embedded VISION SUMMIT 2018

From 2D to 3D: How Depth Sensing Will Shape the Future of Vision

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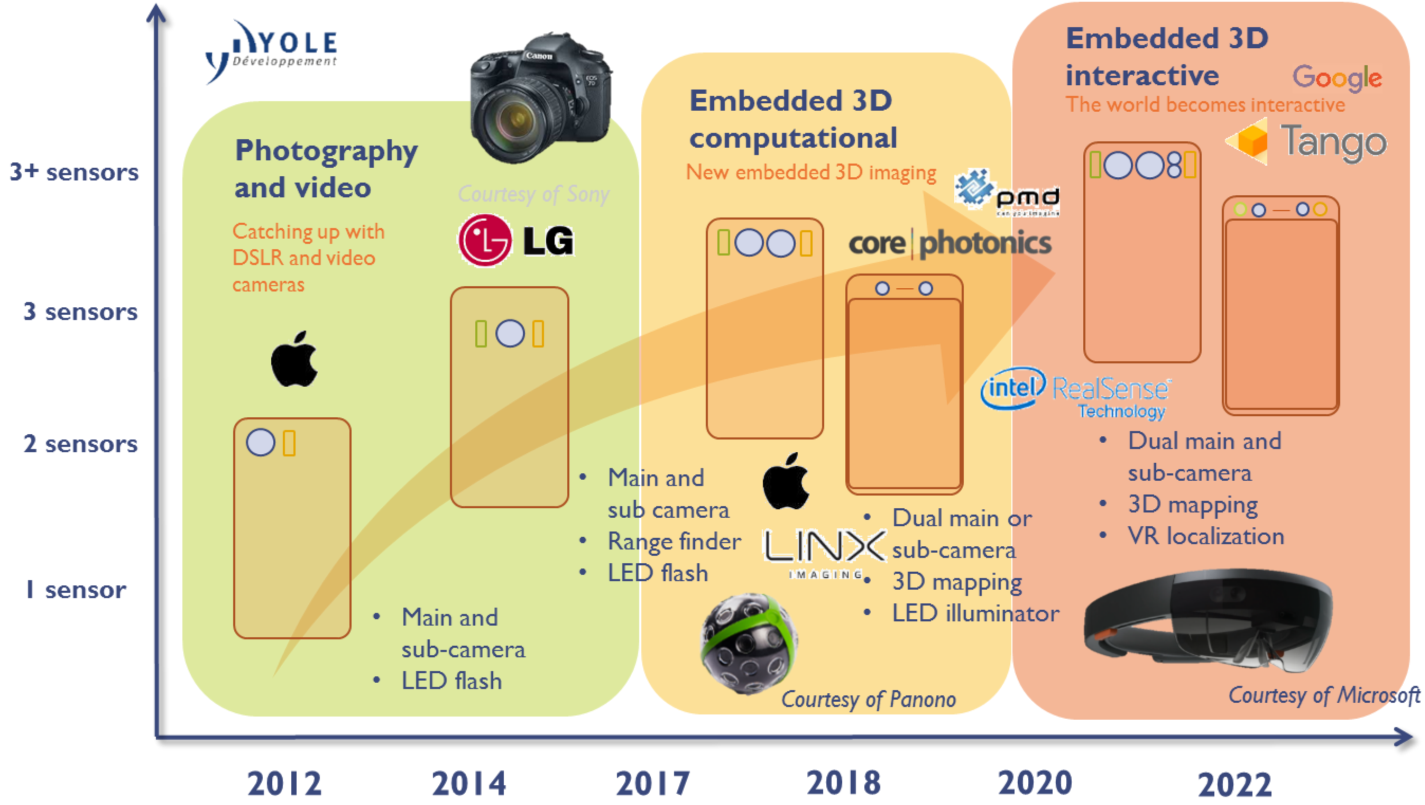
YOLE Développement

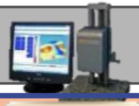
Tuesday, May 22nd 2018

Technology for the Next Decade



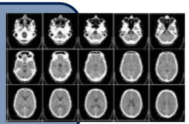
3D imaging and sensing technologies

Single frame 3D

- Interferometric (OCT) —  Courtesy of Heliotis
- ✓ Time of Flight —  Courtesy of Lenovo
- ✓ Structured light —  Courtesy of Intel
- Laser triangulation — 

  Courtesy of Keyence
- Plenoptic —  Courtesy of Lytro
- ✓ Stereo vision —  Courtesy of Stereo Labs
- Computational —  Courtesy of Light

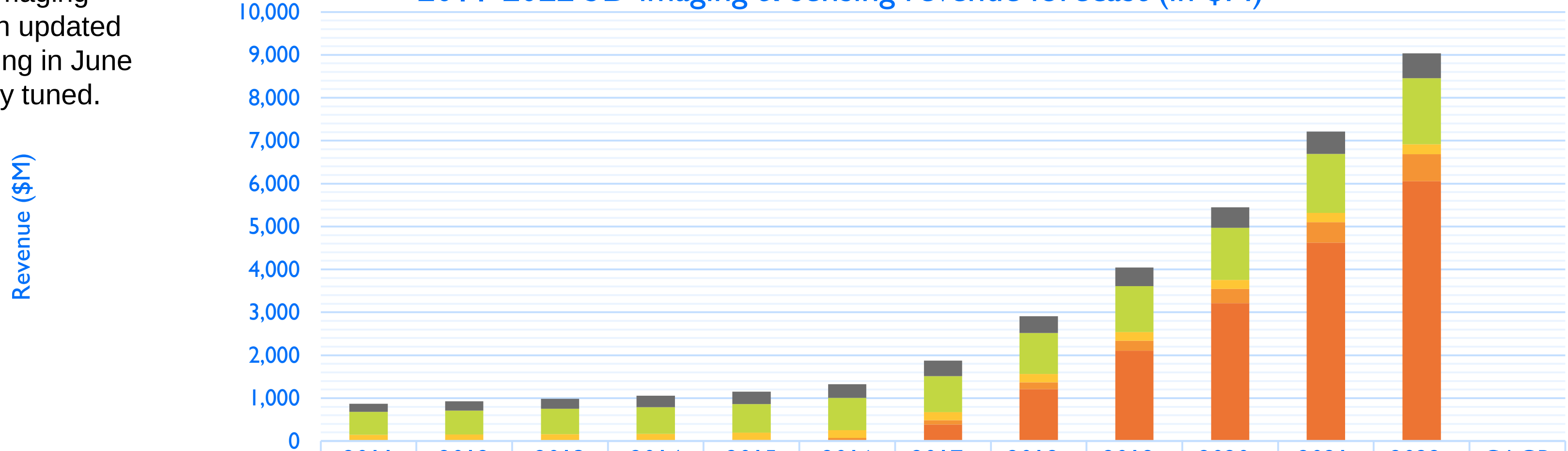
Multiple frame 3D

- Time-gated 
- Structure from motion 
- Computed tomography 

Depth-sensing Technologies

Yole's 2017 Data New 3D Imaging report with updated data coming in June 2018. Stay tuned.

2011-2022 3D imaging & sensing revenue forecast (in $M)



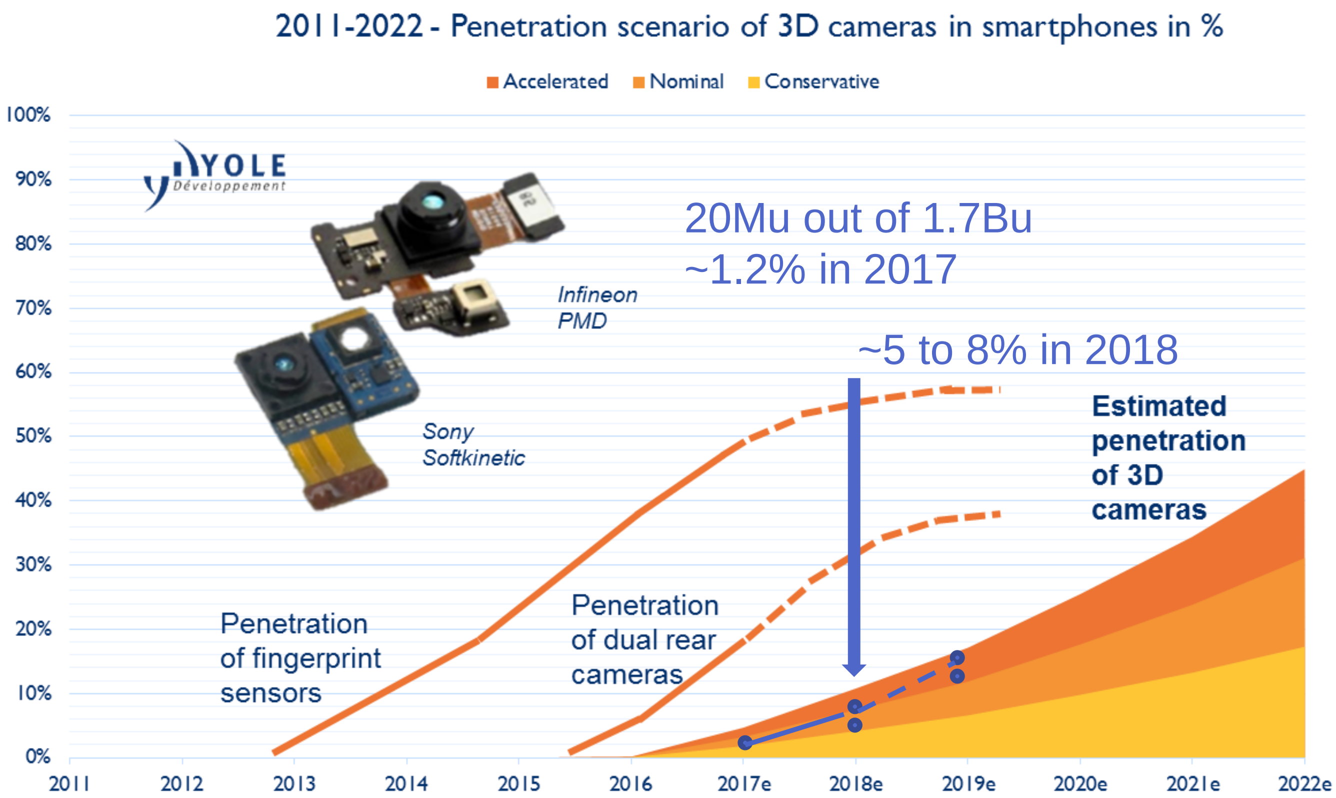
	2011	2012	2013	2014	2015	2016	2017e	2018e	2019e	2020e	2021e	2022e	CAGR
Scientific/Defence/Space	192	213	237	263	293	325	358	393	433	476	523	576	10%
Industry/Commercial	536	562	592	625	662	749	845	953	1,076	1,215	1,373	1,545	13%
Medical	141	148	155	162	169	177	186	193	202	211	220	230	5%
Automotive	0	0	0	0	23	56	99	160	232	332	475	625	49%
Consumer	3	3	3	4	6	20	385	1,211	2,102	3,211	4,623	6,058	158%
TOTAL	**872**	**927**	**987**	**1054**	**1153**	**1328**	**1873**	**2911**	**4045**	**5446**	**7215**	**9034**	**37.7%**
YoY		6%	7%	7%	9%	15%	41%	55%	39%	35%	32%	23%	

Depth-sensing Technologies Adoption Rate

The Lenovo Phab 2 Pro started the trend in 2017.

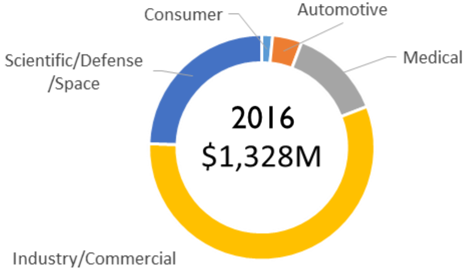
Apple released the iPhone X in September 2017 with their TrueDepth Camera.

The adoption rate will depend on several factors such as availability, appeal of the application and cost.



Depth-sensing Technologies

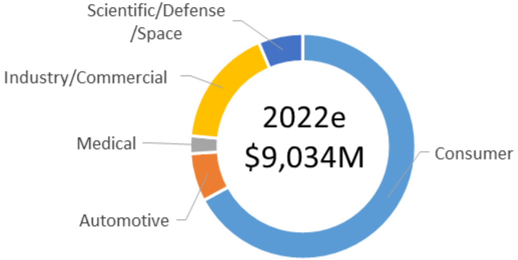
2016 - 3D Imaging & Sensing
revenue breakdown
by market



Courtesy of Faceshift

Market ($M)	2016	2022e	CAGR
Consumer	$20	$6,058	158%
Automotive	$ 56	$625	49%
Medical	$177	$230	5%
Industry and commercial	$749	$1,545	13%
Scientific, defense and space	$325	$576	10%
TOTAL	**$1,328**	**$9,034**	**38%**

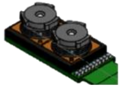
2022e - 3D Imaging & Sensing
revenue breakdown
by market



Technology Comparison

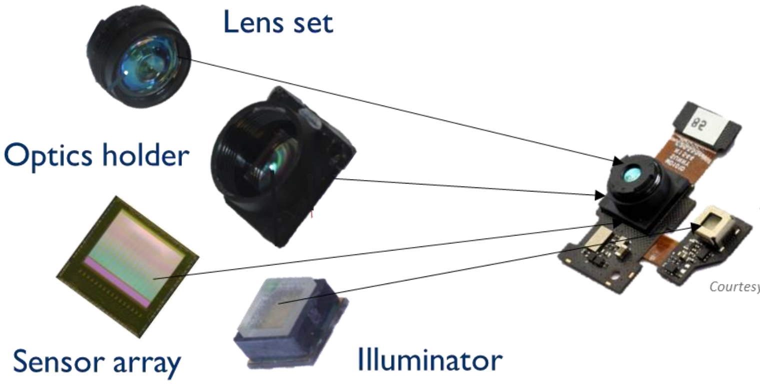
Depth-sensing Technologies

Depth-sensing technologies in mobile devices
(Source: Yole Développement, 2017)

Yole Développement	Stereo vision	Structured light	Time of Flight
Image resolution	Several Mpix	Max. 1–3 Mpix	Max. VGA
Hardware	Simple cameras Complex system	Demanding illumination Complex system	Simple illumination Complex sensors
Computation power	High	Medium	Low
Limitations	May require illumination in low light	Best indoors Need power	Best indoors Low resolution
Picture (example)	 *Courtesy of AMS*	 *Courtesy of Apple*	 *Courtesy of PMD Tech*
Best suited for	Robotic navigation	3D mapping	Short-range gesture capture
Maturity	High	Medium	Low
Players	SONY, ams, ON, SAMSUNG, OmniVision	Himax, ams, ST, NAMUGA Multimedia Lab, intel	Infineon, pmd, SONY, ST, epc, LIPS

From Sub-components to Camera Modules

Minimum resolution
50 pixels x 50 pixels arrays



Courtesy of SystemPlus

Courtesy of PMDTech

Courtesy of Apple

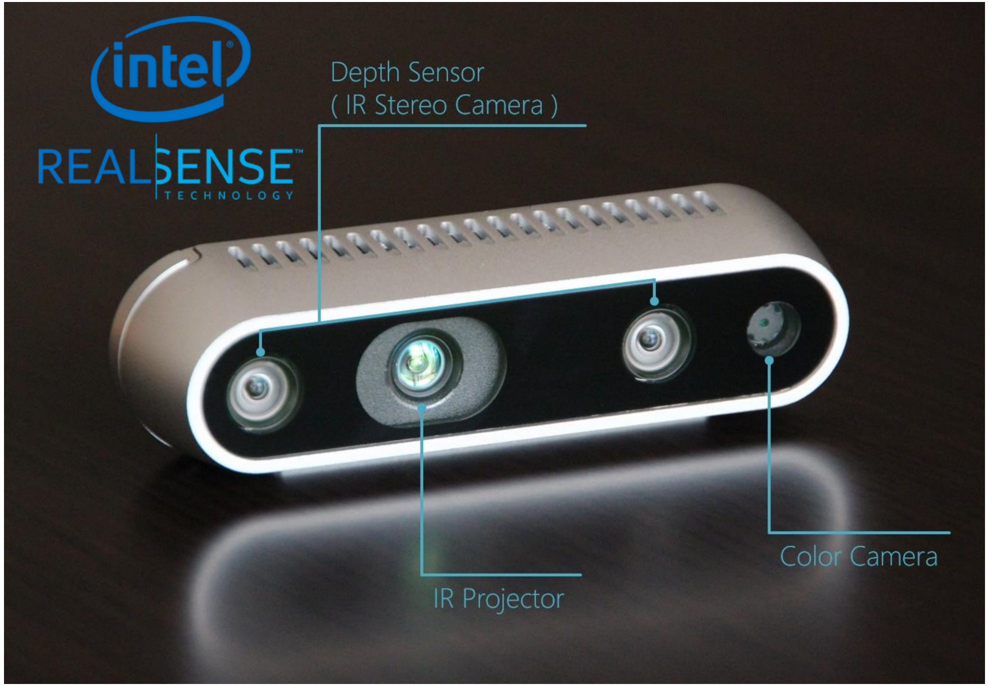
Sub-components
Sensor, optics
& illumiination

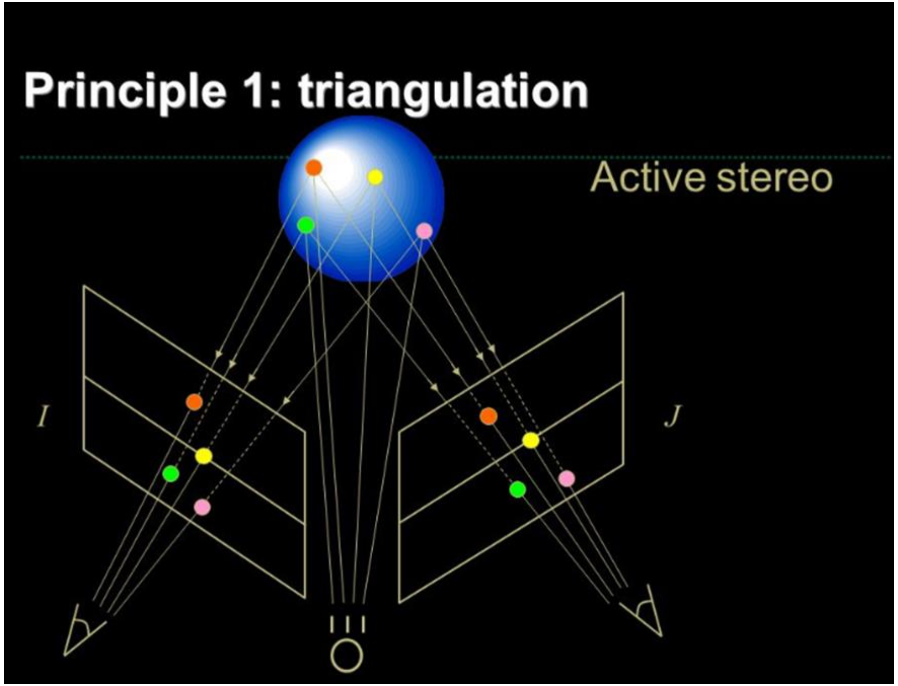
3D Cameras

Systems

Active Stereo

Active Stereo – Architecture & How It Works





Autonomous drones - Stereo

Advanced user experience require obstacle detection and image-tracking capability

DJI first started the trend in 2017 with the DJI Mavic, quickly followed by Spark and Mavic air

Stereo vision is mostly used. on the smallest drone time of flight (ToF) has been prefered

$11M 0.7Mu - in 2017
$35M 3.4Mu - in 2022

DJI Mavic

Skydio R1

DJI Spark

DJI Mavic air

Automotive ADAS - Stereo

Originaly Stereo equipment appeared on high end vehicles

Subaru Eyesight systems has become standard equipment on Foresters

New generation of stereo systems are democratizing the technology

Hisense

RICOH

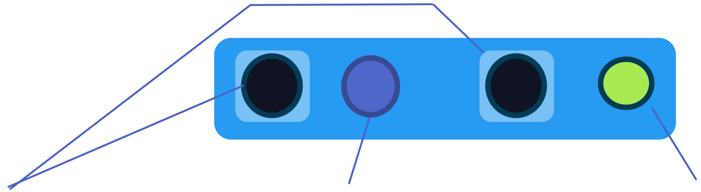
$59M 3Mu - in 2017

$243M 32Mu - in 2022

Mercedes-Benz

SUBARU

Active Stereo - Cost Structure



	NIR GS camera	IR LED Illumination	RGB camera 2Mp	
Chip	\$3.0 x2	\$1.0	\$1.0	**\$8.0**
Optics	\$2.0 x2	\$1.0	\$1.0	**\$6.0**
Mfg.	\$2.0 x2	\$1.0	\$1.0	**\$6.0**
TOTAL	**\$7.0 x2**	**\$3.0**	**\$3.0**	**\$20.0**

NIR GS: Near InfraRed Global Shutter

Impact of assembly yield not accounted for

Structured Light

Unlocking the Next Decade


Facial recognition


Easy unlocking


Avatar


Morphing/Animojis
Social medias

Structured Light front
+ ToF Proximity detection

Fast verification (1 vs 1)
thanks to
A11 chip/Neural network

Dual camera rear
No addition of laser ranging for surface detection.

3D camera technology choice
- High resolution
- Simple cameras
- Complex system
- High computational needed handled by A11 Bionic APU

Lighting control
Automated
Photo editing

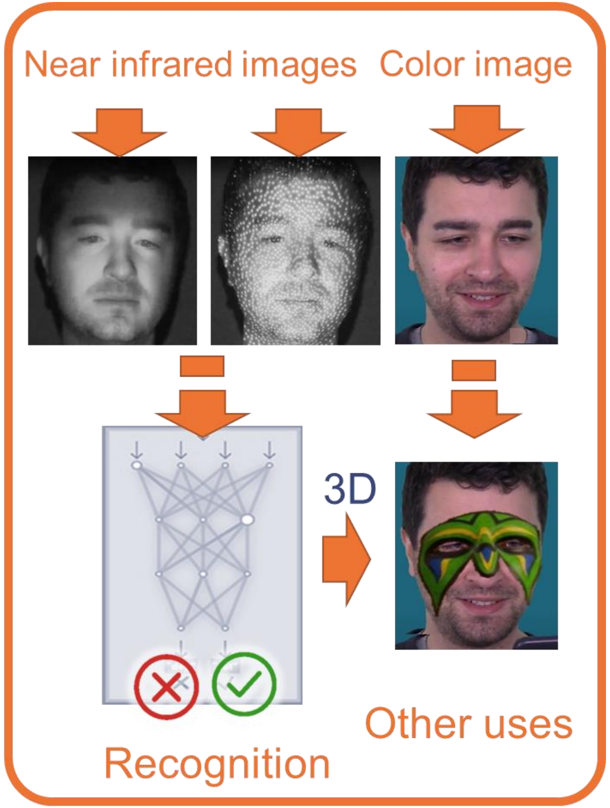
Apple TrueDepth Workflow

1- Triggered with ToF proximity
2- Near infrared light "flood" & "dot"
3- Image captures with NIR camera

The enrollment is using an initial 3D scanning of the owner's face

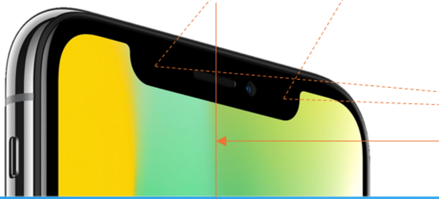
Trained neural network to recognize the owner FRR* 1/1,000,000

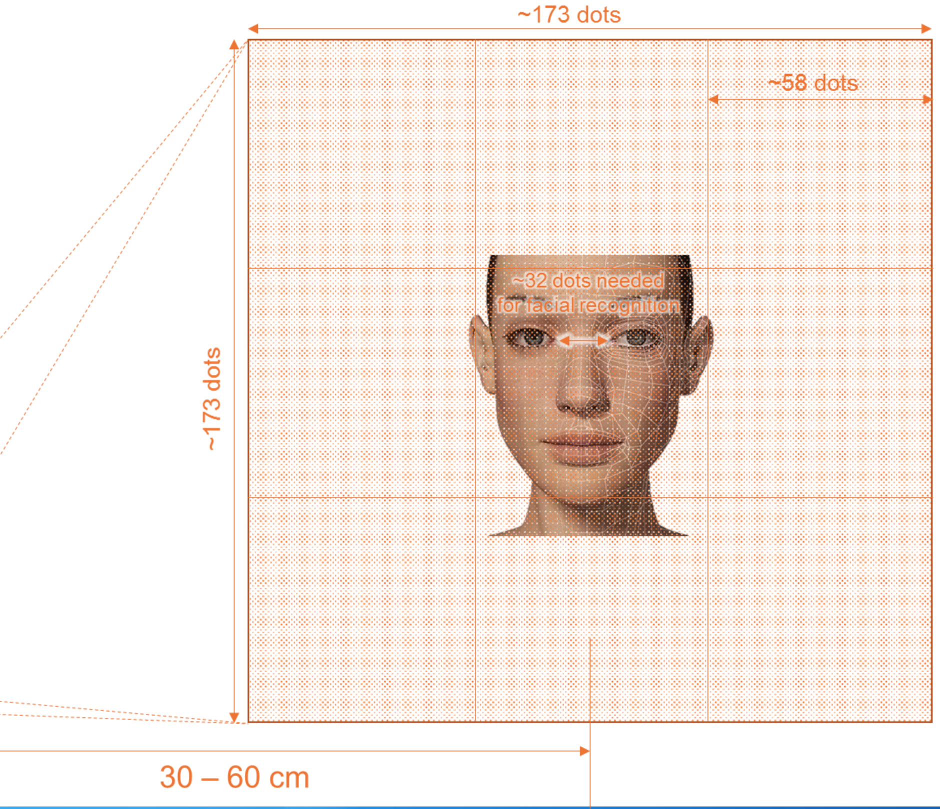
Track slight changes of the face as time goes



*FRR: False Rejection Rate

DOE and Face Recognition





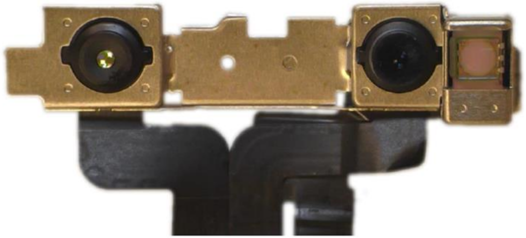
Apple iPhone X TrueDepth Camera Module

Apple iPhone X Teardown

- Overview / Introduction
- Physical Analysis
  - iPhone X Teardown
  - ALS & Color Sensor
  - Proximity Sensor & Flood Illuminator
  - TrueDepth Module
- About System Plus

SYSTEMPlus CONSULTING

Apple iPhone X Opened View
©2017 by System Plus Consulting



Face ID Module
©2017 by System Plus Consulting

Speaker, ALS & proximity Sensor Module
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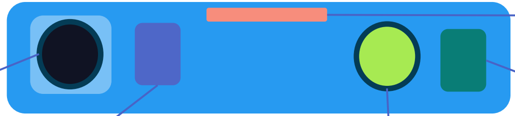
Structured light – Cost Structure



	NIR GS camera		Proximity+Flood		RGB camera 7Mp		Dot illuminator+Light		
Chip	ST	$3.0	ST	$1.0	SONY	$3.0	LUMENTUM	$2.0	**$9.0**
Optics	GSEO	$1.0	LUMENTUM		LARGAN Kantatsu	$1.5	HEPTAGON member of the ams group	$ 2.0	**$4.5**
Mfg.	LG Innotek FOXCONN	$1.0	Tong Hsing Electronics	$1.0	LG Innotek FOXCONN	$1.5	HEPTAGON member of the ams group Tong Hsing Electronics	$1.5 $1.5	**$6.5**
TOTAL	LG Innotek FOXCONN	**$5.0**	ST	**$2.0**	LG Innotek FOXCONN	**$6.0**	HEPTAGON member of the ams group	**$7.0**	**$20.0**

Impact of assembly yield not accounted for

Dot Illuminator - Focus

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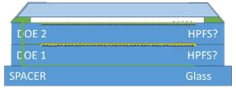
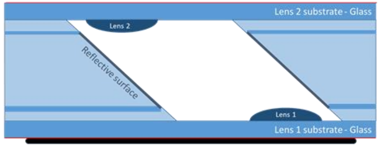
Diffractive Optical Element

~$2.0

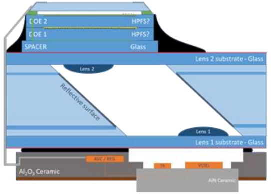


Wafer Level Optic Assembly



HEPTAGON™
member of the ams group

~$2.0

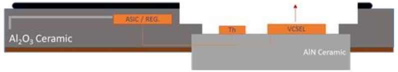


HEPTAGON™
member of the ams group

~$7.0

LG Innotek

VCSEL and packaging



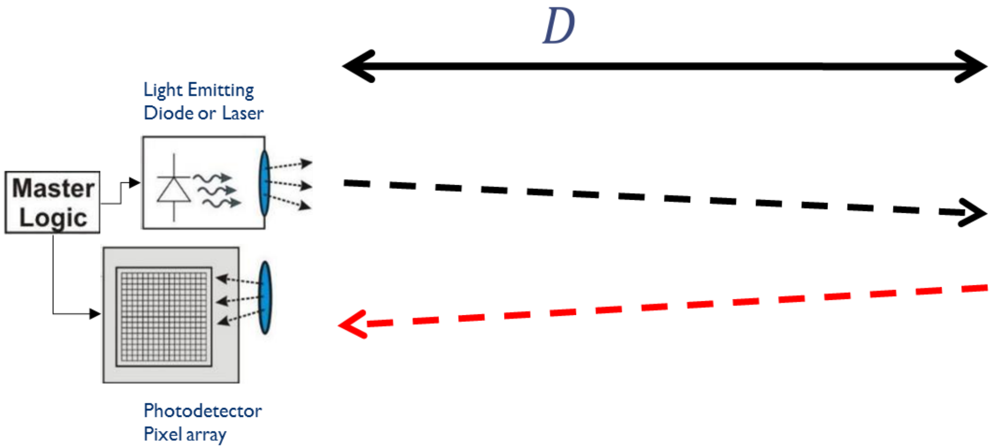
~$3.0

TONG HSING ELECTRONICS

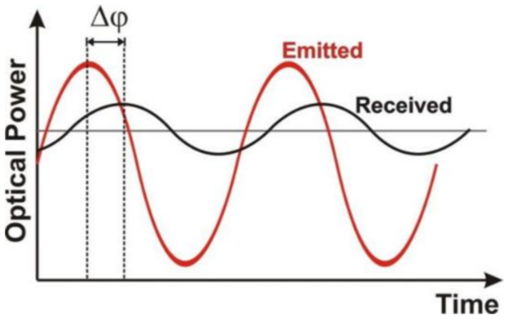
LUMENTUM

Time-of-Flight

Time of Flight – Working Principle



Object



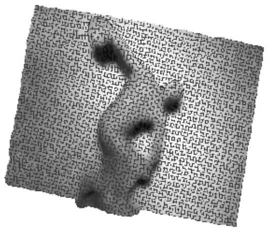
Speed of light

Phase difference

$$D = \frac{c\,\Delta\varphi}{4\pi f_m}$$

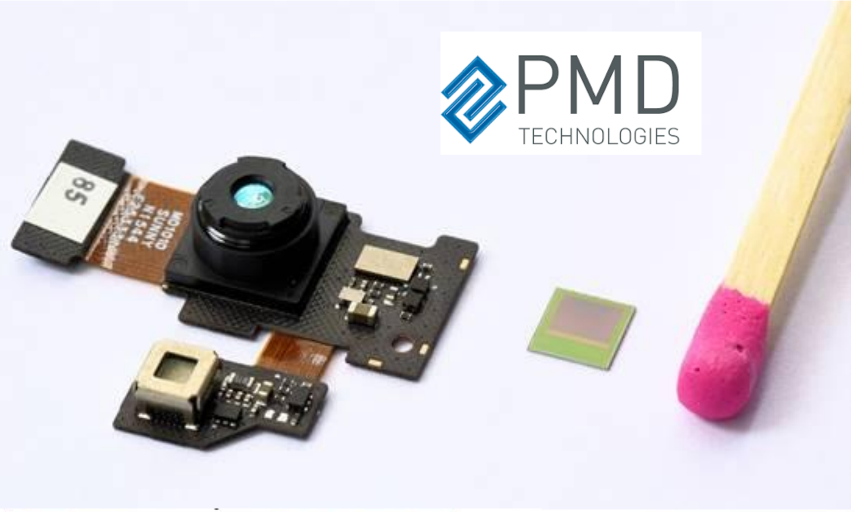
Modulation frequency

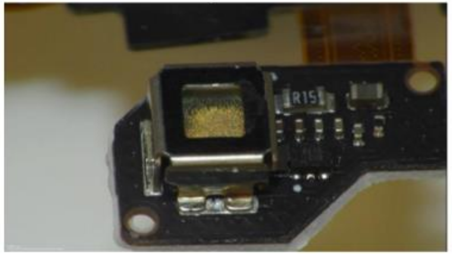
Calculation is made for each pixel



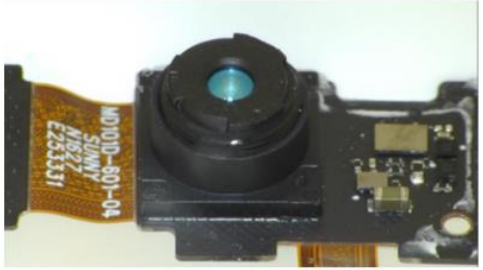
3D image

PMD Time of Flight Solution



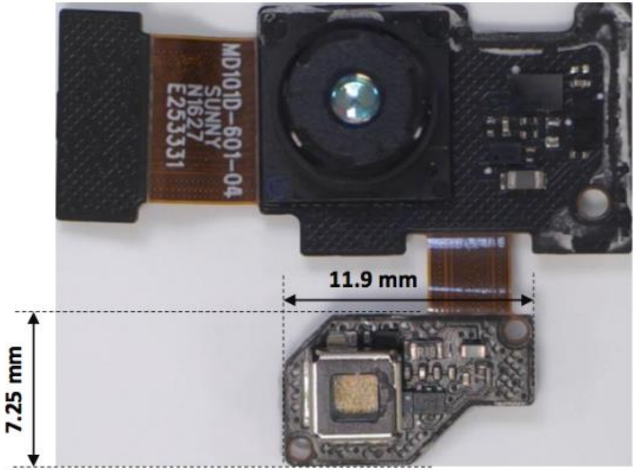


NIR VCSEL – Global View



NIR Sensor – Global View

- Dimensions without Flex : 17.8 mm x 12.0 mm



PRINCETON OPTRONICS

From Sub-components to Camera Modules

Lenovo has been the first End-User OEM to integrate compatible system into consumer smartphone.

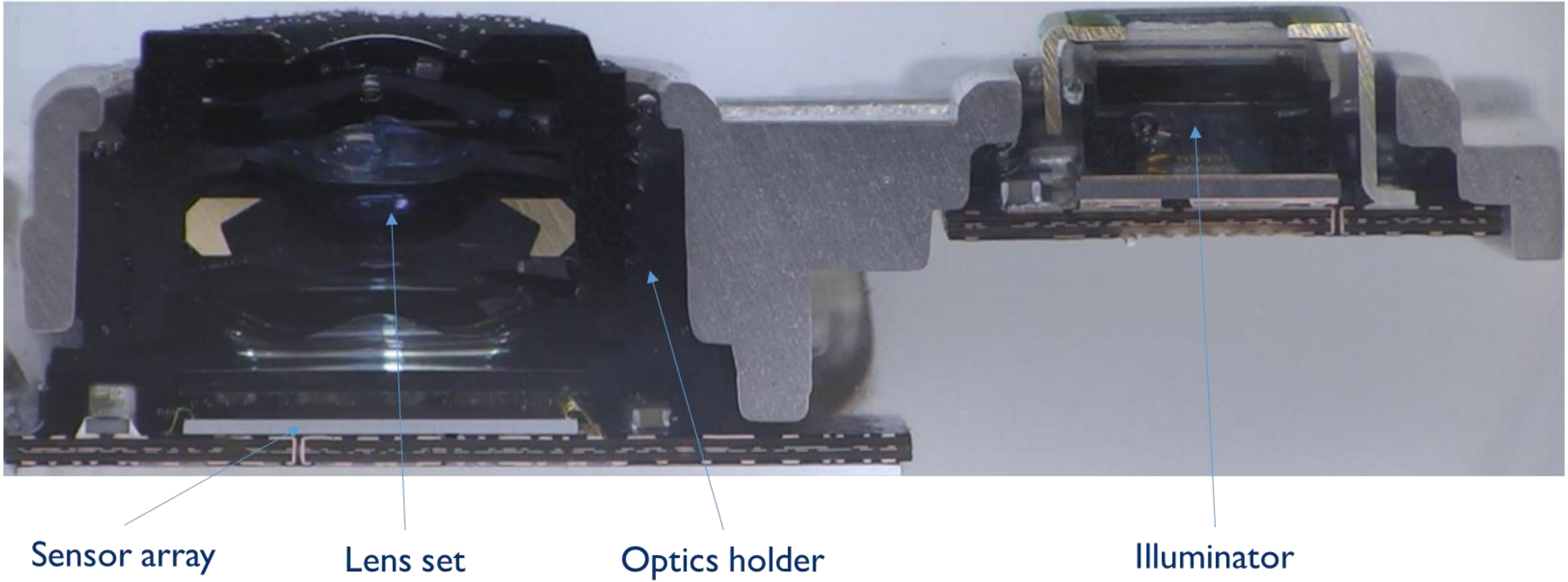
Samsung supply the High Resolution camera with AF. The High Resolution camera (16M pixel, ~57° FOV) offer a textural information of the scene.

Infineon supply the NIR ToF Image Sensor. The sensor (38k pixel :224 x 171, ~64° FOV) detect the reflected signal from the VCSEL. The “time of flight” is converted into distance through special processing by the microprocessor.

An NIR VCSEL is integrated into the module from Princeton Optronics. The VCSEL emitted a NIR signal on all the scene.

Omnivision supply the NIR global shutter motion detector. The motion detector (VGA 300k pixel, ~58° FOV) camera offer a large vision of the scene providing a motion tracking sensing .

3D Camera Module Cross-Section



Time of Flight Sensor from PMD – Infineon

The PMD Infineon 3D ToF sensor found in the Lenovo Phab 2 Pro.

Its resolution is 224x171, with around 40k pixels.

Pixel size: 17.5µm

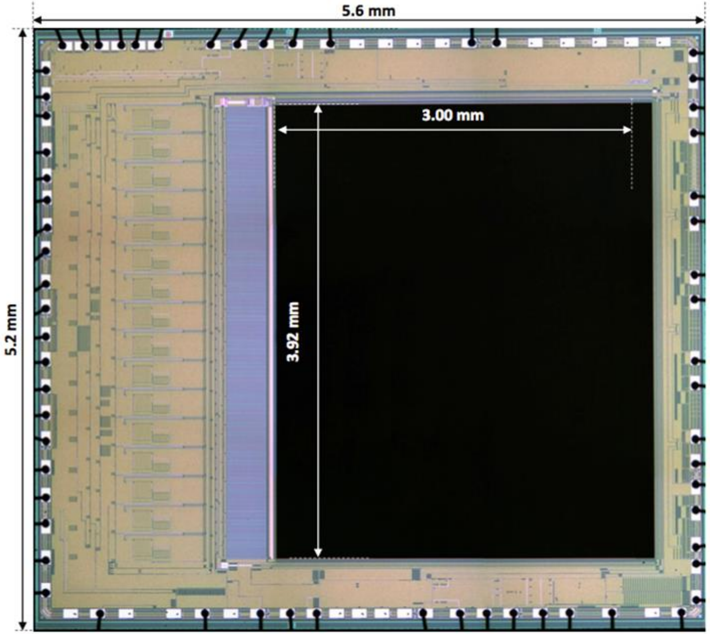
Chip size: 29mm^{2}. This is quite big relative to the resolution.

Chip cost: around $2.5
Estimated chip price: around $5

Module, illumination and ASIC cost: around $9

Estimated module, illumination and ASIC price: around $15

CMOS Image Sensor View, Marking and Dimensions



Courtesy of SystemPlus

infineon

Die Area: 29.12 mm²
(5.6 x 5.2 mm)

Nb of PGDW per 8-inch wafer: 940

Pad number: 81
Connected : 63

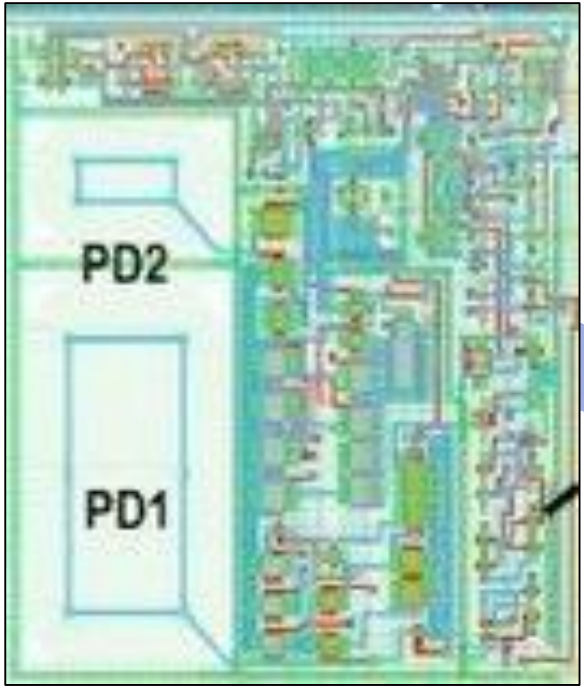
Pixel array: 12.39 mm²
(3.92 x 3.00 mm)

CIS resolution: 224x171
(38,304p)
→ Pixel area: 306.25 µm²
→ Pixel size: 17.5 µm

Die marking

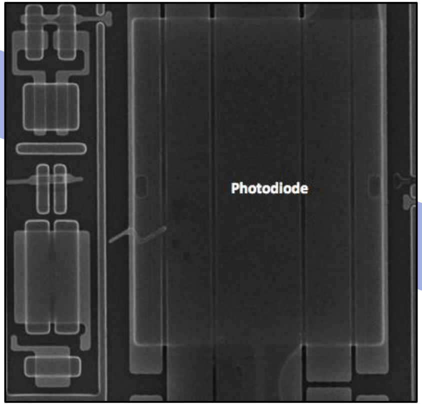
Pixel Size

30 µm



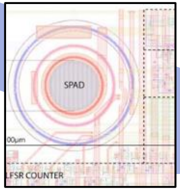
Prophesee
(formely Chronocam)
Event based
Pixel (2016)

PMD Infineon
3D ToF pixel (2017)
17.5 µm



In 2018 ToF is now in the range of 10 to 15um

STM
R&D
SPAD
pixel
8 µm



In 2018 SPAD arrays are still in R&D stage

OVT
Global
Shutter
(GS)
pixel
3 µm

In 2018 small global shutters are in the 2.5 to 2.8um range

Samsung
Mobile
pixel
1.1 µm

Classic CMOS pixel size for comparison

Time of Flight – Cost Structure*

*Based on Lenovo Phab Pro 2 structure

Classical ToF module structure would require only illumination and ToF sensor, thus decreasing the global cost of the solution shown here

	NIR GS camera	Illumination & flash	Infineon PMD ToF	RGB camera 16Mp	
Chip	$3.0	$1.5	$4.0	$4.0	**$12.5**
Optics	$1.5		$1.0	$ 2.0	**$4.5**
Mfg.	$1.5	$2.0	$3.0	$ 6.5	**$13.0**
TOTAL	**$6.0**	**$3.5**	**$8.0**	**$12.5**	**$30.0**

Impact of assembly yield not accounted for

Comparison – Stereo / SL / ToF

	Active Stereo		Structured Light		Time of Flight	
Chip	$8.0	40%	$9.0	45%	$12.5	41.2%
Optics	$6.0	30%	$4.5	22.5%	$ 4.5	15%
Mfg.	$6.0	30%	$6.5	32.5%	$ 13.0	43.3%
TOTAL	**$20.0**		**$20.0**		**$30.0**	

Higher cost of semiconductor for SL

Higher cost of optics for AS

Higher system cost of ToF

Higher overall cost of ToF

2D and 3D imaging are taken into account

Conclusion

- All approaches are currently being used in Consumer space
- They always combine 2D and 3D imaging and maturity is higher for AS and SL with better overall costing than ToF (as of 2017).

- Before 2020 ToF should bridge the cost gap it has with AS and SL as pixel shrinks and system optimisation occurs (SoC approach)
- All solutions involve high « system level » costs due to high accuracy positioning of components (camera module expertise)

- The application is key for the choice of 3D imaging technology as well as implication of computing (neural engine of iPhone X).

- SL and ToF are highly patented so free space is tight.

- Any questions? girardin@yole.fr

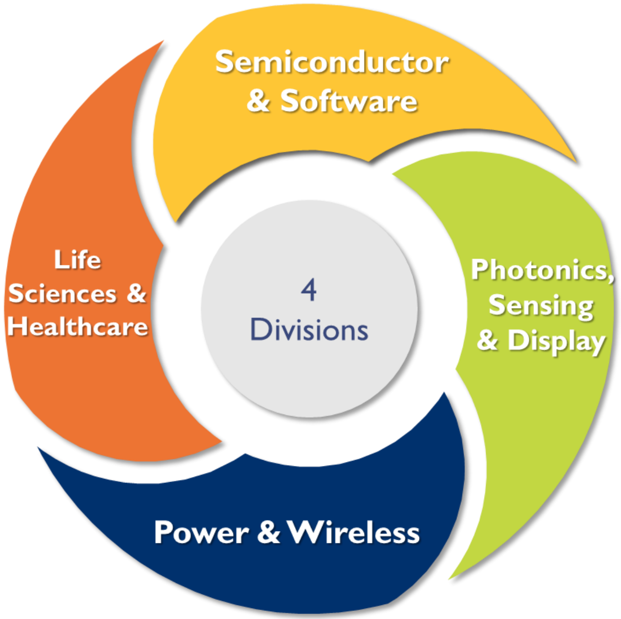
Yole Développement

Life Sciences & Healthcare

- Microfluidic
- BioMEMS
- Inkjet Printing
- Solid-State Medical Imaging & BioPhotonics
- Bio Technologies

Power & Wireless

- RF
- Compound Semiconductors
- Power Electronics
- Batteries



Semiconductor & Software

- Package & Assembly
- Semiconductor Manufacturing
- Memory
- Software & Digital IC

Photonics, Sensing & Display

- Solid-State Lighting & Display
- MEMS, Sensors & Actuators
- Imaging
- Photonics & Optoelectronics

- Consulting and Analysis
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- Media

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