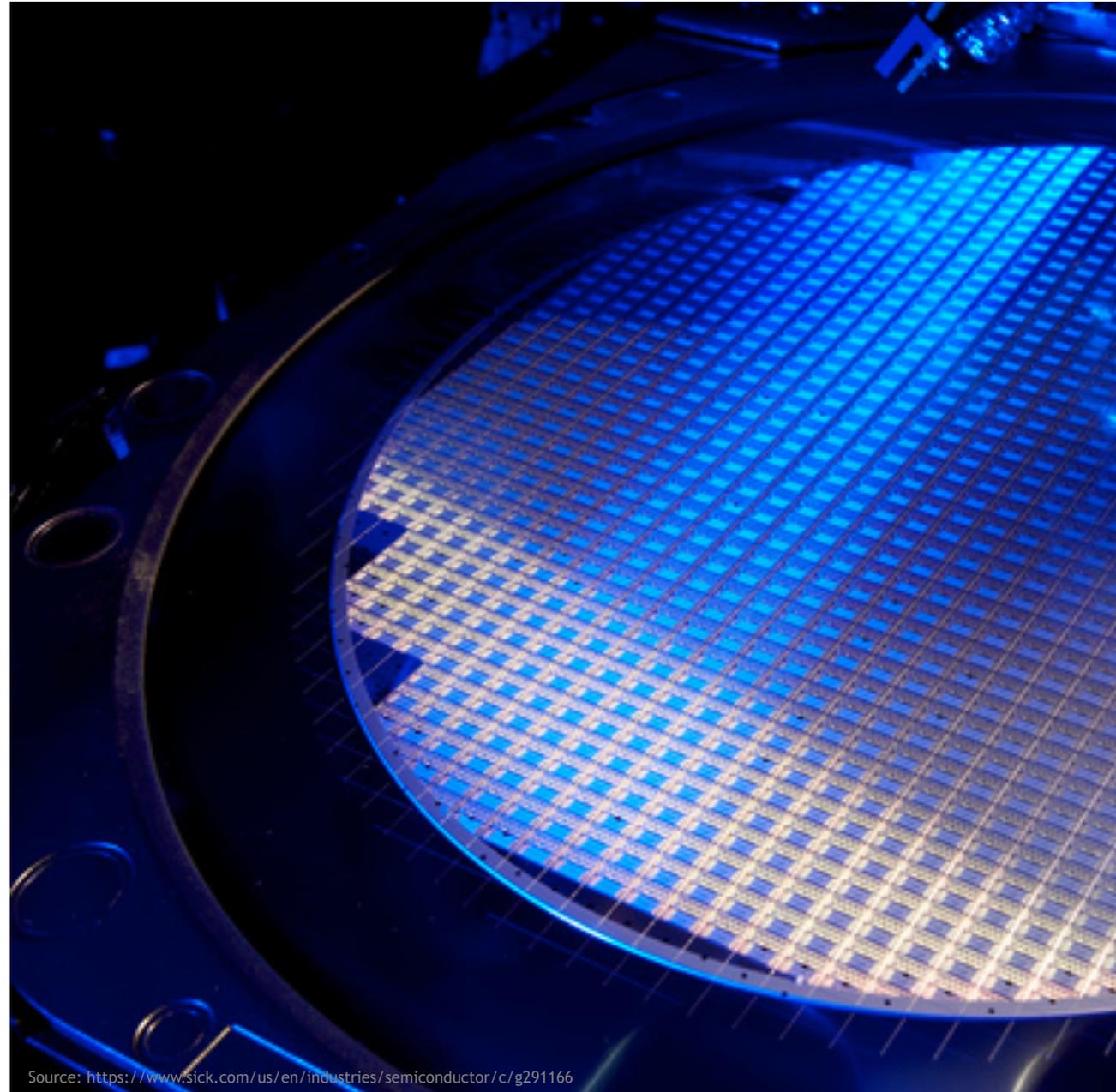
These are mature, low cost, silicon CMOS technologies that are improving with Moore's Law.

2<1000

Replaces thousands of electronics in a traditional lidar with two custom chips: Laser. Detector.

It took 3 years to make this simple approach work, and the result is lower power, lower cost, and higher performance.

Because it's standard CMOS, it gets better every year, keeping pace with Moore's Law.



The Bumper Test



Product Portfolio

OS-1 ^(16 OR 64)



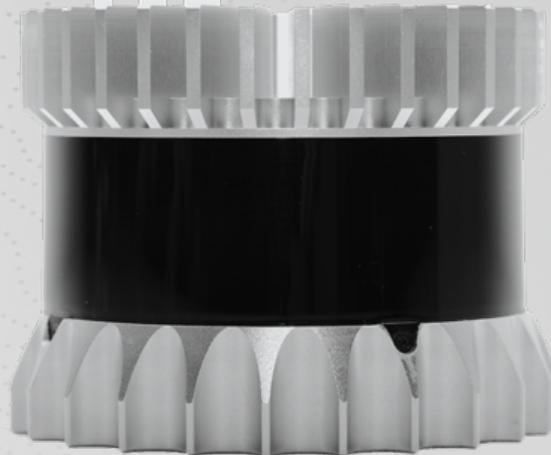
Available Now

64 - \$12,000

16 - \$3,500

Multiple field of view
options

OS-2 ⁽⁶⁴⁾



Available early Q1

>200m range

50% tighter beam
spacing

**Industry
Leading
image quality**

**30X Lighter
30X Smaller**

**4X Less
Power**

6X Cheaper

What sets Ouster apart

- Best-in-class resolution, power efficiency, size, mass
- All semiconductor design
- Shipping today
- Transparent, market-leading pricing
- Publicly available raw data sets
- We never avoid live demos
- Regular firmware updates



What sets Ouster apart

- Unrivaled accuracy: Hardware-triggered & fixed-angle firing
- Camera-like image quality: Best dynamic range, beam-beam uniformity, & spatial resolution
- Native ambient NIR sensing per pixel
- Supports IEEE 1588 Precision Time Protocol
- Limited or no crosstalk between sensors
- Industry leading intrinsic calibration
- Detachable connector



Ambient + Signal + Depth at Every Pixel

Ambient Image



Signal Image



Range Image



Ambient Image



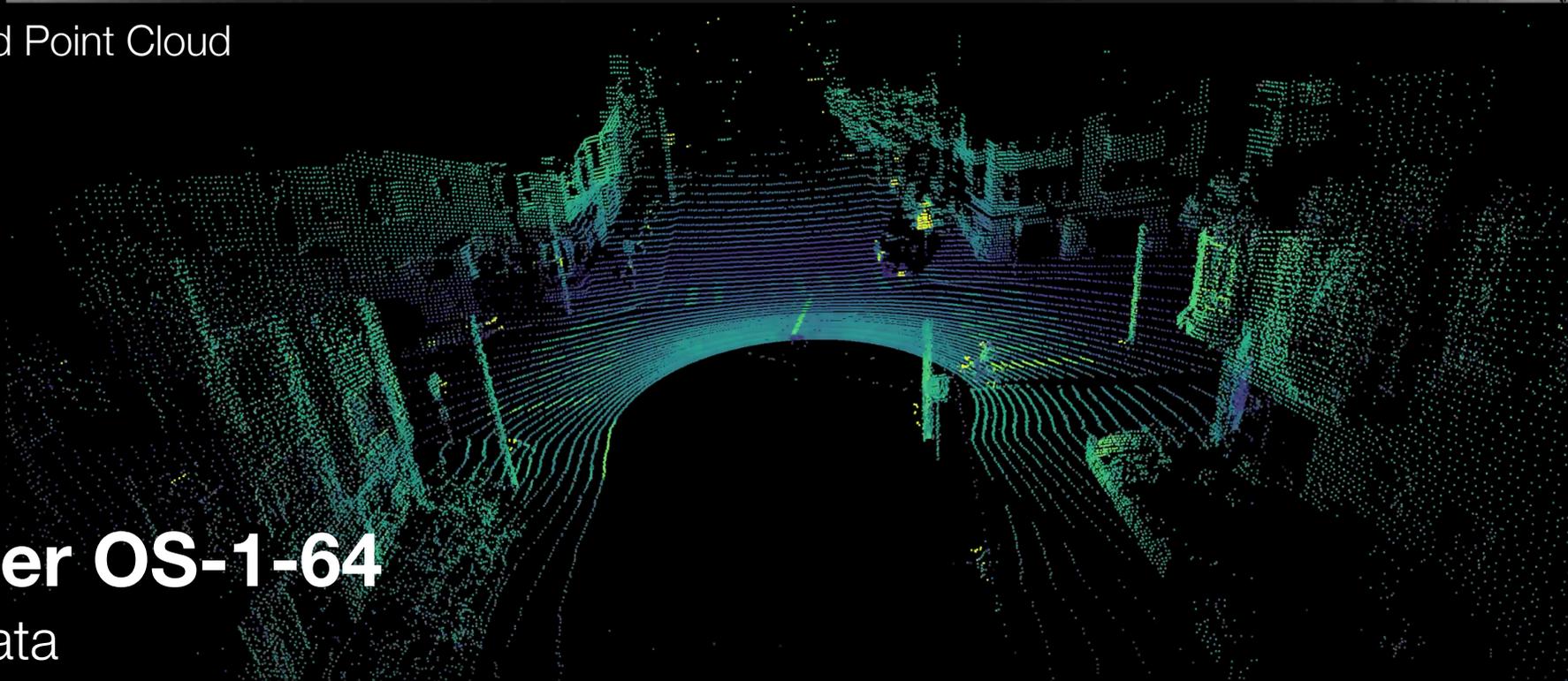
Signal Image



Range Image



Combined Point Cloud



Ouster OS-1-64

Raw data

Ambient Image



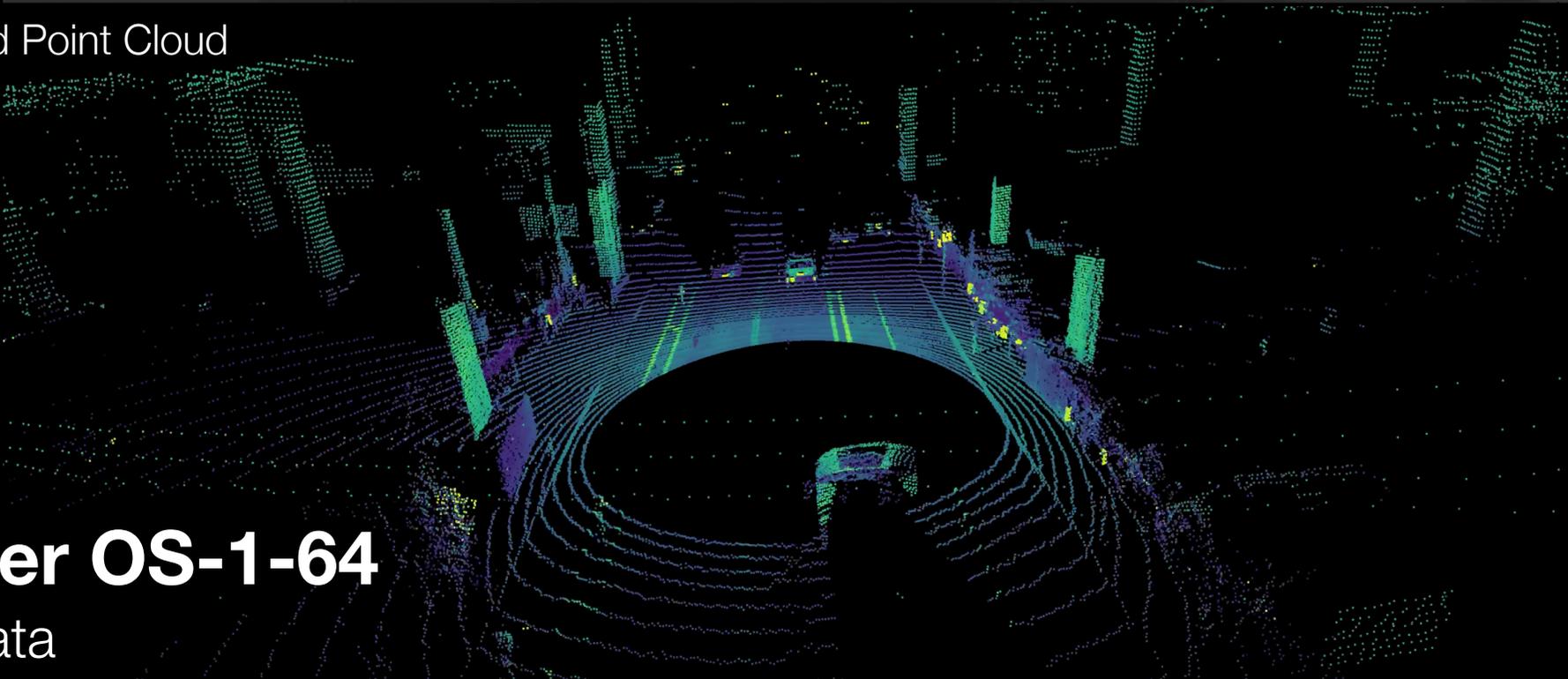
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Range Image



Combined Point Cloud



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Raw data

Ambient Image



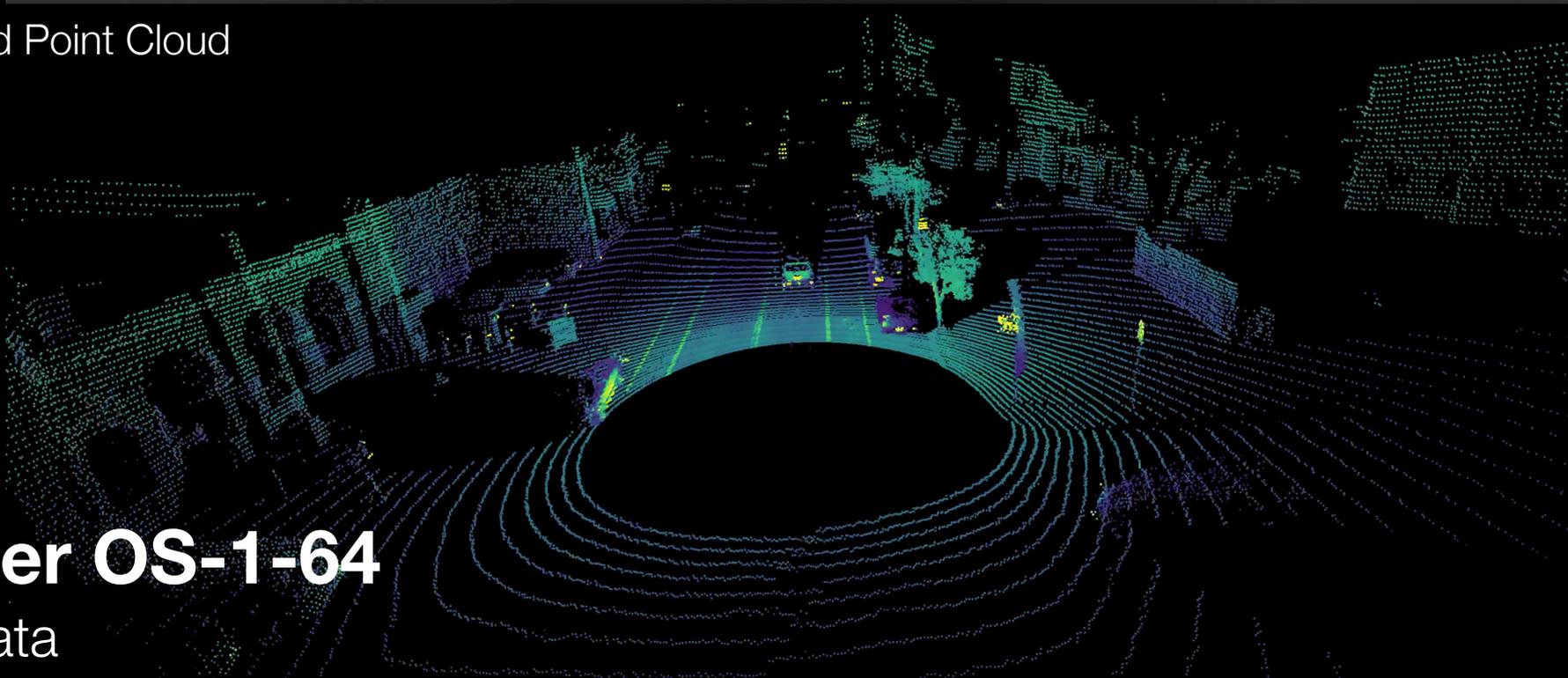
Signal Image



Range Image



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Raw data

Ambient Image



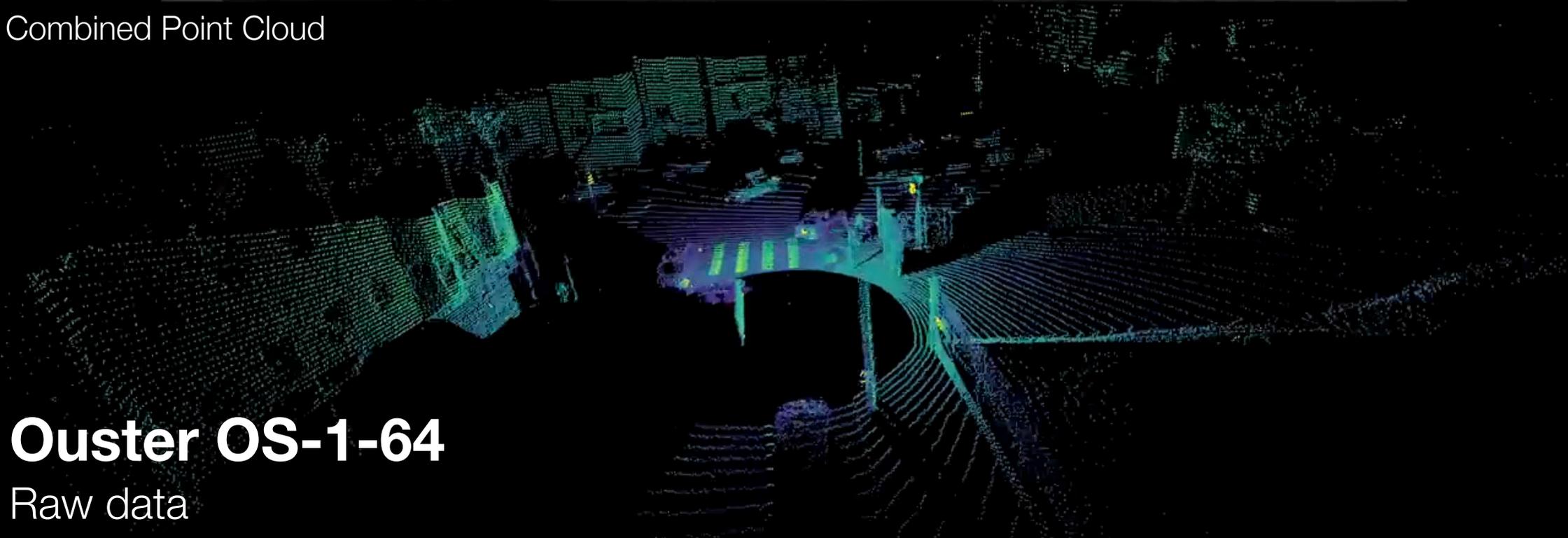
Signal Image



Range Image



Combined Point Cloud

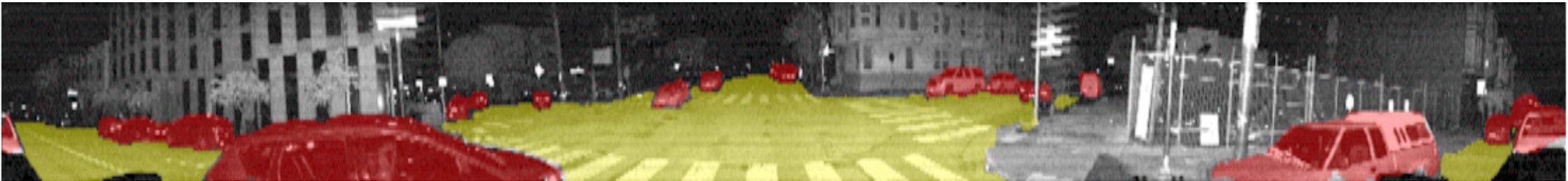


Ouster OS-1-64

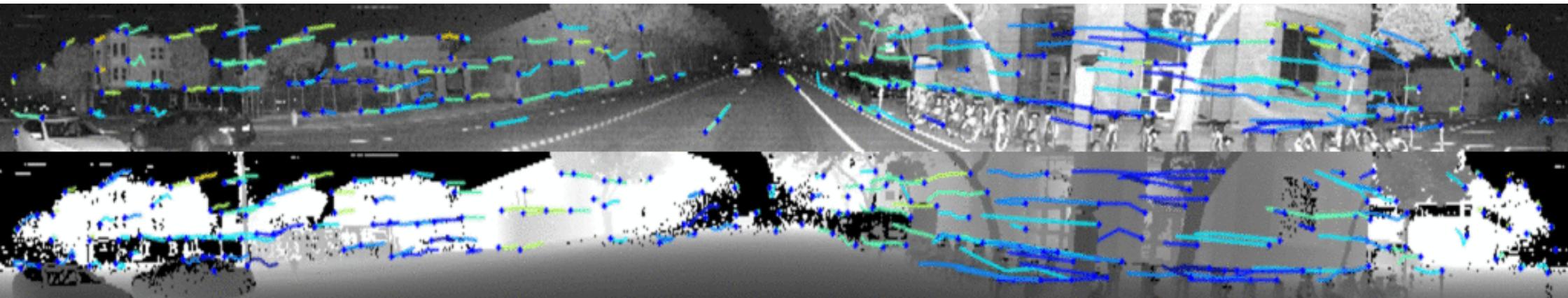
Raw data

New Opportunities for Camera/Lidar Processing

CNN based semantic segmentation on combined ambient, signal, and depth images

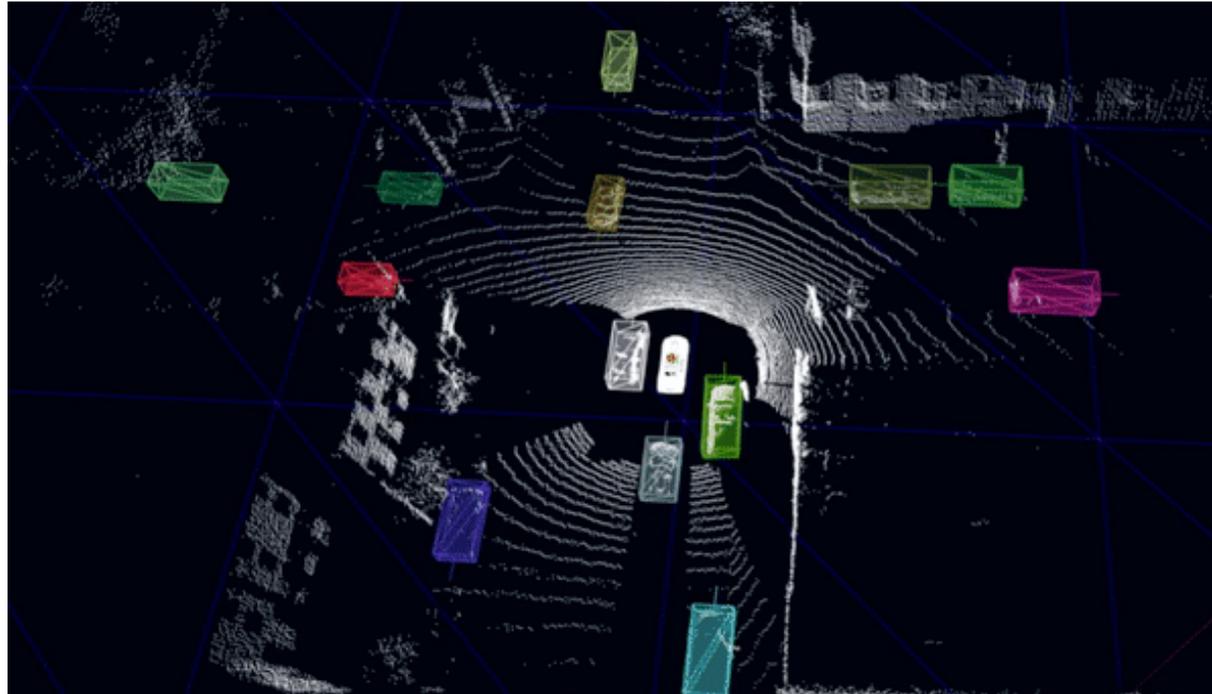
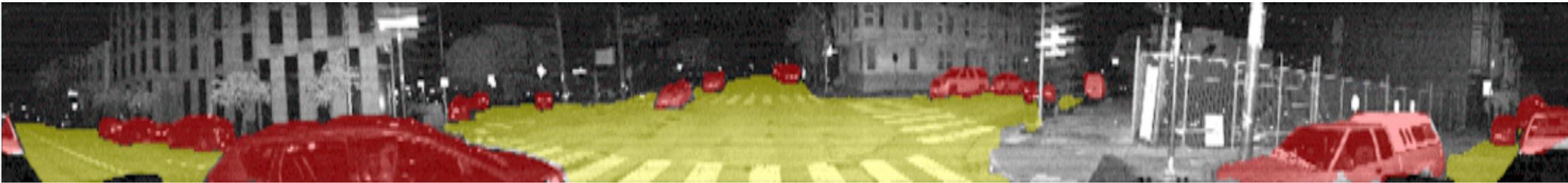


Superpoint: CNN based key point extraction and correspondences run on signal and depth images.



Trivial To Transform Between 2D and 3D Frames

- 1:1 spatial correspondence between ambient, signal, and depth pixels
- perfect temporal alignment of data layers

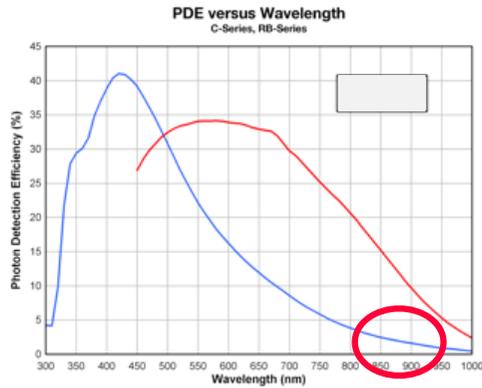


Ouster Roadmap: Continued Platform Improvement

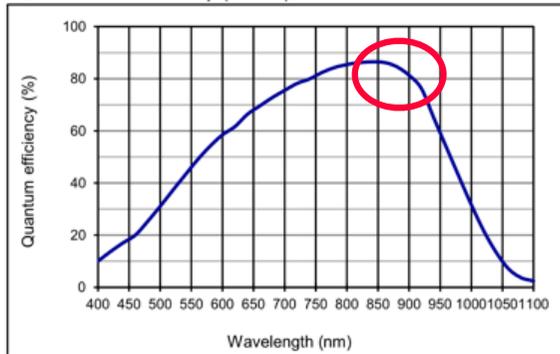
SPADs

- Silicon SPADs could easily have 10x-30x sensitivity improvement in the next 5 years.
- APD's are a mature technology with little headroom for improvement.

Example SPAD



Quantum efficiency (23 °C)



First Sensor
NIR enhanced
APD

VCSELs

- VCSEL peak power and efficiency are growing rapidly
- Global VCSEL production will expand in volume by >100x in the next 5 years

Why Apple is putting \$400 million into lasers

Face ID today, AR tomorrow.
By Dan Frommer | @fromdome | Dec 18, 2017, 1:00pm EST



Setting up Face ID on Apple's iPhone X. | Recode / Dan Frommer

Apple said today that it would give \$390 million to Finisar, one of its suppliers, to build a plant in Texas for a part called "vertical-cavity surface-emitting lasers," or VCSELs.

Osram acquires VCSEL specialist Vixar

08 May 2018

Strengthens portfolio for security apps; also Osram has boosted the efficiency

Osram has announced the acquisition of US-based VCSEL developer Vixar, a deal which the German photonics giant says will enhance its "expertise in semiconductor-based optical security technology."

Osram added that it will now have a breadth of technological knowledge and an expanded product portfolio after bringing on board Vixar's specialist capabilities in the field of VCSELs. While currently known primarily for identification applications in mobile devices, VCSEL also can be used to recognize gestures and measure distances in medical, industrial, and automotive applications.

Vixar was founded in 2005 and is based in Plymouth, Minnesota. Approximately 20 employees of the company will transfer to Osram as a result of the acquisition. Vixar is described as "profitable both on an operational and net results level". Closing of the transaction is expected in summer, 2018, and the parties are not disclosing financial details.

Olaf Berlien, CEO of Osram Licht AG, commented, "The acquisition of Vixar is adding to our expertise, particularly in the fast-growing market for security technologies. Osram is a technology leader in infrared optical semiconductors and has already succeeded in helping to market light engines for

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