Hype Cycle for Display and Vision, 2020

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Initiatives: Technology Innovation

> Multiexperience is a long-term shift from individual devices to a multidevice, multisensory and multilocation environment, empowering human cognitive augmentation. Explore opportunities in display and vision technologies to create compelling value propositions for multiexperience.

Analysis

What You Need to Know

Display and vision technologies are pivotal to multiexperience; they revolutionize the way we perceive and interact between the digital and physical worlds. The combination of display and vision technologies with artificial intelligence (AI), Internet of Things (IoT)-connected edge devices and machine vision makes multiexperience a reality.

There has been a revolution in display and vision technologies, where they have graduated from providing an interface to providing a multisensory, memorable experience. However, the explosion of display and vision technologies and the rapidly emerging use cases increase the risk of addressing opportunities with the wrong technologies. This Hype Cycle characterizes display and vision innovations and highlights potential use cases for IT leaders to espouse a multisensory and multidevice experience.

The Hype Cycle

This Hype Cycle for display and vision technologies, coupled with emerging use cases, can be used to develop a comprehensive view of timely investment to gain competitive advantage. In principle, each innovation profile's position on the Hype Cycle is reviewed in terms of market expectation and technology maturity (prototype versus mass production). We also consider other factors, including long-term vision, vertical industry requirements, underlying technologies and the cost to adopt a specific innovation profile.

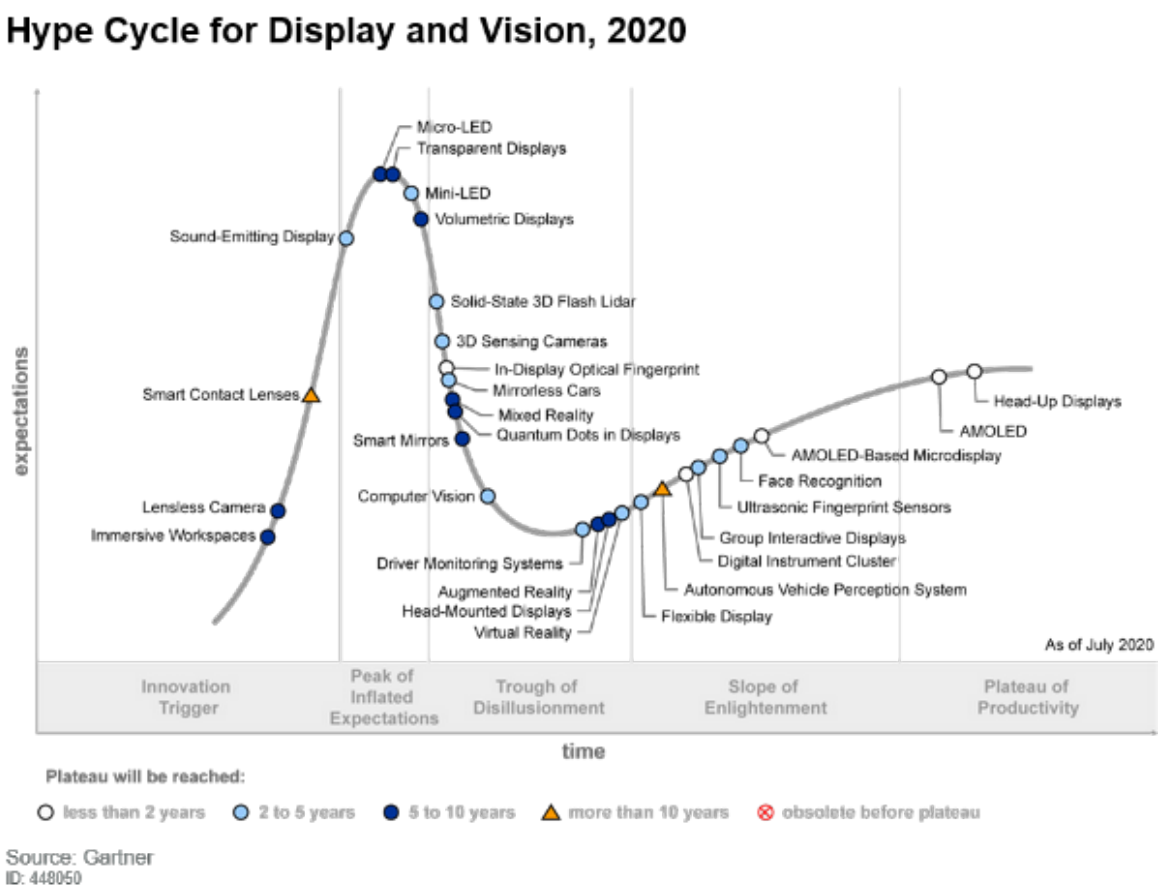
The innovation profiles in this Hype Cycle range across three segments:

- **Vision-related technologies** that capture and/or analyze data of the physical world for reconstructing immersion, such as 3D sensing cameras, solid-state 3D flash lidar and computer vision
- **Display-related technologies** that render images for immersion, such as AMOLED, micro-LED, volumetric displays, transparent displays and flexible displays
- **Use cases and applications** that are enabled by the above two types of technologies, such as augmented and mixed reality, head-mounted displays, smart contact lenses, and face recognition

Additionally, the Hype Cycle has been expanded by adding innovations and technologies that show early market attraction and are worth reviewing for their strategic value and impact. These new innovation profiles are mini-LED, sound-emitting display, ultrasonic fingerprint sensors and immersive workspaces.

Most innovation profiles in this Hype Cycle have passed over the peak. The majority will reach a plateau within two to five years or five to 10 years, indicating that it's a good time to evaluate the potential use cases and the maturity of their required technologies. Caution is needed as risks remain as innovations pass through the Trough of Disillusionment before reaching the plateau, so users should consistently review their viability.

Figure 1. Hype Cycle for Display and Vision, 2020



Source: Gartner
ID: 448050

The Priority Matrix

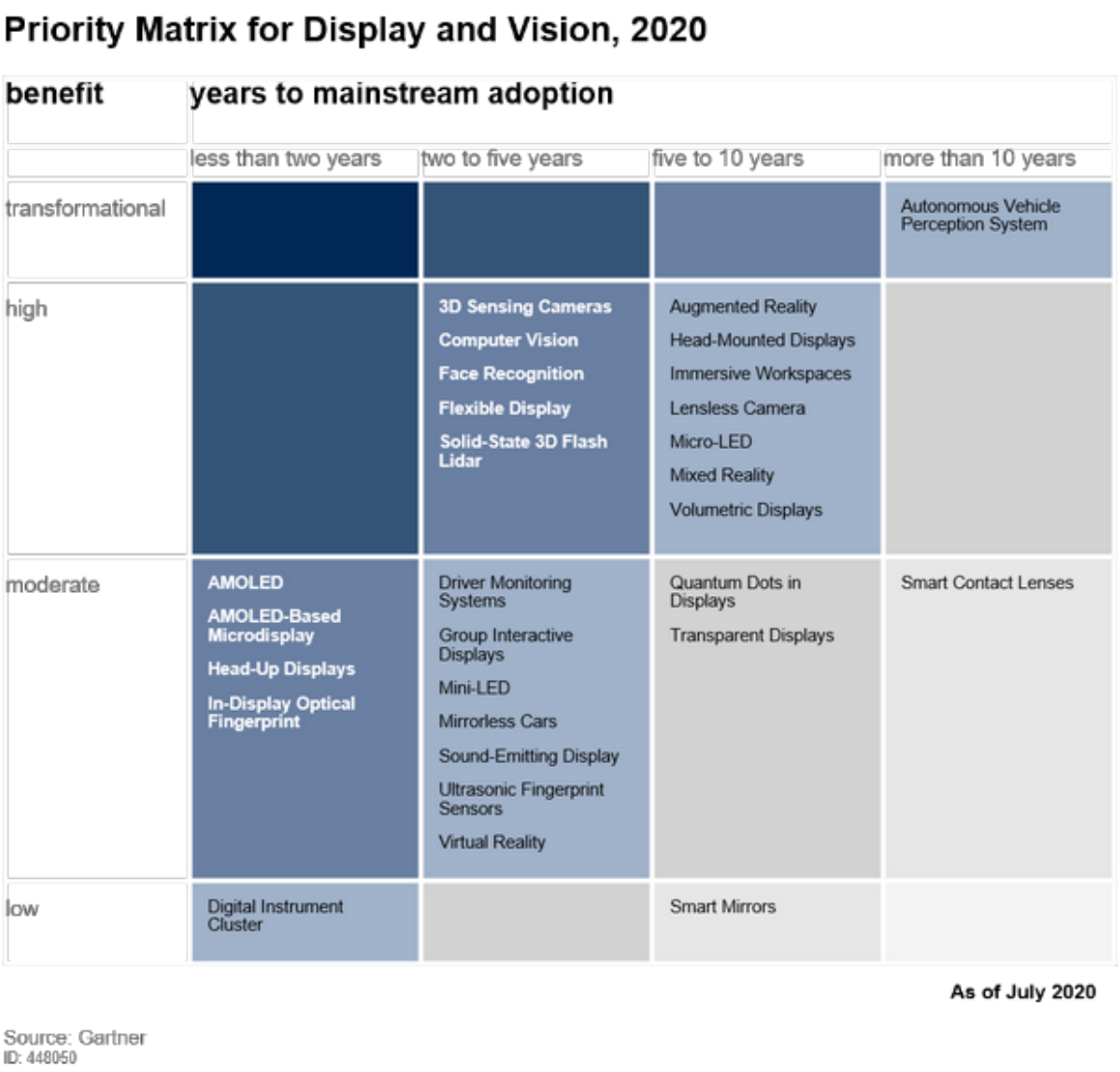
The Priority Matrix combines position on the Hype Cycle, benefit rating and, most importantly, “years to mainstream adoption” for each innovation profile in this Hype Cycle. It is useful for ranking which technologies an organization should examine first based on maturity and business impact.

If an innovation profile is located near the Peak of Inflated Expectations, that means the market has great expectations and believes this innovation can result in new applications. While the technological advancement continues, innovation profiles with transformational and high benefit ratings still need two to five years or beyond to achieve mainstream adoption.

The **transformational** benefit rating refers to game changers in business because of disruptive concepts or technologies. In this Hype Cycle, the autonomous vehicle perception system is the only innovation profile with transformational benefit. This technology has passed through the Trough of Disillusionment and will take more than 10 years to reach mainstream adoption, which means it is a solid but slowly progressing technology, and users who harness the technology now will receive a huge reward.

Technologies with a **high** benefit rating also have a high impact on product development, including new feature enablement. Performance improvement is a critical way to drive revenue (because of product differentiation) and cost savings. Generally, vision-related technologies, such as 3D sensing cameras, face recognition and solid-state 3D flash lidar, will reach mainstream adoption faster (in two to five years), whereas the five- to 10-year segment is almost completely dominated by display-related technologies. This is because the displays have seen major technological advancements since 2017 (e.g., AMOLEDs displacing LCDs in smartphones), and the next-generation display technologies are now at the R&D stage.

Figure 2. Priority Matrix for Display and Vision, 2020



Source: Gartner
ID: 448050

Off the Hype Cycle

The following profiles appeared in last year's Hype Cycle but have been dropped from this year's:

- Light field cameras
- Multilens cameras
- Multiscreen multistream rooms
- HD maps

The first three profiles have been impacted by erosive market attraction, slow investment or complementary technologies.

An HD map is a next-generation, purpose-built navigation system for autonomous and robotic systems and is covered in the automotive electronics Hype Cycle.

On the Rise

Immersive Workspaces

Analysis by: Marty Resnick

Definition: Immersive workspaces are collaborative work environments that convey a sense of real-world presence through the use of visual, auditory, haptic and other sensory elements. They principally employ virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies and techniques, but also utilize multiple displays and are delivered to users through head-mounted displays.

Position and Adoption Speed Justification: Immersive workspaces will provide enhanced opportunities for meeting solutions and telecommuting by delivering environments designed for deeper collaboration. They will facilitate richer and more natural collaboration, knowledge sharing, onboarding, and training, facilitated by the use of immersive technologies, multiple displays and other sensory elements.

Immersive workspaces are continuing to appear and mature within VR platforms, such as those of Oculus, but developments have also moved toward MR. Immersive workspaces have the ability to create 3D virtual offices and desktops in a VR world. Also emerging is the ability, using MR, to place digital objects (such as images of monitors) on walls in virtual representations of the physical world, which offers new collaboration, interactivity, visualization and productivity opportunities.

Immersive workspaces are at a very early stage of development, but the demand for them is increasing, especially as organizations continue to work from home. They are deployed in pilots and proofs of concept (POCs). However, large enterprises are investigating new and innovative ways to enhance collaboration and communication through the use of immersive technologies.

User Advice: Organizations looking to use immersive workspaces to enhance communication and collaboration among members of an increasingly remote workforce and with business partners should:

- Evaluate the market and experience virtual desktop applications through VR ecosystems, such as those of HTC (Vive) and Facebook (Oculus), as well as MR ecosystems such as Microsoft (HoloLens 2).
- Give their employees the opportunity to test immersive technologies.

- Review unified communications vendors' roadmaps and plans for immersive workspaces.
- Start small with a POC, based on a specified business outcome — for VR conferencing, for example. Then, plan specific use cases for a wider rollout, taking account of requirements for networks, hardware and software.

Currently, the use of 3D-enabled applications in immersive workspaces is limited, and availability of these applications will need to grow to meet the true value of immersive workspaces.

Business Impact: Immersive workspaces could offer organizations opportunities to support work from home, reduce travel expenses by improving remote collaboration and to increase productivity through design visualizations. They also could provide enhanced analytics collaboration through immersive analytics. Immersive workspaces could improve connections and engagement between office-based workers and remote workers and suppliers. Providers of virtual meeting, conferencing and training solutions should be looking to add immersive workspace capabilities to their products.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Cisco; Facebook; HTC; Igloo Vision; Microsoft; Spatial Systems; vSpatial

Recommended Reading: "Cool Vendors in Augmenting Human Experiences"

"Maverick* Research: Being Human 2040 — The Life of the Architected Human in a More-Than-Human World"

"Market Guide for Workstream Collaboration"

Lensless Camera

Analysis by: Juhi Gupta

Definition: Lensless cameras have no lens assembly and capture the image directly on the sensor. Without the quality focusing and filtering provided by a normal lens assembly, the captured image requires digital processing to reconstruct the captured lower-grade images.

Position and Adoption Speed Justification: Lensless cameras will be smaller and thinner, because they don't need lenses and modules. The form factor will be completely changed from cubic to flat, allowing the camera to be easily installed into any small, thin, light and/or flexible electronic equipment. The cost of a lensless camera will be greatly reduced, because there is no lens or complex assembly work required. Also, using different software algorithms can achieve altering field views (wide angle or tele) or different resolution with the same image setup, because this technology isn't limited by the lens' focal length. In addition, lensless cameras can also be modified to capture a wide spectrum, including near-infrared, millimeter or ultraviolet wavelengths, thus further extending their applications and use.

There is no mainstream approach to developing lensless cameras. A few notable approaches include:

- Using a unique film, mask or aperture assembly (e.g., a liquid crystal panel) on top of a conventional image sensor to capture visible and invisible light
- Using silicon photonics to mimic the lens and sensors of a conventional camera, with a much thinner form factor. These are aligned as large arrays of light receivers, each of which can independently add a tightly controlled time delay (or phase shift) to the light received, providing a controlled time-delay. This optical phased array (OPA) enables the camera to have a selective and directional focus.
- Using conventional glass to mimic the lens. The benefit of this approach is that the glass can be the windows in a house, which can be turned into security cameras. Or a windshield in a vehicle can become a dash camera.

No matter the approach used, computational work is required to reconstruct the captured lower-grade images. The computational workload for better image quality will be high, resulting in high power consumption and/or slow image output. However, early traction can be found in high-volume Internet of Things (IoT) applications, where absolute image quality can be traded for a low cost and a small form factor.

Lensless technology is still in infancy stage, and during last year, different research labs have made continuous progress, working on prototypes. The improvements focus on improving the image quality, including better resolution, and reducing signal noise. Thus, the position on the Hype Cycle has moved forward slightly.

User Advice: Electronic equipment can be easily installed with multiple lensless cameras at a low cost. With this design, electronic equipment will be able to collect all light/image/environment information surrounding the electronic equipment as an input for machine vision.

The computational work for image reconstruction needs to improve, because it's still high, resulting in high power consumption and/or slow image output. Improvements for the image quality enhancement and faster real-time response needs to be done by employing artificial intelligence (AI) chips with machine learning (ML) capability. Or they can use alternative mechanisms for better light capture or design better sensors that enable much larger receivers with higher resolution and sensitivity.

Electronics OEMs should monitor the technology's improvements and look to form strategic partners to stay ahead of the competition.

Business Impact: Lensless cameras will allow IoT products to adopt multiple lensless cameras to collect detailed information about depth and visible/invisible light at low cost. In addition, no further weight will be added, because the camera doesn't have a lens. These cameras can be used in security or disaster relief applications that employ cameras as sensors, such as cars, drones or household security systems.

Lensless cameras will benefit the medical industry and life sciences with their architecture of small form factor, inexpensive and lightweight designs. This will aid their usage in applications such as digital in-line holography, 3D fluorescence microscopy, and portable or in-vivo imaging. This will also decrease the pain that occurs during human body inspection and their applications in point-of-care diagnostics devices.

Today's smartphones are thinner than camera modules. Thus, they have camera bumps in the back. Smartphone OEMs will have more product design flexibility enabled by the small and thin form factor of lensless cameras

Lensless cameras can also be used for 3D photography, and recent research studies are also exploring their applications, such as in food safety and forensics. This is based on their ability to be tuned to capture a wide spectrum of wavelengths, including near-infrared and ultraviolet, and to reveal indications of materials, such as chemicals or microorganisms, and everything else that remains invisible to the naked eye.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Caltech; Harbin Institute of Technology; Hitachi; Rambus; Rice University; Tsinghua University of Shenzhen; University of California at Berkeley; University of Utah

Smart Contact Lenses

Analysis by: Jessica Ekholm

Definition: Smart contact lenses use embedded visual technology to support augmented and virtual reality, or sensors to perform chemical analysis of ocular fluid for purposes such as diabetes monitoring.

Position and Adoption Speed Justification: During 2019-2020, we have seen some movement in the market after having seen very little for the past few years and where the market was in a “stalled” stage. In particular event that may become a trigger is that the United States Patent and Trademark Office published a grant for Samsung for augmented reality (AR) contact lenses in July 2019. The contact lenses have a built-in camera and will allow users to take photos, record videos and display images into the user’s eyes. It is controlled through motion sensors detecting eye movement where each movement would activate a different function where would blinking for example would take a photo.

That said, smart contact lenses are still in an embryonic state, where providers such as Samsung, Mojo Vision, Sensimed, IMT Atlantique, Innovega and Sony are working on prototypes. Google was prototyping a smart contact lens through the company Alphabet (Verily) who was working on a prototype that helps track glucose levels for diabetes patients, however Verily discontinued the project in November 2018. Some criticism was raised and pointed toward the difficulty of getting accurate readings from tears as opposed to blood for monitoring glucose levels. The use cases Samsung and Mojo Vision are discussing are generally around AR functionalities rather than healthcare options so it is likely that we see a movement toward focusing on AR rather than healthcare over the coming year.

However, there are several technical challenges such as how to get a wireless power supply to the eyes, finding a way to mass manufacture in all the different prescriptions people will require and the issue of utilizing transparent batteries.

User Advice:

- Keep track of innovative uses and providers in this space to stay ahead of the competition.
- Expect pushback from consumers worrying about intrusion and fear of using smart lenses due to potential complications to eyesight.
- Expect skepticism from health standard bodies due to fears for health compliance purposes.
- Market the fact that smart lenses may not have the same social stigma as glasses, as they are less obtrusive; however, make sure to highlight any legal implications from recording events.
- Partner with already established contact lens providers in order to embed the technology into as many various contact lens options available due to the plethora of the types of lenses that users are already using.

Business Impact: Tech providers should first and foremost focus on use cases surrounding smart contact lenses supporting immersive experiences, like AR, MR or immersive collaboration in future as this is likely to move faster in terms of adoption and uptake.

Tech providers wanting to use lenses for augmented user experiences will need to offer the embedded tech into a plethora of contact lenses, to suit the eyes of the users. They have to be comfortable to wear without harming eyesight. In order to convince nonusers of contact lenses to use them, the value proposition and value-add must be high enough to convince them to start using contact lenses. In addition, be cognizant of potential privacy issues that may arise through the use of AR and unauthorized visual recordings.

Smart contact lenses could be of use to healthcare providers for health tracking and monitoring purposes. However, due to the embryonic state of the technology, the slow movement of the market, and the potential pushback from healthcare providers and end users, we are likely to see the market growing very slowly.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Google; Mojo Vision; Samsung; Sony

Recommended Reading: "Venture Capital Growth Insights: Smart Wearables"

"Top 10 Strategic Technology Trends for 2020: Hyperautomation"

"Forecast: Wearable Electronic Devices, Worldwide, 2018"

At the Peak

Sound-Emitting Display

Analysis by: Kanishka Chauhan

Definition: A sound-emitting display integrates a piezo-electric or an electromagnetic actuator/exciter with an organic light-emitting diode (OLED) display screen, allowing the display to emit sound, thereby eliminating the need for a conventional speaker in an audio-visual (AV) device.

Position and Adoption Speed Justification: With increasing emphasis on small form factors, and demand for increases in active viewing area in AV devices, vendors are actively working to find new technologies to eliminate the conventional speaker. In this quest, sound-emitting display is one of such technologies that has emerged in recent years, and, because of its advantages, it is gaining traction.

Sound-emitting displays can be integrated with OLED based devices, because the display panels in these devices are flexible. Using this technology, the entire screen can be converted into a sound-emitting structure; thus, users will be able to listen to the calls by placing their ear anywhere on the screen. Many different vendors are actively adopting this technology in their new products; however, they have named it differently. For example, Samsung refers to it as “Sound on Display (SoD),” LG calls it “Crystal Sound OLED (CSO)” and Sony calls it “Acoustic Surface Audio.” For Vivo, it is “Screen SoundCasting Technology.”

Sound-emitting display has been placed on pre-peak position in this Hype Cycle, because the technology has started experiencing commercialization by a few vendors. It will take two to five years for the technology to reach the plateau, because it is still in development phase, and the vendors need to solve issues with output and clarity. Below are some of the factors that are expected to fuel the adoption of this technology in the near term:

- **Increasing penetration of front 3D sensing** — Front 3D sensing modules are generally placed near the primary speaker (along with the front camera) of the phone. With increasing penetration of front 3D sensing, manufacturers will have to work on creating space for sensing modules, and they might consider employing this technology to eliminate primary speakers and free up space.
- **Increasing emphasis on durability** — It will be easier to waterproof smartphones based on this technology, because the number of water ingress points will be reduced.

User Advice: To create product differentiation, OEMs should keep sound-emitting display in their consideration. This technology will enable them to improve the look and feel, while reducing the form factor of their devices. They will be able to leverage the space volume saved by adopting this technology to add additional functionalities such as 3D sensing, better camera, etc. For better sound output and reduction of noise, OEMs will have to work to improve panel characteristics by collaborating with panel manufacturers.

Business Impact: Sound-emitting displays will support manufacturers in improving the look and feel of AV products. In smartphones and tablets, the sound-emitting display will enable manufacturers to maximize the viewing areas. Vendors have already started making camera punch holes to minimize the notch. By adopting the sound-emitting display, the notch can be completely eliminated. It will also help manufacturers ease the process of waterproofing their devices (by reducing water ingress points). Lastly, it will be able to provide more privacy to the users by restricting sound leakage (for devices based on bone-conduction).

In TVs, for maintaining a sleek form factor, manufacturers are often forced to locate the speakers at the back. This restricts immersive experience, because placing the speaker away from the screen directs the sound away from the viewer. With an ability to produce sound using the screen, dialogues and sound effects will emerge directly from the screen. Also, the user experience can be greatly enhanced by localizing sound output using several actuators/exciters on the screen (creating an illusion that the dialogues are actually emerging from the character on the screen).

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Huawei; LG; Samsung; Sony; Vivo; Xiaomi

Recommended Reading: "Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest"

Micro-LED

Analysis by: Rajeev Rajput

Definition: Micro-LED is a micro version of a conventional LED chip. There is no standard definition yet; however, micro-LEDs are usually smaller than 50 microns and have potential applications in display and lighting space. Micro-LED display is a type of direct-view (self-emissive) LED display consisting micron-sized RGB LEDs to form individual pixels. Micro-LEDs can also be used in general lighting as well as automotive interior/exterior lighting.

Position and Adoption Speed Justification: Micro-LEDs are inorganic and self-emitting, so they have the benefits of a longer lifetime and stable color quality. The small die size of micro-LED is ideal for immersive displays requiring high resolutions (aka high ppi). One micro-LED chip represents one sub-pixel thus allowing light control at pixel level. The power consumption can be more efficient than LCDs and AMOLEDs as micro-LEDs don't require additional films or packaging layers in front of LEDs. Finally, they have benefits similar to conventional LED displays — flexibility in terms of form factor and shape.

Micro-LED is a next-generation display technology, owing to its superiority in terms of performance and benefits, but it has its own challenges in terms of mass production and chip transfer. A typical FHD display has about 2 million pixels, meaning 6 million micro-LEDs are required (each pixel contains three sub-pixels: RGB). It is difficult to produce such small size LEDs on a wafer — 99.9% yield rate is not good enough and that means 6,000 micro-LEDs will be lost. Mass transfer of micro-LED involves moving large number of micro-LEDs from epitaxial wafer to target substrate and precise alignment each of sub-pixel on large scale is a big challenge. So far, we have seen only Sony and Samsung adopt micro-LEDs for their bigger screen sizes where pixels are closer to 50 microns; however, their target application is niche compared to mobile devices. These challenges directly link to cost, which is a critical factor for mainstream adoption. GaN-on-silicon for mass production and inkjet, laser lift-off, etc., for mass transfer can be a silver lining for technological advancement in micro-LEDs.

Mainstream adoption depends not only on mass production and chip transfer technologies but also on development from input suppliers. Many new players have started R&D activities in supply chain ranging from LED foundries to display manufacturers and driver IC to equipment suppliers. Several prototypes have surfaced in last two years, making this technology on the Peak of Expectations; therefore, the position on this Hype Cycle stands on the peak.

User Advice: Micro-LEDs are emerging and supply chain formation is imperative for technology to mainstream; therefore, collaboration among vendors on different stages of supply chain is necessary for micro-LED to compete with existing display technologies like LCD, OLED, and quantum dots.

Technological challenges vary with respect to target application panel size. Vendors must include micro-LEDs in their long-term product plans, on either side of size spectrum, i.e., large-panel applications like indoor signage and television and small-panel applications like head-mounted displays and smartwatches.

- The LCD is the major display technology for large-panel applications like indoor signage and television, but its square shape often limits the creativity especially in indoor signage. Conventional LEDs could solve this form factor issue, but their big die size hurts the immersive experience (low resolution or a shorter viewing distance makes pictures seem “jagged”). In fact, Sony’s Crystal LED and Samsung’s The Wall are aiming at this market with their micro-LED solutions.
- AMOLEDs are the major solution for small panel applications like head-mounted displays and smartwatches, but their color stability and lifetime are not as strong as micro-LEDs have. Latency is one of the biggest challenges in AR/VR devices and response rate of displays significantly contributes to the latency, micro-LEDs with their high response rate can address latency challenges. With largest patent portfolio, Apple (acquired LuxVue) is leading in micro-LED for small panel applications to decrease its dependence on other display panel manufacturers.
- Micro-LEDs have the capability to offer sensor integration on display panel, i.e., fingerprint, CMOS image sensor, proximity or gesture control sensor, and 3D image sensor can be placed with tiny pixels of micro-LED display as significant space is empty on the panel. This can solve many challenges faced by OEMs and lead to higher screen-to-body ratio in mobile devices.

Business Impact: Indoor signage that is used in shopping malls or theaters can get benefit from micro-LEDs. This is because micro-LEDs are capable of a flexible form factor, along with customizable aspect ratios and screen sizes, whereas AMOLEDs and LCDs have very limited options in larger screen sizes. In addition, micro-LEDs can offer better picture quality than conventional LED displays within a short viewing distance. Viewers won’t see the pixelated picture (the so-called screen door effect on micro-LED signage when standing close to the screen).

Wearable devices, including head-mounted displays and smartwatches, can get benefits of light efficiency and low power consumption from micro-LEDs. Especially for virtual reality goggles, micro-LEDs can offer improved picture quality, such as ultrahigh resolution (particularly important for near-eye displays) and fast response rate. These are important for hardcore gamers who are also heavy users of virtual reality goggles.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: ALLOS Semiconductors; Apple; Oculus; Plessey Semiconductors; Samsung; Sony; X-Celeprint

Recommended Reading: "Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest"

"Market Trends: A Micro LED Strategy Is Critical for VR/AR, Indoor Signage and Wearable Technology Providers' Success"

Transparent Displays

Analysis by: Juhi Gupta

Definition: Transparent display is an electronic screen populated with LCD diodes or AMOLED that allow the viewer to see through the device and thus superimpose electronic images to augment the view of the physical world. LCD is fitted with a transparent screen substrate and linear polarizing filters which modulates incoming light through illumination source. AMOLED has diodes placed as arrays laid out on plastic films; sandwiched between layers of glass. Electrical signals pass through the conductive layers of the LEDs and illuminate the emitting layer.

Position and Adoption Speed Justification: Transparent display panels are being increasingly used in consumer and retail applications such as digital signages, refrigerators, TVs and other screens, along with few prototypes for smartphones. The hype around technology has amplified with several product demonstrations and commercial production commenced by vendors during 2019-2020 such as:

- LG started commercial production of transparent OLED panels in early 2019. Applications include digital signages, refrigerators fitted with touch interface and monitors.
- Manufacturers like Panasonic, Skyworth and Crystal Display Systems introduced their transparent OLED Displays and panels in various conventions.

- Automotive industry also witnessed few demonstrations and pilots with augmented visual experiences in the driver console, creating opportunities to leverage windshield, windows, sunroof as potential heads-up displays (e.g., HARMAN Kardon's Aftermarket Connected Automotive Platform, Audi's In-Car Transparent Display).

For over a decade, display vendors such as LG Display, Pro Display and Planar have been experimenting with transparent displays. Research in nanotech has yielded favorable results with pilots using a combination of basic or Digital Light Processing (DLP) based projector and a high transmissive transparent medium such as LCD screen, embedded with resonance nanoparticles that selectively scatter the projected light. Given the strong financial possibilities in play here, through advertising, sports broadcasting, automotive safety and others, adoption will be a function of technology evolution rather than market acceptance, and there are many use cases that will drive adoption. Presently, the aggregate use cases of transparent display justify a position on the Gartner Hype Cycle that reaches the peak.

User Advice: Display makers should accelerate efforts to further commercialize transparent displays in automotive, retail, consumer and other markets. The degree of transparency and the manufacturing costs are still improving to fall within desirable range to competing technologies such as optical and projection-based AR. For example, to enhance its usability in automotive windshield applications which requires a minimum transparency of 70%, transparent electroluminescent displays are being developed offering ~80% transparency. Further R&D is required to enhance its usability in outdoor display and automotive to reach vital transparency and brightness levels. Further research in nanotechnology will strengthen commercial viability of transparent displays. Increasing commercial viability of nanoparticles and use of electronic miniaturization will further improve transparency levels and reduce the manufacturing cost as well.

Transparency can be combined with other display innovations such as curved transparent displays can enhance the immersive use cases, especially in the automotive domain — e.g., curved HUDs. The combination with tactile interfaces, such as touch and haptics, can bring interactive gestures, acting as a human-machine interface blend between gestures and AR. A viewer can interactively respond to the virtual or the physical image, and the system can respond by blending in and out the level of augmentative information in devices that are not head-worn.

Business Impact:

- These displays can act as an excellent interface to AR and VR, providing immersive experience advancing toward more sophisticated applications. The ability to contextualize physical environments with augmentative information leads to new user experiences. Recently, transparent micro-LED display panels have also been under development or introduced by vendors such as PlayNitride, Tianma, OSRAM and China Star Optoelectronics Technology (CSoT).
- Retail shopping experience can be enhanced with impactful and targeted advertising and product information, displayed in an augmented reality mode on digital signages, shop fronts and windows, with customization options. This will allow product buyers to differentiate and increase propensity to buying, resulting in higher sales.
- Installation of transparent displays as HUDs and windows in automobiles to display relevant information can improve passenger and driver experience. Recently, integration of holography and transparent displays was introduced to enable a personalized AR user interface, featuring real-time navigation, safety, and infotainment content in HUDs. Public transportation systems can open new sources of revenue and subsidization by displaying advertising messages and locational information on the windows of buses and trains.
- The entertainment industry would benefit from a new medium of mixed reality content, with the juxtaposition of the physical and virtual worlds creating stunning effects, especially in live and performing arts. For example, in sports, transparent displays can be used to superimpose player stats, standings and score alerts without distracting the live event.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Beneq Oy; LG Display; Lux Labs; LUMINEQ; Planar; Pro Display; Sharp

Recommended Reading: "Hype Cycle for Emerging Technologies, 2019"

"Top 10 Strategic Technology Trends for 2020: Immersive Experience"

Mini-LED

Analysis by: Kanishka Chauhan

Definition: Mini-LEDs are miniaturized versions of conventional light emitting diodes (LEDs). They are also known as submillimeter LEDs, because the usual size ranges from 50 to 200 microns (there is not yet a standard definition of mini-LED based on size). Mini-LEDs find application in backlights for liquid crystal displays (LCDs), as well as self-emissive displays. They can also be used in general lighting and automotive applications.

Position and Adoption Speed Justification: Mini-LEDs can replace traditional LEDs in major applications; however, after factoring in their advantages and cost increment over traditional LEDs, two applications outshine:

- Self-emissive (direct-view) displays
- LCD display backlights

In backlighting, mini-LED is a promising upgrade. Its small size allows thousands of mini-LEDs to be placed in a display backlight, without adding extra thickness to the panel. These LEDs are able to perform local dimming to very fine zones and achieve a high contrast ratio, thus bridging the gap between OLED and LCD.

This technology is slowly picking up pace, with significant developments from chip manufacturers, panel manufacturers and OEMs. Chip players, such as Epistar, Lextar, Harvatek and Sanan Optoelectronics, are making efforts to gain the lead in the market. Yenrich Technology (a subsidiary of Epistar) focuses on mini-LED and micro-LED development. The company has made inorganic advancements by collaborating with ProLight Opto Technology for the packaging of mini-LEDs. Harvatek started the shipment of its mini-LED products, 4-in-1 Mini COB and RGB mini-LED COB, etc.

Lextar has launched a new series of mini-LED products for TV, gaming monitor, laptop, automotive display and virtual reality (VR). Panel manufacturer Innolux showcased a flexible automotive display, and AU Optronics showcased LCD display for TVs/monitors using mini-LED backlighting. Lastly, on the OEM side, adoption has already started with TCL offering its 8-Series mini-LED TV. MSI showcased its Creator 17 laptop with a mini-LED display.

With several vendors working in the mini-LED space and the commercialization of products, the technology has reached the peak of expectations. However, vendors are slowly realizing that, regardless of the developments, mini-LED offers only incremental advantages over traditional LEDs. With the current price trend and the majority of products still in the development phase, it will take two to five years for the mini-LEDs to reach the plateau.

User Advice: OEMs should include mini-LEDs in their product plans, because it would help them create better product differentiation. For example, mini-LED can be targeted to large TVs and high-end monitors, where it can offer a significant upgrade in terms of brightness and contrast over edge-lit TV/monitors. The potential of mini-LED in these applications is immense, due to the limited penetration of OLEDs. Curved displays can also be made using mini-LEDs, because their small size allows them to uniformly light up curved LCDs.

Indoor signage, which is currently dominated by LCD, is another lucrative market for mini-LEDs. They can be used to make direct-view displays in any form factor. Mini-LEDs can also be used in backlight for signage LCDs, helping achieve higher brightness and better contrast. The adoption of mini-LED in signage will help overcome the limitations of LCD in terms of form factor and brightness.

Business Impact: By investing in mini-LED; vendors can regain the market share lost to OLEDs. The manufacture of mini-LEDs is feasible in the existing facilities (with some modifications for higher yield). Because of the high potential in display backlighting, manufacturers have a favorable beginning, and will be able to recoup their investment quickly. Vendors should focus on the premium products segment, because it will provide the price buffer to absorb high manufacturing costs and will enable higher profit margins.

However, vendors should be careful with their investments in mini-LED and should act fast, because the development and commercialization of micro-LEDs is underway. It has the potential to cannibalize mini-LED in all major applications.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: AU Optronics; Epistar; Lextar; Sanan Optoelectronics; TCL

Recommended Reading: "Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest"

Volumetric Displays

Analysis by: Kanishka Chauhan

Definition: Volumetric displays create visual representations of objects in three dimensions. Unlike most 3D planar displays, which create the illusion of depth through a stereoscopic or an autostereoscopic technique, volumetric displays create lifelike images in 3D space.

Position and Adoption Speed Justification: Volumetric displays have attracted a lot of interest in past few years, vendors in this technology have showcased their potential with the release of new solutions. However, the expectations with the technology have started to settle because of the absence of strong use cases; majority of the use cases revolve around advertisements or decoration. Vendors are working to improve traction by offering predesigned content library and development environment to allow rapid, agile deployment along with rental models for temporary users. Also, there is a limitation with the size of image that can be produced. For larger image, big displays are needed, which adds to the complexity of the system and is space consuming. But, as the technology is developing and vendors are working on content, it will take five to 10 years for it to witness mainstream adoption.

Volumetric displays fall into three categories: swept volume, static volume and free space. Swept volume uses the persistence of human vision to recreate volumetric images from rapidly projected 2D "slices." Static volume displays rely on a 3D volume of active elements. Swept and static volumetric displays have enclosed view volumes, which means that they suffer from the significant dangers of rapidly moving parts or ionized particles in the vicinity of people. However, the free space displays solve the issue of view volume and can create display in the air. The volumetric nature of the generated image convinces the brain that it is solid and "real" and, therefore, can be touched. In all cases, the physical volume of data required to generate a volumetric image is considerable, which will limit its overall advancement in the coming years.

User Advice: Product marketers, brand managers, retail managers and other potential users of holographic technologies should reconsider any lingering preconceived notions of high price points and limited portability. New products and vendors are coming to market with value propositions that could disrupt the current way to attract retail customers or visitors of public shows such as concerts, sports, museums, etc. Installations with price points as low as $2,000 can make for attractive, eye-catching displays for use in retail advertising and public communications. Product marketers' influencer marketing campaigns can be stimulated and differentiated by designing and rendering a 3D facsimile of their brand ambassador.

Systems such as Looking Glass Factory are targeting the market for desktop applications of holographic rendering. This could find use cases in telepresence, unified communications and call/customer contact center. Used in combination with virtual assistants, new and compelling customer experiences could be realized as a 3D holographic display replaces or augments the interaction with a purely voice-based agent. Interactive devices such as kiosks (e.g., those used by hospitals and healthcare providers or border protection agencies) could add a more lifelike interaction and/or replace human customer agents with AI-enabled holograms. Interactions with clients and customers can be made to move one step closer to anthropomorphic scenarios by rendering a real-time 3D agent.

Further potential application areas include medical imaging, consumer entertainment, gaming and design.

Business Impact: Attract new customers and develop new, intuitive and lifelike customer experiences with your brand and at your site, by using affordable, scalable holographic rendering platforms. Create deeper client engagement and sustainable customer intimacy by creating virtual customer assistants that are not only anthropomorphic in voice but in visual appearance and impact. The advent of affordable, highly portable systems can save cost and scale across locations and a growing customer base, especially when combined with contextualized, hyperpersonalized AI experiences. Volumetric displays can also be used for making medical displays used in surgeries and training. The technology can be used to display CT and MRI scans, it can also be extensively utilized for conducting training for doctors and for remote consultations/surgeries.

Eye-catching volumetric displays carry high-impact brand and product messaging, and attract attention in retail stores, shopping malls and public places. The availability of design platforms and design elements allows brand marketers to create custom content and agile brand messaging. Scalable form factors allow content messaging from product data to highly emotive brand advertising. Used in conjunction with corresponding audio messaging, this technology can impact consumer-facing businesses.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: HoloLamp; HYPERVSN; Leia; Looking Glass Factory; MDH Hologram; Realfiction; VNTANA; Voxon

Recommended Reading: "Hype Cycle for Emerging Technologies, 2019"

"3 Critical Enabling Semiconductor Technologies Essential to Drive Immersive Experience Products in Marketing"

Sliding Into the Trough

Solid-State 3D Flash Lidar

Analysis by: Masatsune Yamaji

Definition: Solid-state 3D flash lidars contain arrays of laser emitters and optical receivers. In principle, solid-state 3D flash lidar operates similar to a camera with a flash. Wherein, the laser lights emit from the lidar, spread into objects and surroundings, are captured by photo diode arrays or image sensors and are finally processed to form a 3D mapping point cloud using time-of-flight algorithm.

Position and Adoption Speed Justification: Solid-state 3D flash lidars have emerged to solve the cost, size and complexity issues of scanning lidars. Solid-state 3D flash lidars are semiconductor-based with no moving parts. The result is a small device, that is less complex to manufacture and is better packaged for mass production, thus improving yields and reducing costs. The critical issue with solid-state 3D flash lidars is the limited field of view (FOV) because it cannot rotate and scan the surroundings like a scanning-type lidar does. The solution for limited FOV is having multiple solid-state 3D flash lidars in a car, and this requires advanced and faster image processing capability.

Mechanical lidar is currently very expensive and the capability of mass production determines the cost. With many vendors developing solid-state 3D flash lidars, further improvements in scale will increase the yield rates, speed up mass production lead time and thus reduce costs. Therefore, over time it will be more affordable for mass market vehicles to have multiple solid-state 3D flash lidars. In addition, range with flash lidar is significantly shorter than the scanning lidar. Solid-state flash 3D lidar will be used with MEMS-based lidar to cover longer distance.

The position of solid-state 3D flash lidars on this Hype Cycle is sliding into the trough because vendors are continuously improving performance with new releases; however, the size and cost have reduced over the past year.

User Advice: Automotive makers should include solid-state 3D flash lidars as part of their roadmap design because of the potential low cost and small form factor, which promotes better car designs. Automakers should understand that solid-state 3D flash lidars will not replace radar or cameras, but rather they complement each other with their advantages for better safety.

Service providers should identify business opportunities with solid-state 3D flash lidars vendors. For example, offering cloud-based processing and traffic data mining with 3D mapping point cloud data from solid-state lidars.

Business Impact: Solid-state 3D flash lidar enables vehicles' upgrade to a higher level of driving automation at affordable prices. In addition, the low cost and lightweight, solid-state 3D flash lidar has the potential to be widely adopted in manufacturing automation, logistics delivery and drones.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Advanced Scientific Concepts (ASC); Continental; LeddarTech; Oryx Vision; Ouster; Quanergy Systems

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

3D Sensing Cameras

Analysis by: Amy Teng; Rajeev Rajput

Definition: 3D sensing cameras capture depth information of objects and surroundings. There are various solutions including stereo vision with two cameras, structured-light solution, and time-of-flight (TOF).

Position and Adoption Speed Justification: 3D sensing cameras enable various use cases including gesture recognition as human-machine-interface, factory automation, automotive ADAS for safety, etc. Smartphones are the largest application segment as Apple brought this technology into smartphones for augmented reality (AR) activities and authentication. Chinese OEMs and Samsung tend to place 3D sensing cameras on the back side of smartphones for picture quality enhancement and a wide variety of AR applications.

3D sensing cameras combined with increased resolutions of vision cameras and improved imaging processing power of smartphones, have enabled accurate object detection and spatial measurements. It enables innovations like virtual fitting that helps mobile consumers make decisions, 3D object measurements that can create a 3D model through physically scanning the object and then materializing it by 3D printing.

The fierce competition of the smartphone market has made smartphone OEMs introduce 3D sensing cameras as differentiations, the vertical integration of camera module supply chain have made cost of 3D sensing cameras more affordable for vendor adoption, as a result the market saw increased penetration during the past year.

Microsoft started shipping Azure Kinect DK in March 2020, Intel expanded RealSense depth camera family by adding LiDAR Camera L515 in April 2020. With these vendor products, we expect to see more AR/MR and autonomous applications in the commercial market.

Some home appliances, like robot vacuums, have adopted 3D sensing cameras for obstacle detection and avoidance. The adoption of 3D sensing cameras in cars is complex concerning critical requirements for safety and reliability, regulations and evolution of autonomous vehicles. Currently the one-vision camera solution with a mm wave radar is the major technology used in 3D sensing in cars. LiDAR will be used with vision cameras to provide deeper perceptions of surroundings for L3 and L4 autonomous driving capabilities throughout the next five years.

User Advice: The idea of 3D sensing camera enabled interactive experiences started from game consoles like Nintendo Wii and Xbox One Kinect, but its value in mobile devices is still at early development.

Electronics OEMs should build a multiphase feature roadmap by specifying incremental 3D features and corresponding 3D sensing solutions across their product lines. Focus at building 3D sensing algorithms and sensor fusion platform through reuse experiences to develop synergy.

Service providers should identify possible uses with 3D sensing camera and develop software applications and cloud services for targeted audience. A good software should be designed based on the specific use case, rather than a generic one.

Businesses, in general, should strive to use an optimized 3D sensing camera solution to digitize the physical objects and/or steps to optimize work process, improve workforce collaboration and improve customer experience.

Business Impact: Many AR applications can be achieved without 3D sensing cameras, but some applications that require accurate depth and edge information will find 3D sensing cameras are very useful and time-saving. Facial recognition for authentication is the typical example, others are like virtual fitting for e-commerce, 3D model reconstruction for product reviews, floor plan for renovations.

Business can leverage 3D sensing cameras' object recognition ability to achieve autonomous operations to improve productivity. For example, using 3D sensing cameras and machine learning (ML) to train an algorithm to recognize defective parts.

Continuous 3D sensing in motion can build simultaneous localization and mapping (SLAM), combined with microphone array to collect surrounding sound will and/or other sensing technologies (like gas sensor) can collect more detailed environmental data, and reconstruct a high-fidelity model for other advanced applications like re-examinations or simulations. For example, using drones carrying 3D sensing cameras to scan the walls of tunnels.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: ams; Apple; Google; Infineon Technologies; Intel; Microsoft; Sony

Recommended Reading: "Emerging Technology Analysis: 3D Cameras in Smartphones Enable Differentiation via Authentication and Augmented Reality"

In-Display Optical Fingerprint

Analysis by: Roger Sheng

Definition: Optical in-display fingerprint is integrating the fingerprint function into displays with optical sensor solutions. The optical receiver module which is attached on the bottom of the display panel detects the lights traveling from the surface of displays to recognize the fingerprints for user authentication. It can be a unique CMOS image sensor or a typical compact camera module.

Position and Adoption Speed Justification: Optical in-display fingerprint is seen as an essential user authentication solution when Android smartphones adopt full-screen display trend which can provide larger view area. Compared to Apple, Android smartphone OEMs tend to have both fingerprint and face recognition functions in their premium products and keep fingerprint function in the mainstream market. With highly integrated fingerprint sensors and displays, a finger can simply be placed on the surface of displays for authentication which is the replacement of traditional capacity fingerprint sensors in the full-screen display models.

In 2019, optical in-display fingerprint market had very strong growth due to the population of full-screen display in the premium Android smartphones. Goodix Technology leads the market by its innovative products and strong relationship with Chinese local smartphone OEMs. The growth of optical in-display fingerprint also needs to thank the growing AMOLED adoption. The simplified structure of AMOLED displays enables easy implementation for this solution. The cost competitiveness of optical in-display fingerprint solution is quickly improved after the rising volume and intensive competition among Chinese chip vendors. The chip vendors are developing new generation optical fingerprint which will have larger sensor area and faster response time. Besides AMOLED solution, some Chinese companies are developing LCD-based optical in-display fingerprint solutions for lower cost. We estimate it will be adopted in the entry-level smartphones when the LCD-based solution is ready. Thus, optical in-display fingerprint technology position is moved forward aggressively in this Hype Cycle update.

User Advice: There are various emerging authentication technologies for smartphones, such as ultrasonic and 3D face recognition. Optical in-display fingerprint will not compete with face recognition directly but they are complementary because multiple authentication methods for a smartphone are reasonable to handle unexpected situations. In the COVID-19 pandemic period, people have to wear masks which shows the convenience of fingerprint solutions. Ultrasonic in-display fingerprint is a major competitor of the optical in-display fingerprint. Compared to ultrasonic in-display fingerprint, optical in-display fingerprint has advantage in cost, but smaller detection area and less security due to the lack of 3D bio-check. Smartphone OEMs should design more authentication schemes by software to enhance the security when they use optical in-display fingerprint in their products.

Besides smartphones, optical in-display technology will be significant in portable personal electronics such as smartwatches where AMOLED adoption rates are the highest among display electronics. Consumer device OEMs focusing on portable personal electronics should monitor the improvement of this technology and design it in the new full screen products.

Business Impact: Optical in-display fingerprint is growing quickly, smartphones and wearables will be the major markets because these electronics need a quick and convenient authentication solution to improve user experience with personal data protection.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Goodix Technology; Samsung Display Solutions; Synaptics

Recommended Reading: "Market Trends: New Biometric Authentication Methods in Smartphones Will Redefine User Experience"

Mirrorless Cars

Analysis by: Masatsune Yamaji

Definition: A mirrorless car replaces the rear-view mirror and the side-view mirrors with camera monitoring systems.

Position and Adoption Speed Justification: "Mirrorless cars" can increase more in-vehicle space with the same body width. It can also improve the energy efficiency by reducing the air resistance.

Adopting the cameras for side monitoring will assist the lane changing, and is also an inevitable step to realize the Level 3 (or higher level) autonomous driving systems.

Several governments such as Japan and the European Union updated legislation to allow mirrorless cars. For the first time, vehicle OEMs could design a car that utilizes camera monitoring systems in place of conventional side-view mirrors.

On the other hand, NHTSA, which has been studying the possibility for more than a decade, says camera monitoring systems may also introduce new safety risks. A five-year agency study of the technology on heavy-duty vehicles found display screens were too bright, making it harder for drivers to see objects on the road ahead.

Lexus ES shipped in 2018 had a camera system instead of mirrors, and the mirrorless system is expanding to more affordable cars now.

Mirrorless cars will have more than three cameras (rear and both sides) in the future to eliminate all the blind spots.

These multiple cameras that support mirrorless cars can also be used to support autonomous driving functionality.

The position of the technology moved ahead to “peak-trough midpoint” this year. The adoption is growing in new car models — not at a huge pace but consistently. In some cases, it’s already even getting to more mainstream models like the Honda e.

User Advice: Rear-view camera module vendors should extend their target market to the camera modules for mirrorless cars. The camera modules for this application must have both video data outputs — one for display for the driver, and one for machine vision.

It would be better to integrate AI capability in the camera module for collision warning as well. Sensors will be used for autonomous driving in the future.

Business Impact:

- Mirrorless cars can improve fuel efficiency due to its improved aerodynamics.
- Vehicle design will be refreshed.
- The camera monitoring systems used in mirrorless cars are much safer than using mirrors because the camera views are wider, thus, eliminating blind spots.
- The camera system for mirrorless cars will have collision warning capability, using AI technology.
- The width of mirrorless cars can be much narrower.
- Mirrorless cars will require more displays for the camera system, which the driver can access inside the vehicle.
- The camera modules replacing mirrors will be used for the sensors of autonomous driving in the future.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: BMW; Daimler Group; Honda; JVCKENWOOD Group; Mitsubishi Motors; Toyota Motor

Recommended Reading: "AI Multisensory Tech in Automotive HMIs, Part 2: Visual Immersion"

"Market Insight: Roadmap for Semiconductor Technologies in Machine Vision for Autonomous Vehicles — When to Invest"

Mixed Reality

Analysis by: Tuong Nguyen; Marty Resnick

Definition: Mixed reality (MR) is the merging of real and virtual worlds, where physical and graphical objects appear to interact and integrate naturally. MR, in concept, is a single technology. However, MR includes an underlying group of technologies encompassing the spectrum of immersive displays and interactive systems that spans from the digitization of real environments to augmented reality (AR) and virtual reality (VR).

Position and Adoption Speed Justification: MR is an overarching technology that includes all immersive displays (mainly, head-mounted displays [HMDs]) and combines functionality that spans from the displaying of fully immersive virtual worlds to ones that are augmented with matching graphics and overlays. MR's position on the Hype Cycle curve is roughly similar to AR and VR technologies, but earlier in its maturity due to its more sophisticated capability and wide-ranging use cases.

In some respects, MR devices will be the ultimate AR/VR systems, but the most sophisticated ones are still years away from being produced. However, MR's advanced capability means it is not as mature as its component technologies and likely won't be adopted at mass-market levels for five years due to limits of the technology and the lack of popular apps. Leading startup Magic Leap's decision to reduce head count in response to the COVID-19 impact will have limited impact on the progress of MR IP development due to the long maturity horizon of MR. Furthermore, new vendors such as Nreal and ThirdEye Gen are gaining press and traction in the marketplace. Microsoft continues to empower the ecosystem with advancements introduced by HoloLens 2 as well as enterprise partnerships through its Mixed Reality Partner Program. Minecraft Earth has brought significant exposure to MR experiences. Finally, technology improvements and advancements such as object occlusion provide the steppingstones to more sophisticated experiences. The combination of these developments continues to move Mixed Reality along the Hype Cycle at a steady pace.

User Advice: Apply MR technology to enable new types of experiences and interactions; more personal and contextually relevant for the user to:

- Assess the tactical value of MR. While it may be the culmination of AR and VR technologies, MR will demonstrate more value in scenarios that will benefit from digital objects being aware or interacting with the physical environment. For example, fitting new surgical equipment into dimensional constraints of an operating room
- Evaluate ROI potential by focusing on a small number of pilots benchmarked against traditional, non MR experiences as well as AR and VR experiences
- Build in-house expertise for MR experiences by hiring developers with immersive skills (such as gaming engine, 3D modelling and UI design)

Business Impact: During the next 10 years, MR and the user experiences that it enables will undergo a fundamental change above and beyond the capabilities of AR and VR. Today, MR capabilities focus on optimizing "hands-busy" work environments such as maintenance and repair. Over time, MR will expand to include many types of experiences that can visually enhance everyday objects. New business models will emerge that change how customers buy products using MR or how they conduct operations by visually connecting the user's view of the real world with their data-driven virtual world counterparts such as for rapid prototyping and testing of products and marketing.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Google; Magic Leap; Microsoft; Nreal; ThirdEye Gen

Recommended Reading: "Venture Capital Growth Insights: Immersive Technologies"

"Emerging Technology Analysis: Augmented and Mixed Reality Opportunity for 3D Design Software and Vertical ISVs"

"Quality Is the Key to Avoiding 'Digital Distortion' With Your Augmented Reality Strategy"

"Top 10 Strategic Technology Trends for 2020: Multiexperience"

"Gartner's 2020 Strategic Technology Trends for Product Leaders"

"Forecast Analysis Wearable Electronic Devices, Worldwide"

"Competitive Landscape: Head-Mounted Displays for Augmented Reality and Virtual Reality"

"3D Design and Device Convenience Hinder AR and VR Adoption"

"Market Insight: Mixed-Reality Immersive Solutions Are the Ultimate User Experience for Everyone"

"Competitive Landscape: Augmented Reality Tools for Enterprise, 2018"

Quantum Dots in Displays

Analysis by: Roberta Cozza; Rajeev Rajput

Definition: Quantum dots (QDs) are based on inorganic, self-emitting semiconductor nanocrystal particles. They can be applied to a tube or film to enhance color and brightness for a conventional LCD display. They can also work as light source (due to their self-emitting properties) with unique and customized chipsets to activate them. Thus, this type of self-emitting QD display will no longer need LED backlights. Recent innovation of applying QDs on AMOLED displays is also within the scope of this technology profile.

Position and Adoption Speed Justification: Today QDs are used in LCD displays as color enhancement layer which leads to improved color performance in LCDs, including a wider color gamut and higher contrast ratio. This type of displays are directly competing with AMOLED displays especially in large panel devices as QDs offer a longer color life span due to their inorganic characteristics, whereas AMOLED's color typically degrades noticeably in longer run. However, multiple new approaches of using QDs have surfaced including QD filtering layer in LCD and WOLED. QD filtering layer in WOLED can lead to higher color conversion efficiency while significantly reducing the panel cost by simplified manufacturing process.

Samsung recently decided to close its LCD manufacturing facilities by the end of 2020 to focus on developing advanced technologies like Quantum dot and OLED specifically for large panel applications. It can be assumed that closing LCD fabs will lead to no production of QD-LCDs. This indicates that Samsung doesn't see value in this tech and therefore will now focus on QDs as filtering layer or possibly on True quantum dot displays (aka self-emitting QD displays).

Self-emitting QD displays are in the early phase of development and still away from commercial availability. In addition to technological challenges, several new display technologies are emerging that could affect the future of QD displays. For example, supply chain of micro-LED is getting stronger as many players have started investment in R&D thought out the supply chain from LED suppliers to display manufacturers and driver IC to equipment suppliers.

High competition in display eco-system and requirement of huge investment for developing advanced display technology is the prime reason why limited vendors have ventured in quantum dots so far. With emergence of new display technologies, quantum dots have fallen off the peak of expectations and it will take more than five years for its mainstream adoption. Therefore, the position of QDs on the Hype Cycle is sliding into the trough.

User Advice: Consumer electronics OEMs seeking immersive experience improvements with display technologies should consider how to leverage QDs' advantages to differentiate their products. For example, Samsung, TCL and Hisense have been promoting QD-LCD TVs to compete with expensive AMOLED TVs.

AMOLED has grown rapidly in the smartphone market, and the issue of color performance is not well-addressed yet. Smartphone OEMs should consider QD for AMOLED-based smartphones to see if this can improve color performance and stability, however impact on power consumption must be also carefully assessed.

Business Impact: Displays are an essential part of the user experience for mobile devices and smartphones. As video, web browsing and gaming apps become more sophisticated on mobile platforms, display performance considerations play a key role, especially in relation to the high demands they place on the battery.

Quantum-dot-based displays promise key advantages over existing display technologies (such as LCD and OLED), but implementation in devices like smartphones is still years away. Display panel manufacturers can collaborate with QD developer to enhance the capabilities of their existing LCD and OLED portfolio.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Nanoco; Nanosys; Samsung

Recommended Reading: "Plan Your Hardware Product Roadmap Around Top 5 UX Trends and Technologies"

Smart Mirrors

Analysis by: Masatsune Yamaji

Definition: Smart mirrors are digitized mirrors in which a hyperpersonalized experience is reflected back to the person. The technology consists of digital displays and can include cameras, sensors, communications and software that analyze and present the resulting information on the mirrored panel.

Position and Adoption Speed Justification: Smart mirrors can be produced easily from the viewpoint of hardware design, as the necessary components are almost same as camera/display-enabled smart speakers.

Obstacles to adoption center on creating a compelling enough offering to drive interest. The technology will need to adapt to how mirrors can be used by consumers, for example, in the home, as an information appliance. Mirrors are typically only used in certain places; they are considered a somewhat private device. However, giving them intelligence could enhance their usability to a point where they can be used in any room or place.

Improvements in technology and notable announcements, such as CLO Virtual Fashion's AR Smart Mirror at CES 2019, keep this technology tracking along the Hype Cycle. However, smart mirrors' progress through the Hype Cycle depends on other technologies that could obviate the need for mirrored displays. Such technologies include digital signage and NFC, virtual and augmented reality, products such as Amazon Echo Look, or mobile apps such as L'Oréal's Makeup Genius.

User Advice: The market for smart mirrors got underway in 2014 with prototypes and product launches. Although the devices are useful, their limited capabilities show the early stage of the market. The possibilities for smart mirrors are considerable, but the technology must be able to offer an enhanced mirror experience. Vendors should define privacy standards, follow applicable privacy regulations (such as the GDPR), and help consumers and businesses that would value digital and personal interactions using mirrors to better understand the technology's value proposition.

Only a handful of vendors are making products. There are a number of smart mirrors available or planned, such as Embrace Smart Mirror, Electric Mirror's Vive and Savvy SmartMirror, MemoMi Labs' Memory Mirror, and Panasonic's Smart Mirror.

Because data and information are the enabling technologies in smart mirrors, vendors should focus on quality display experiences and data gathering. Data from users can be detected from their actions, behaviors, voices and physical characteristics; additional context will come from the wearables and mobile devices users carry. Mirrors could come in many shapes and sizes, and can be virtual displays that use video, depth sensors, computer vision and augmented reality to reflect graphics-enhanced scenes. Vendors should optimize the smart mirror experience to best impact how users will integrate mirrors into personal and business scenarios.

Business Impact: Smart mirror use cases will be focused on home, car, business and public spaces; will likely be marketing- or commerce-focused; or will provide a technical function, such as a medical evaluation. As computing user interfaces grow in complexity and sophistication, smart mirrors will be integrated as one of the many visual display devices that people will come in contact with. They will be used as mirrors to try on clothing, as an enhanced contextual information display, for music playback, for personalized advertising, or for business and brand information. Mirrors are used in cars, home bathrooms and in medicine, and can be combined with other technologies, such as facial recognition, to personalize the mirrored image.

Benefit Rating: Low

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: CLO Virtual Fashion; Electric Mirror; Magic Mirror; MemoMi Labs; NOBAL Technologies; Panasonic; SenseMi

Recommended Reading: "2019 Gartner Eye on Innovation Award Winners in Financial Services Raise the Bar for User Experience"

"Market Insight: IoT Opportunities for CSPs in the Retail Industry"

Computer Vision

Analysis by: Nick Ingelbrecht

Definition: Computer vision is a process that involves capturing, processing and analyzing real-world images and videos to allow machines to extract meaningful, contextual information from the physical world.

Position and Adoption Speed Justification: Computer vision capabilities have advanced through the Hype Cycle as a result of improvements in the application of machine learning methods including deep neural networks, the availability of tooling and services as well as greater processing efficiencies. Enterprises everywhere face the challenge of how to exploit their visual information assets and automate the analysis of exponential volumes of image data. However, they face difficulties activating computer vision models in business processes, along with security and privacy concerns that impact their ability to realize business value. Gartner anticipates early mainstream adoption in the 2023-2025 time frame. Computer vision has progressed through the Hype Cycle in line with the growing maturity of machine learning solutions, including advances in optical character recognition products and object/behavior recognition models. Computer vision has broad applicability across numerous domains including automotive, retail, robotics, security, healthcare, manufacturing and many IoT applications, both in the visible and nonvisible spectrum including thermographic systems for remote fever and vital signs detection and facial recognition.

User Advice: Use computer vision to augment your organization's workforce capabilities by automating the processing of image and video data. Audit your organization's image/video assets and engage with business stakeholders to discover how computer vision applications can alleviate operational pain points, improve productivity and create new business opportunities. Ensure business stakeholders clearly articulate the tangible business benefits they are expecting from the computer vision assets to be developed.

In addition, we recommend:

- Focus initially on a few small projects, use fail-fast approaches and scale the most promising systems into production using cross-disciplinary teams. Do this by ensuring that sufficient software engineering resources are available to activate AI models in business processes and that governance and maintenance costs of image-based machine learning models are properly accounted for in ROI estimates.
- Critically assess change management impacts of implementing advanced analytics on the organization and its people as this has high potential to derail computer vision projects.
- Test production systems early in the real-world environment since lighting, color, object disposition and movement can break computer vision solutions that worked well in the development cycle.
- Build internal computer vision competencies and processes for exploiting image and video assets. This will enable the organization to make better procurement choices and lay the groundwork for more advanced innovation and product development opportunities.
- Exploit third-party computer vision tooling and services to accelerate data preparation and time to value by deploying early production systems.
- Evaluate legal, commercial and reputational risks associated with deploying computer vision solutions at the outset of customer/employee experience improvement projects.
- Be warned that the fast-evolving regulatory environment may derail computer vision projects due to privacy concerns.

Business Impact: The ability of organizations to capture value and generate insight from their own video/image data assets will become a question of competitiveness and ultimately survival. Key impacts of computer vision include:

- Greater levels of automation by reducing the demands on human monitoring staff and resulting in improved quality, speed and reliability of monitoring camera surveillance feeds.
- Improved decision support via event correlation, alarm management/prioritization and policy and rule engines for predetermined workflows.
- Enhanced customer experience in features such as queue monitoring and management, enhanced customer service and technical support.
- Reduced costs due to the ability to scale video systems without requiring greater human monitoring resources or manual processes.

Data is viewed as potentially one of the most important and unique strategic business assets that organizations control. Gartner estimates around 80% of these dark data assets — including uneventful surveillance video, video meetings and unsearchable text and graphics — are composed of image or video data which typically gets discarded because it has no apparent value. Key use cases today include the use of advanced analytics for video surveillance automation, health and safety compliance (PPE detection, COVID-19 mitigation, etc.), visual search, shopper and shelf analysis, automotive applications, OCR and quality assurance/production line automation in manufacturing. Increasingly, in the future, organizations that are unable to value and leverage their computer vision assets strategically will become uncompetitive.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Amazon Web Services; Another Brain; Baidu; Clarifai; Deepomatic; Google; Matroid; Microsoft; Nyris; Tencent

Recommended Reading: "Venture Capital Growth Insights: Computer Vision"

"Competitive Landscape: Computer Vision Platform Service Providers"

"Survey Analysis: Computer Vision Drives Enterprise Adoption of Artificial Intelligence"

"Market Trends: Facial Recognition for Enhanced Physical Security — Differentiating the Good, the Bad and the Ugly"

"Market Trends: Machine Vision Will Be the Game Changer Across Markets"

"Innovation Insight for Video/Image Analytics"

"Emerging Technologies: Top Advanced Computer Vision Use Cases for Retail"

"Critical Steps to Cash In on the Computer Vision Gold Rush"

Driver Monitoring Systems

Analysis by: Jonathan Davenport

Definition: A driver monitoring system (DMS) is an in-vehicle system that employs sensing technologies and analytics to monitor head and body pose, eye state, attention, drowsiness, emotions, and impairment. This system can also identify drivers. DMSs are used not only to prevent accidents caused by fatigue or distraction, but also to ensure effective handovers between the vehicle and the human in semiautonomous driving situations. Other applications include multimodal user interfaces with gestures or gaze in combination with voice.

Position and Adoption Speed Justification: DMSs have been implemented in some premium vehicles for more than 10 years. The technology has three broader applications:

- *Distraction monitoring* — If the DMS becomes aware of a distraction, it can inform other systems of the driver's condition (for example, altering the following distance for automatic cruise control systems).
- *Intention* — By monitoring head and eye movement, the DMS can inform lane-keeping solutions that the driver intends to change lanes, thus allowing a smooth maneuver if the driver seeks to move lanes without using an indicator signal.
- *Gesture* — Video cameras within the DMS can be used for gesture recognition to, for example, when the driver lights a cigarette or picks up a mobile phone.

Work is also underway to enable DMSs to support:

- *Driver identification* — The DMS can be used to identify drivers. This identification can be used to offer personalized services, such as adjusting seat and mirror positions. The tension of seat belts can also be adjusted based on the size, gender or age of occupants.
- *Voice* — The DMS is capable of recognizing where a driver is looking, which can be linked to voice-based virtual assistants to allow location-specific questions, such as "What is that?" mouth movement or voice recognition is used to determine who is giving the command.

DMS technology is now common within fleet operations as companies seek to fulfill their duty of care to staff and other road users by ensuring that drivers operate vehicles safely. Alerts from the DMS can be used by fleet managers to educate drivers on safe behaviors while behind the wheel. Euro NCAP is encouraging automakers to include DMS in their vehicles now and the European Commission's new general safety regulations (GSR) will mandate driver drowsiness and attention monitoring/distraction recognition for all new vehicles applying for type approval from July 2022. The rate of penetration of DMS could be raised further if regulations (like the UNECE 79) are put in place that require DMS.

User Advice: DMS can be used to get the driver's attention back on the road when he or she is distracted or to suggest the driver take a break when tired. Furthermore, DMS can be integrated into fleet management solutions or usage-based insurance applications. Integrating DMS into these types of applications creates an opportunity to educate people about safe driving practices.

The automotive industry should also be utilizing DMS to monitor driver attention when the car is driving itself. DMS should be used to ensure drivers maintain concentration on the road during Level 2 autonomous driving. For Level 3 applications, DMS supports a smooth machine-human handover, by tailoring the period of time necessary to perform a handover based on the activity the driver is engaged in.

The ability for a vehicle to recognize occupants will allow digital personalization of the vehicle environment. With the rise of mobility-as-a-service offerings, the ability to perform identification and identify who is in the vehicle (not just the person who made the booking) by utilizing the DMS will ensure a smooth and rapid personalization of the vehicle. This sort of personalization is expected to be important for retention purposes.

Even though DMS technologies are already available, remedial action for drowsiness is mostly dependent on the driver. Improved integration with advanced driver assistance systems (ADASs) will be important to accelerate the adoption of DMS. Gartner forecasts that by 2025, 28% of new vehicles will be sold with a DMS system up from less than 1% in 2019. Government regulation would further accelerate adoption of this type of system.

Business Impact: DMS is an automotive safety technology that could have a significant impact on reducing motor vehicle accidents caused by driver fatigue or distraction. Driver alertness is a crucial factor in a significant proportion of road accidents, according to research studies such as those conducted by The Royal Society for the Prevention of Accidents (RoSPA). Current solutions still mostly rely on the driver to act on the system's warnings. DMS will play an important role in the adoption of semiautonomous vehicles, by verifying that the driver is able to resume manual control if necessary or if the autopilot function should take control of the vehicle. Future additional uses of the cabin camera of a DMS could be for facial recognition, using face scan as a biometric starting key for the car to acknowledge and authorize the driver. This feature could increase vehicle security and reduce thefts. More advanced solutions will need complex algorithms, so semiconductor vendors need to work in partnership with software providers and system integrators.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Eyesight Technologies; Jungo Connectivity; Seeing Machines; Sony Depthsensing Solutions; Tobii; TriLumina

Recommended Reading: "Invest in 3 Critical Semiconductor Enablers for a Successful Driver Monitoring System Product Portfolio"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"AI Multisensory Tech in Automotive HMIs, Part 1: Smell"

"AI Multisensory Tech in Automotive HMIs, Part 2: Visual Immersion"

"AI Multisensory Tech in Automotive HMIs, Part 4: Emotion AI"

"Market Insight: IoT-Based Digital Personalization, Part 1 — Improve Customer Retention"

"Market Insight: IoT-Based Digital Personalization, Part 2 — Architecture for Automotive Customer Retention"

"Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem"

"Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies"

"Market Trends: Machine Vision Will Be the Game Changer Across Markets"

Augmented Reality

Analysis by: Tuong Nguyen

Definition: Augmented reality (AR) is the real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects and presented using a mobile, head-mounted-type display or projected graphics overlays. It is this "real world" element that differentiates AR from virtual reality. AR aims to enhance users' interaction with the environment, rather than separating them from it.

Position and Adoption Speed Justification: Current technology is best suited for purpose-built, specialized solutions. As such, position and adoption speed will vary by vertical and industry. Current horizontal tasks seeing the most traction are task itemization, visual design and context-based work instruction. This profile represents a homogeneous view of AR implementations across market segments.

Market interest is growing steadily, but AR continues to struggle with mismatched expectations (vendors promising solutions beyond current capabilities) and poor implementations (for example, solutions delivered without immersive development [3D design and interface] knowledge or workflow integration, or not mapped to business value or need). Current solutions are better described as AR-inspired solutions — experiences that contain elements of AR to offering limited, purpose-built capabilities. AR adoption continues mainly in enterprise applications. Consumer-facing implementations are still struggling to show consumers consistent value. Better hardware, coupled with more compelling use cases, is needed before further progress can be made.

Based on Gartner inquiry (25% increase in inquiries in 2019 over 2018) and industry news, B2B AR continues to gain traction as more enterprises are seeing the value of using AR in their workflow. Moreover, a Gartner 2020 CIO survey indicates that 27% of respondents are currently using, or evaluating/exploring AR. HMD sales reflect the burgeoning pilot deployments. Advancements in HMD hardware (lighter, more durable, safer, etc.) will provide more compelling hands-free use cases for AR as well.

User Advice: Organizations looking to implement AR experiences should:

- Decide on the audience for your AR experience. Internal- and external-facing solutions are not transposable.
- Restrict initial trials to a specific task or goal. Set benchmarks against unaugmented solutions to understand risks and benefits.
- Set the business goals, requirements and measurements for your AR implementation before choosing a provider.
- Rich and robust offerings can bring value only if you have a clear intention for the deployment. For external-facing implementations, use AR as an extension of your brand and experience. For internal-facing implementations, use AR as a tool that will enhance employee job function.

This could include, for example, delivering context-specific information at the point of need for mobile workers, better leveraging experts (using one-to-many video support) in plant and maintenance operations, or enhancing business processes via AR-based training and instruction.

Business Impact: AR bridges the digital and physical world and provides cognitive augmentation for user. AR provides a digital filter to enhance the user's surroundings with relevant, interesting and/or actionable information. This has an impact on both internal- and external-facing solutions. For example, internally, AR can provide value by providing checklists for training and maintenance or for remote telestration in see-what-I-see video collaborations. Externally, it offers brands, retailers and marketers the ability to seamlessly combine physical campaigns with their digital assets. As such, AR is broadly applicable across many markets, including gaming, industrial design, digital commerce, marketing, mining, engineering, construction, energy and utilities, automotive, logistics, manufacturing, healthcare, education, customer support, and field service.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Apple; Atheer; Google; Librestream; Microsoft; PTC; Scope AR; Ubimax; Upskill; Wikitude

Recommended Reading: "Venture Capital Growth Insights: Immersive Technologies"

"Emerging Technology Analysis: Augmented and Mixed Reality Opportunity for 3D Design Software and Vertical ISVs"

"Quality Is the Key to Avoiding 'Digital Distortion' With Your Augmented Reality Strategy"

"Competitive Landscape: Head-Mounted Displays for Augmented Reality and Virtual Reality"

"3D Design and Device Convenience Hinder AR and VR Adoption"

"Augmented and Virtual Reality in the Digital Workplace: Top Use Cases"

"Market Opportunity Decision Framework for Tech CEOs: Augmented Reality and Virtual Reality Use Cases"

"Competitive Landscape: Augmented Reality Tools for Enterprise, 2018"

"Market Guide for Augmented Reality"

"Market Trends: Advancements in Immersive See-Through Technologies Will Differentiate Augmented Reality Glasses"

Head-Mounted Displays

Analysis by: Tuong Nguyen

Definition: Head-mounted displays (HMDs) are small displays or projection technology integrated into head-worn devices. They are worn or mounted on or near the head so their displays can be seen by the wearer at an ideal viewing distance. Additionally, aspects of the visual content will be contextual information that translates the wearer's state into visual cues.

Position and Adoption Speed Justification: HMDs were subject to significant hype, and as a technology it is maturing. Industry efforts indicate positive momentum in this market, key factors include:

- Growing popularity, availability and success (for example, Oculus Quest) of all-in-one VR HMDs; creating a midtier category of product that's more user-friendly
- More accessible and usable devices driven by all-in-one VR HMDs
- Growing landscape of mixed reality (MR) HMDs
- Steady enterprise adoption of augmented reality (AR) HMDs
- Continued technology improvements across the spectrum of HMDs such as 6DOF, field-of-view, and interfaces have made experiences much more immersive

Despite sales growth in 2019, HMD sales (dominated by VR) continue to be modest, with indications that sales have slowed in 1Q20 (even prior to the pandemic). While industry interest in the potential of virtualized interactions for consumers is high, that impact and investment is more likely to be seen in the enterprise; where the value proposition is still much stronger. Mass-market penetration won't be achieved until key elements such as content availability and device usability and accessibility are vastly improved. Apple's rumored head-worn device currently has a limited impact on the pace and trajectory of HMDs, but will likely accelerate adoption as the launch date draws near and details are confirmed by the company. In the meantime, prosumer devices such as Vuzix Blade and Focals 2.0 by North will improve visibility and acceptance among the broader market.

User Advice: Use HMDs as an extension of your current endpoint devices (laptops, smartphones, tablets, monitors) spectrum and also:

- Evaluate AR/MR HMDs for situations where the user's hands are occupied with a task or when the user is moving while accessing information — for example, to review work instructions, schematics or customer data.
- Assess the cost of VR experiences against the benefits. The cost of service and customization for VR experiences can come at a high cost, but there are also barriers around user interfaces (how to interact with virtual, 3D objects) and user experience (motion sickness and other adverse, physical reactions due to sensory mismatch).
- Adopt HMDs tactically — current devices are purpose built hardware with rapid (yearly) product release cycles.

Evaluate ROI potential by monitoring HMD advancement such as improvements in display resolution, expanded fields of view, better battery life, comfort and lower cost.

Business Impact: HMDs can provide an immersive and potentially hands-free, intuitive way to interact with the physical and digital world. Large enterprises are seeing value in using AR HMDs for use cases such as first-time fix reduction, increase in productivity and work order completion, and improved safety. Value from VR HMDs is mostly for entertainment, but businesses are seeing more adoption for training and product design and reviews. MR HMD use cases are further down the timeline and technology intersects with usability and use cases that benefit from digital interaction with physical objects such as combining physically accurate dimensions and measurements for large equipment, or facilities to visualize architectural fit.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Epson America; Facebook; Google; HTC; Microsoft; Nreal; RealWear; ThirdEye Gen; Varjo; Vuzix

Recommended Reading: "Venture Capital Growth Insights: Immersive Technologies"

"Top 10 Strategic Technology Trends for 2020: Multiexperience"

"Gartner's 2020 Strategic Technology Trends for Product Leaders"

"Competitive Landscape: Head-Mounted Displays for Augmented Reality and Virtual Reality"

"Market Trends: Advancements in Immersive See-Through Technologies Will Differentiate Augmented Reality Glasses"

"Forecast Analysis Wearable Electronic Devices, Worldwide"

"3D Design and Device Convenience Hinder AR and VR Adoption"

Virtual Reality

Analysis by: Tuong Nguyen

Definition: Virtual reality (VR) provides a computer-generated 3D environment (including both computer graphics and 360-degree video) that surrounds a user and responds to an individual's actions in a natural way, usually through immersive head-mounted displays (HMDs). Gesture recognition or handheld controllers provide hand and body tracking, and haptic (or touch-sensitive) feedback may be incorporated. Room-based systems provide a 3D experience while moving around large areas, or they can be used with multiple participants.

Position and Adoption Speed Justification: Current use cases continue to focus on gaming, entertainment and 360-degree video. A number of supply side and demand side factors have slowed the momentum of consumer and enterprise adoption:

- The supplier ecosystem has been slow to advance products
- Breadth and quality of content remain limited
- Solutions lack scalability
- Lack of enterprise-ready solutions
- Consumer interest has slowed
- Hardware and technology innovation, while progressing will take three to five years to significantly improve solutions

User Advice:

- Use VR to support your organization's efforts for training, visualization and collaboration tasks requiring 3D content (such as BIM and CAD).
- Identify procedures and experiences which may benefit from virtualized visual interactions.
- Discover potential benefits of VR by benchmarking traditional practices against VR experiences.
- Focus on a small number of pilots based on platforms designed to meet enterprise requirements.

- Avoid point solutions and mixing VR trials with AR/MR ones.

Business Impact: While VR can be amazingly sophisticated and beneficial, the level of customization and limited scalability can come at a high cost — outweighing potential benefits in many situations. VR developers should consider targeting scenarios where using advanced visualization and HMDs can benefit the task or customer interaction point due to their ability to offer higher degrees of visual fidelity and personalization over what flat-screen-based systems can provide. Examples include immersive video game development, interactive movies and new storytelling experiences, and live events. Alternatively, focus on training simulations for empathy and decision making skills that are high-cost, high-insurance or high-risk. Examples include expensive or inaccessible locations such as space or deep sea exploration, surgical training, and onboarding for dangerous, or remote locations such as an oil rig. Potential benefits of VR include:

- Reduce training costs for inaccessible and centralized training facilities, or equipment downtime to train employees
- Reduce risk/increase safety by allowing employees to acclimate to equipment and environments through simulated experiences prior to live participation
- Improve design cycle time through direct collaboration with 3D assets

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: EON Reality; Facebook; Google; HTC; Insta360; Matterport; Motive; Ricoh; Sony; STRIVR

Recommended Reading: "Venture Capital Growth Insights: Immersive Technologies"

"Top 10 Strategic Technology Trends for 2020: Multiexperience"

"Gartner's 2020 Strategic Technology Trends for Product Leaders"

"Competitive Landscape: Head-Mounted Displays for Augmented Reality and Virtual Reality"

"3D Design and Device Convenience Hinder AR and VR Adoption"

"Augmented and Virtual Reality in the Digital Workplace: Top Use Cases"

"Market Opportunity Decision Framework for Tech CEOs: Augmented Reality and Virtual Reality Use Cases"

Flexible Display

Analysis by: Anshul Gupta

Definition: Flexible displays are display panels constructed of thin or flexible substrate that can be bent, rolled, folded or flexed without loss of functionality. The flexible substrate can be plastic, metal or thin glass. A flexible display panel can be printed or deposited onto thin foil. Flexible displays will ride maturity through different stages, going from fixed and curved (where it is today) to truly flexible when it can be bent and rolled according to end users' wishes.

Position and Adoption Speed Justification: Flexible display is already a reality at display manufacturers' level, but frequent flexing of flexible display-equipped devices to change and resume shape remains a challenge. Flexible display-equipped devices with a fixed curve is commercially available for past few years. Flexible display equipped foldable devices from a fixed position have started to come into market since 2019. Fully flexible devices are yet to come to market.

Flexible active matrix organic light emitting diode (AMOLED) makes current generation flexible displays a reality, but flexible liquid crystal display (LCD) remains a near-term possibility. Flexible AMOLED displays are printed on top of a flexible substrate like a thin layer of plastic, and current generation foldable devices allows user to directly interact with flexible OLED displays unlike a glass screen in case of traditional LCD equipped devices. Direct exposure of flexible OLEDs to users, encapsulation, limitation to use a glass or plastic, and achieving narrow bends remains a challenge for fully flexible devices.

Current generation flexible display allows a fixed, curved and predetermined foldable display device. High cost and complexity of manufacturing flexible OLED-equipped displays is likely to smoothen out as more devices and vendors introduce commercial foldable devices in the coming years.

User Advice: Flexible display will bring new use cases and form factors for mobile devices such as two-in-one form factors and lightweight, energy-efficient and multidisplay devices. Mobile device manufacturers are using flexible displays to differentiate their devices such as smartphones. Commercial availability of large size flexible displays at lower cost will see adoption into segments beyond mobile devices such as automotive, display advertising, smart spaces, fashion accessories, etc.

Current generations of flexible display-equipped devices require a very specialized manufacturing process with relatively low yield, making them costly and limited manufacturing capacity. Increasing the yield and production capacity requires display manufacturers to invest in advanced inspection, testing and repair systems to identify and quickly repair defects. However, with continued interest from device manufacturers to introduce flexible display panels in new smartphones, wearables and ultramobiles is likely to bring in process efficiencies and achieve lower costs. Further efficiency and cost gains will be made as display manufacturers builds larger 6-Gen and 8-Gen flexible OLED fabs and invests into R&D.

However, truly flexible mobile devices will continue to be a challenge until the manufacturing process matures. Flexible display-equipped devices with certain limitations such as curve at bends, the direction of bend, curved to retain a fixed shape will continue to grow in the near future.

Device manufacturers looking at integrating flexible displays to achieve curved, foldable or total flexible form factors should consider:

- High costs due to the complex manufacturing process and low yields experienced by display manufacturers.
- Advantage of thin form factors and lightweight.
- Limited availability of flexible displays due to manufacturing capacity constraint and large device players being preferred customers.
- Challenges in achieving consistent quality across displays.
- Challenges in meeting mechanical design requirements and adjusting user interface to achieve best possible experience.

Business Impact: Flexible display will bring benefits across industry markets:

- Automotive manufacturers with connected vehicle could look at using flexible displays for enhancing onboard entertainment, design and end user experience.
- Brands can use flexible displays to merge digital displays with curved surfaces to turn various structures into smart digital displays for advertising.
- Consumer goods companies can use flexible displays to create new types of interactive displays to be used in a smart home.
- Flexible displays can be used by smartphone manufacturers to differentiate product offerings and deliver differentiated experiences.
- Flexible displays will bring a revolution in the device market. The displays could bring multiple devices — such as laptops, ultramobiles, tablets and smartphones — together into a single device. You could unroll or unfold the device to the size needed based on the use.
- Flexible displays could be extremely disruptive to the display industry as they could allow new form factors to create new markets. They could completely disrupt the current display technology ecosystems.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: AU Optronics; BOE; Cambrios; LG Display; Samsung Display Solutions

Recommended Reading: "Forecast Analysis: PCs, Ultramobiles and Mobile Phones, Worldwide"

"Emerging Technology Analysis: Foldable Display Brings New Market Opportunity"

"Top 10 User Experience Technologies That Will Drive Innovation"

Climbing the Slope

Autonomous Vehicle Perception System

Analysis by: Jonathan Davenport

Definition: Autonomous vehicle perception systems generate a virtual representation of static obstacles and moving objects to identify free space and plan a vehicle's path. Software takes sensor data as an input, fuses camera, radar, lidar and other sensor data based on statistical methods or artificial intelligence, and outputs a representation of the vehicle's surroundings that neural networks can use to control automated vehicles. Varying system sophistication exists, underpinning Level 2 now, and up to Level 5 functionality in the future.

Position and Adoption Speed Justification: Advanced sensor data fusion and perception systems are fundamental to autonomous driving use cases. So all OEMs and technology firms working on the perception part of automated vehicles are developing this technology and implementing it in development projects and some even have limited commercial deployments. Autonomous vehicle perception systems are currently only being sold as a product in Level 2 ADAS offerings. The functions for Level 3 and higher automation require significant computing power (high-performance CPUs with additional AI coprocessors).

For autonomous driving, access to huge quantities of situational sensor data (different junctions, road networks and objects) is required to train the neural networks. The fact that automated vehicles will operate in highly diverse traffic situations and road conditions means the perception system technology must be able to address a long tail of rare incidents.

A main challenge that remains is standardization of methods for performance validation of usage/functional safety within ISO 26262.

We expect a consolidation in this space and a reduction to a limited number of larger vendors as the efforts of validation for highly automated functions is a major cost driver. Cross-vendor standardization, developed in collaboration with OEMs, will follow based on lessons from ongoing/emerging large pilots, and standardization can also be driven by safety considerations and regulations.

User Advice: Create a perception system that is adaptable to different sensor feeds, sensor positions and environmental inputs. The ability to abstract specific sensor configurations that can have unique characteristics (specifications and positions) will allow the system to be easily deployed on different vehicle models or lines. The ability to take one platform and deploy it into different situations will also be key. This means that perception algorithms will need the capability to be retrained quickly to enable deployments into different countries (road signs and markings, traffic regulations, animals etc.), cities or use cases (e.g., robotaxi, mining or delivery robot).

Ensure embedded software engineers and perception system sensing experts are working closely together to industrialize these advanced algorithms on embedded hardware. As many solutions remain in a research and development stage at present, it is important that perception systems have scalable, functional software components to cope with ever-increasing volumes of test use cases. Furthermore, that any alterations can be implemented within test vehicles in an agile manner.

Companies must invest in simulation software/application technologies that help train the deep learning networks for executing safe and secure driving maneuvers that are required for certain parts of the perception systems.

Another area to closely monitor is sensor technology development, coupled with the emerging fusion of sensor technologies and hardware platform vendors, that provide the hardware base and related software services for perception systems. An especially important area is lidar sensor, camera and imaging radar technology. The innovation dynamic in this area is still very high, and companies building the technology must make sure that they have access to sensor technology arrays that will be capable of handling future capability requirements.

Business Impact: The core application of this technology is ADAS and the evolving space of autonomous driving (Level 3 to Level 5). It is one of the core elements that will make the autonomous vehicle safe, secure and trusted by consumers — eventually meaning a steering wheel is no longer required. All automated vehicles require a perception system, so eventually the technology will become a commodity.

In principle, the applicability will not be limited to the automotive industry. The perception system in its final developed stage will provide a generic capability of “things,” “vehicles,” “sensors” and “machines” to make sense of a complex environment populated by human beings. Furthermore, the perception system will initiate actions in a safe and secure way within a business context. The technology could easily be adopted in commercial transportation, automated security applications (for example, perimeter security) and robotics, and it may also have military applications.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Aptiv; Baidu; BMW; Bosch; Continental; Mobileye; NVIDIA; Tesla; Waymo; Zenuity

Recommended Reading: “Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide”

“Top 10 Strategic Technology Trends for 2020: Autonomous Things”

“Market Trends: Monetizing Connected and Autonomous Vehicle Data”

“Cool Vendors in Autonomous Vehicle Systems”

“Public Opinion Will Be Critical to Successful Autonomous Vehicle Adoption”

“Market Trends: Establishing Autonomous Vehicle Safety Standards Is Critical for Successful Implementation”

“Automotive and Smart Mobility CIOs Must Play a Crucial Role in the Autonomous Driving Technology Stack”

“Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem”

“Market Insight: Use Situationally Aware Platforms to Enable Safe Autonomous Vehicle Handovers”

Digital Instrument Cluster

Analysis by: Masatsune Yamaji

Definition: A digital instrument cluster replaces electromechanical gauges with a digital display that allows the driver to select how information is presented for the primary dashboard instruments in a vehicle. The type, quantity and appearance of information — such as speed, engine rpm, fuel quantity and navigation directions — can be changed to suit different driving conditions and user preferences.

Position and Adoption Speed Justification: Many automobile manufacturers, including Volkswagen, BMW, Mercedes-Benz and Jaguar Land Rover, have already replaced traditional gauges with LCDs or AMOLED screens that display digital information designed to mimic the look of a conventional instrument cluster. As the use of digital display technology and graphics processors for instrument clusters expands, it opens up the possibility that the instrument panel's layout, color and other aspects of its appearance can be set according to user preferences. A digital instrument cluster can be integrated with other systems in the automobile, such as the infotainment head unit and a head-up display, for a more seamless user experience.

In the past few years, adoption of digital instrument clusters has proceeded even in the affordable car market. A lot of emerging Chinese local Tier 1 companies have joined this market and produced low-price digital clusters for local customers. The quality of these low-end products is not as good as in the luxury car market, but affordable car manufacturers can attract many car buyers with some additional costs for digital instrument clusters. The expanding digital clusters have light RTOSs rather than multimedia-capable general-purpose OSs, making the cost reasonable.

The adoption is rapidly proceeding, so we moved the position to the Slope of Enlightenment in this year. The display panels shift now from LCD to AMOLED, which enables better performance against backlight, hence, enabling greater freedom in terms of dashboard design. Also in several cases, automakers are starting to merge digital instrument cluster to center display stack.

User Advice: Digital instrument cluster technology offers some potential for product differentiation, and it aligns well with growing consumer expectations for a greater degree of user customization based on consumer experiences with other electronic products, such as smartphones. These benefits should be weighed against the additional cost of the system and the investment required for product development. In addition, the degree of user configurability must be carefully considered with respect to its impact on driver attentiveness, and effective mitigations for driver distraction should be designed into the system.

Instrument cluster designers must ensure that critical information, such as speed, can be effectively displayed over the full range of environmental conditions in which the vehicle will be operated. Some LCD screens can be affected by temperature extremes, and many countries have a legal requirement that vehicles are equipped with an operating speedometer.

Business Impact: The primary business impact of this technology is as a product differentiator among automobile manufacturers, and it represents an opportunity for incremental profit if sold as a high-margin option. A dynamic display can present critical information in a way that is more easily interpreted by the driver. For example, a warning icon could grow in size to dominate the display as a hazard became more imminent. Instrument clusters incorporating such dynamic information presentation might have a positive impact on safety, but it must be implemented in a manner that is not distracting to the driver. Initially, this feature was made for high-end luxury and sport-oriented models and models aimed at younger buyers. However, adoption is spreading to even affordable models, especially in China, as the technology is perceived as having strong differentiation.

Benefit Rating: Low

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: Bosch; Japan Display; JVCKENWOOD Group; Kyocera Group; MARELLI; Sharp; Visteon

Recommended Reading: "SWOT: Luxoft, IT Services, Worldwide"

"Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies"

Group Interactive Displays

Analysis by: Stephen Kleynhans

Definition: Group interactive displays are large-format (typically, 50-inch to 86-inch) touch displays that include the ability to project content from various devices and enable markup, using touch or special pens. These peripheral devices are usually connected to a PC.

Position and Adoption Speed Justification: The focus on the digital workplace continues to drive increased interest improving conference and meeting rooms across organizations. Large interactive digital whiteboards have been available in the market for more than a decade, but have seen limited traction due to high cost, poor performance and uneven support. Decreasing hardware costs for large, full HD and 4K displays is enabling more organizations to outfit meeting rooms replacing projectors, as they renovate their meeting spaces. They are often paired with a large nontouch display for use in video conferencing set ups. However, the promise of delivering a truly interactive meeting experience is often lost due to the complex setup and generally poor user training. This situation began to change with Microsoft Windows 10, as software support improvements (in collaborative tools, OS and other apps in general) and user familiarity with collaboration and touch technologies increased. Microsoft has also introduced the Windows Collaboration Device specification to standardize capabilities across multiple vendor products.

User Advice: Group interactive displays enable relatively low-cost deployment, good flexibility, and are not tied to a specific collaboration vendor or presentation tool. However, the experience provided is limited to the applications that users are able to run on their devices and is not specifically tuned for particular meeting or collaborative experiences. Additionally, starting a meeting is often still a multistep process, and this complexity has limited the success of many deployments. Compare the physical device experience with the vendor's PC client, browser and mobile apps. If there are gaps in terms of feature parity, prepare best practices to share with workers who need the richest capabilities. Providing user training, information cards and encouragement to engage with the devices continues to be important to a successful project, as does providing simple tools for connecting and displaying from multiple devices.

While usually installed in meeting rooms, these large interactive displays can also be considered for larger private offices and, potentially, classrooms or executive briefing facilities. They cost only marginally more than basic large displays, but provide significantly more functionality.

Business Impact: Meeting room technologies have a long life and must take into account long-term enterprise needs and future growth, so analyze organizational requirements for meeting space technologies by looking at current and future digital workplace needs.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: Dell; HP Inc.; Newline Interactive; Ricoh; Samsung; Sharp; SMART Technologies

Recommended Reading: "Select the Right Technology for Modern Meeting Rooms"

Ultrasonic Fingerprint Sensors

Analysis by: Amy Teng

Definition: Ultrasonic fingerprint sensors make use of the principles of medical ultrasonography. The sensor radiates high frequency sound waves and collects the reflected waves to create visual images for identifying biometric syndrome of fingerprint.

Position and Adoption Speed Justification: Ultrasonic fingerprint sensors are competing with many other similar purposes but different biometric detection technologies. The advantage of ultrasonic fingerprint sensors is obvious, but cost is the decisive factor because its major market — smartphones — is highly competitive and price-sensitive.

Currently placing an ultrasonic fingerprint sensor under the display module without blocking the display viewing area is the main design trend, wherein Qualcomm is the major technology provider. Optical fingerprint sensor technology that is integrated in the display is the main rival technology led by Chinese semiconductor vendors like Goodix Technology and Egis.

Samsung's S10, Note 10 and latest S20 series of smartphone have adopted the technology, alongside Qualcomm's new fingerprint sensor, 3D Sonic Max, and the partnership with display panel maker BOE Technology Group. Qualcomm has further enhanced the capabilities of its ultrasonic fingerprint sensor technology by offering larger active area, faster processing power per area, and support from its Snapdragon processors. The partnership with BOE will drive vertical integration and cost reductions. As a result, we move its HC position a bit forward.

User Advice: An ultrasonic fingerprint sensor offers more design flexibility in contrast to Apple's Touch ID technology:

- It can penetrate the surface layer of electronics devices to reach the fingertip and sense the fingerprint.
- It is immune to noises caused by dirt, lotion and water.
- Its sensing area can be curved and broadened.

Ultrasonic fingerprint sensors can create an "invisible biometric sensing" aesthesia for mobile devices. The sensor can be placed beneath an OLED display or metal casing, and sensing areas can be larger so secured gestures or other innovative features (like dual fingerprint sensing to improve security).

Biometric sensing technology used as identity authentication provides a straightforward, native and secure feeling to users physically. It will continue to evolve and coexists with the increased adoption of 2FA (two-factor authentication).

Technology product managers should view the biometric-sensor-based technology as part of the fundamental security elements in the product roadmaps, keep on recruiting vendor expertise and cumulating experiences to build a security strategy across different product lines.

Biometric sensing and identity authentication technology is more than locking and unlocking a device in faster speed and an easier way; product manager should collaborate with fingerprint technology suppliers to expand this secured, convenient experience to engage ecosystems (like mobile payment and access control) to add value to products.

Business Impact: Fingerprint sensing technology has been evolving for more than 10 years since iPhone 5S introduced Touch ID in 2003. The capacitive fingerprint sensor has been widely adopted due to its cost advantages. Emerging technologies like facial-recognition-based authentication technology (starting from Apple introduced Face ID in 2017) have gradually cannibalized its market share.

Additionally, ultrasonic fingerprint sensors compete against optical fingerprint sensors that provide similar use experiences at much lower cost. Investment for this market must carefully review technology suppliers' ability of vertical and system integrations because they are facing a highly competitive smartphone market where only vendors who scale in short-time can make profits.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Qualcomm

Recommended Reading: "Growing Adoption of Fingerprint Technology in China Brings New Opportunities for Biometric Sensor Suppliers"

"Market Trends: New Biometric Authentication Methods in Smartphones Will Redefine User Experience"

Face Recognition

Analysis by: CK Lu

Definition: Face recognition is a biometric technology and an application of computer vision that identifies a person against a previously enrolled image of the subject's face.

Position and Adoption Speed Justification: Face recognition has been a focus of data science since the 1960s, and the enterprise biometric and surveillance markets are the main enterprise use. The technology and use can be grouped into three types: 1:1 (verification), 1:n and n:n (identification). The advancement of 1:1 (mainly on consumer devices) and 1:n (mainly used by the public sector) of face recognition is driving the technology to mature and be widely adopted.

Face recognition has found application in markets such as identity and access management, device control, and city/home surveillance, which draws business attention for safety and security purposes, business intelligence, and marketing tools. Face recognition can also work as complementary technology to estimate people's age, gender and eye attention.

Consumer applications have begun to lead the adoption of face recognition in everyday use. In 2018, Apple introduced the TrueDepth camera for use in various applications, including Face ID, Animoji, Apple Pay and selfies. 3D sensing of users' faces potentially provides better security than passwords and most biometrics. It is highly resistant to spoofing attacks from photos, video and mannequins. However, even with 2D (RGB-based) cameras, liveness detection technologies (such as angle tilt/rotation, computer vision, facial expression changes and dual cameras) can largely improve accuracy and resistance to spoofing. The Android camp is quickly catching up on 3D-sensing cameras and face recognition ecosystems on smartphones. Alibaba Group's Alipay is developing an application with Ant Financial to allow users to make payments by using face recognition technology.

User Advice: Add other biometrics modes — multifactor authentication (such as iris, voice, behavior and fingerprint) — to improve accuracy and security.

Public sectors, financial services firms, airline companies, retailers and healthcare providers can use face recognition to more easily identify/verify the identity of VIP customers, blacklists and suspects. Face recognition can be used in some countries as part of a marketing strategy to analyze customers based on their age, gender and other facial attributes. Doing so could improve customer engagement.

In the home, face recognition is possible via cameras on TVs, security cameras (such as Amazon Key) or gaming systems that identify people in the room. Beware of privacy concerns over other ways face recognition information is used.

Business Impact: World pandemics such as COVID-19 has sped up the implications of face recognition. For example, in Russia, the government is using street cameras to ensure people are doing shelter in place and to track virus carriers. In China, tech companies are developing infrared temperature systems that can quickly identify a person's forehead area, even with a mask on.

Faster and more accurate image processing will enable gaming and automotive applications that rely on instant-response systems.

In high-secure areas, the use of multifactor credentials, such as an iris or a palm vein, should be added. This provides more rigorous identification in areas such as customs or voter registration.

Face recognition will enable a robot/virtual personal assistant (VPA) speaker with a camera to be a mix of watchdog, butler and assistant in our homes, retail stores and bank branches. Robots could have a more natural human interface that people can have a conversation with.

The future of retail experience will heavily leverage face recognition. For example, Amazon Go stores or Alibaba Group's no-man store concept (Tao Cafe) will be possible scenarios for face recognition.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: Alibaba Cloud; Amazon Rekognition; Apple; Baidu Cloud; Cognitec; FaceFirst; Herta; Milestone; NEC; SenseTime

Recommended Reading: "Three Biometric Authentication Risks You Can't Ignore"

"Market Trends: Facial Recognition for Enhanced Physical Security — Differentiating the Good, the Bad and the Ugly"

"Top 10 Strategic Technology Trends for 2020: Democratization"

AMOLED-Based Microdisplay

Analysis by: Rajeev Rajput

Definition: AMOLED-based microdisplays are tiny displays manufactured by applying AMOLED on a CMOS substrate. They are used in near-eye products including head-mounted displays (HMD) and electronic viewfinders (EVF) used in DSLR cameras. There are various terms for this technology, such as AMOLED on silicon, OLEDoS, or micro-OLED.

Position and Adoption Speed Justification: AMOLED-based microdisplays have been developed for years and were mainly used in military and EVF applications. This technology has been expanded into AR HMDs few years ago and is now competing with liquid crystal on silicon (LCoS). With no external light source required, advantages of AMOLED over other technologies are compact size & weight, superior contrast, wide color space, power efficiency, and faster response time. However, AMOLED-based microdisplays have more technical challenges because of their limited color lifetime and brightness required (ideally >5,000 nits) in AR HMDs.

AMOLED-based microdisplay developers are not traditional display makers. Instead, most of them are startups such as eMagin, Kopin, OLiGHTEK and MICROOLED. Also, there are large conglomerates such as Sony and Epson which are manufacturing AMOLED-based microdisplays at a small scale mainly to fulfill in-house demand for EVF and AR HMDs.

Mass production of AMOLED-based microdisplay is challenging and with niche end-markets, the technological innovation cannot be as fast as traditional displays. However, this situation is changing as display panel manufacturers are joining forces in this space. BOE partnered with Kopin and OLiGHTEK to establish OLED-on-Silicon manufacturing facility with capacity of ~1 million modules per year for HMD applications. Company is aggressively investing in microdisplay space to address increasing demand from these applications.

AMOLED is gaining share in microdisplay market to become the mainstream technology especially in HMDs due to the combined effort from startups and big players, therefore the position on Hype Cycle has been moved forward in the Slope of Enlightenment.

User Advice: AMOLED-based microdisplays will equip OEMs to modulate the design of HMDs because less components are needed in microdisplay thus consuming lesser space. This is especially important for the use cases where the weight is critical to end users such as in military or field service for inspection.

Micro-LED is another technology which offers big promises to microdisplays for HMD applications, however, it will take significant time to attain technological maturity and mass adoption. Therefore, HMD makers should watch the technology evolution of both AMOLED and Micro-LED respective changes in the supply chain to plan their product roadmap accordingly while looking at the current demand. Partnership with microdisplay supplier will be very important to develop customized displays specific to the requirements.

Business Impact: Augmented reality (AR) glasses will be more easy to use because the size of light engine can be greatly improved when using AMOLED-based microdisplays and thus will have more room for other components to be built in such as 3D-sensing camera, human interface (either touchpad or voice control) or larger battery for long hour operation. Particularly, in professional work, this ease of use of AR glasses will further improve safety and productivity.

Large cost-effective OLED microdisplays (LOMID) project, collaboration among Fraunhofer FEP, CEA-Leti, and MICROOLED, has developed flexible OLED microdisplay with 2000 ppi and 10 micron pixel size for VR smartglasses. BOE, Kopin and OLiGHTEK joint venture is also producing microdisplays for AR/VR HMDs. This shows potential of OLED microdisplays in VR HMDs, a new application where traditional display panels have been used so far.

With COVID-19 impacting countries worldwide, AMOLED microdisplay supplier have growth potential in medical equipment like thermal imagers. Manufacturers can also explore niche applications such as monocular and binocular systems, rifle scopes, and advertisement as their long-term goal.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: BOE Technology Group; eMagin; Kopin; MICROOLED; Seiko Epson; Sony

Recommended Reading: "Market Trends: Advancements in Immersive See-Through Technologies Will Differentiate Augmented Reality Glasses"

"Market Trends: Adoption of New Non-LCD Technology in Smartphones and VR/AR Will Be Supply-Side-Driven"

Entering the Plateau

AMOLED

Analysis by: Rajeev Rajput

Definition: Active-matrix organic light-emitting diode (AMOLED) is a display technology that uses organic self-emitting material applied onto a glass or plastic substrate. This self-emitting characteristic doesn't need LED backlights and each pixel turns on upon electrical activation and turns off when electrics disappear.

Position and Adoption Speed Justification: Along with thin form factor, light control can go down to pixel level in AMOLEDs and thus a faster response rate, higher color contrast ratio, and wider color range can be achieved compared to LCDs. These benefits have led to rapid adoption of AMOLED in high mobility electronics, such as smartphones, smartwatches and VR goggles.

The major issues of AMOLED are discoloration (resulting from imbalanced pixel usage) and shorter life span of blue color. Manufacturing AMOLED is also challenging due to lower yields which lead to higher cost; however, high adoption rate, technological advancements and established supply chain have resulted in significant cost reduction, now even comparable to LCD panels. Today, an increasing number of display makers have started mass producing AMOLED panels for smartphones, smartwatches, TVs, tablets, and other devices. There has been increased focus on R&D and fab construction for AMOLEDs in last three years especially for flexible panels.

AMOLED with plastic substrates allows bendable and foldable displays, and we have seen AMOLED moving beyond basic displays. Most leading mobile phone OEMs including Apple, Huawei, OPPO, vivo, Samsung, etc., adopted flexible AMOLEDs in real-life production for smartphone and wearables. Yet, AMOLEDs with foldable form factor need time to reach maturity. The latest high-profile application of the foldable AMOLED are Samsung Galaxy Fold and Z Flip, Huawei Mate X and Motorola razr; however, these products have not seen wider consumer acceptance due to reliability concerns. Efforts are being made by leading vendors to improve robustness and yield by encapsulation, cover glass and related technologies; therefore, we can expect more product launches with the foldable AMOLED going forward.

The cost and performance of AMOLED have greatly improved which has led to mainstream adoption of rigid as well as flexible panels. Given its increasing penetration rate, ranging between 20% to 50% of target audience, we move forward the position of AMOLED on Hype Cycle into the Plateau of Productivity.

User Advice: As AMOLED continues to grow in smartphones, smartwatches and tablets, electronic OEMs should consider how to exploit the benefit of flexible/foldable form factor design, as early adopters will have the advantage of genuine product differentiation.

Despite the adoption by several OEMs like LG, Sony, Panasonic, TPV, Hisense, Skyworth; AMOLED penetration in TV segment is still at a very nascent stage. Electronic OEMs should continue to monitor AMOLEDs in TV space in comparison to other emerging display technologies like quantum dots, mini-LED, and micro-LED, and should implement this technology in their products when pricing can compete with aforementioned technologies.

Samsung recently launched Galaxy Chromebook with AMOLED panel while several OEMs like HP Inc., ASUS, Dell have already adopted AMOLED in their flagship laptops. Improved battery life, better color, contrast, viewing angles, and better response times (benefiting video applications) compared with LCDs play significant role in mobile PCs where OEMs can gain edge over competitors by adopting AMOLED in their products.

OEMs are attaching light, color, proximity, and fingerprint sensor behind AMOLED panel (Behind-OLED Sensors) in smartphone devices. Next generation AMOLED panels have potential to hide 3D sensing system, and other circuits behind the screen to offer full view experience to end user.

Business Impact: AMOLED is a low-power, high-performance alternative to traditional LCDs. Moreover, AMOLED provides sharper color (especially showing true black), better contrast and viewing angles, and better response rate (good for video and gaming applications) — all of which benefit handset OEMs across their entire lineup.

Developing a new display technology requires huge R&D effort and establishment of display fab can cost billions of dollars, which is why limited numbers of panel manufacturers have ventured into AMOLED space. Yet increasing competition has reduced the profit margin of AMOLED manufacturers rapidly especially in smartphone and smartwatch applications. To achieve higher ROI, manufacturers will have to address existing production challenges with technology enhancements and tap into applications like automotive, notebook, monitor, and signage.

For large panels, Quantum Dot-OLED hybrid displays can be better than White OLED as quantum dots offer 100% efficiency (better than the color filters) and use of only one color can lead to significantly reduced cost. Additionally, inkjet printing (IJP) has cost reduction potential as it optimizes material usage and required low investment in fab construction.

Cost of AMOLED panels will eventually reduce with higher yields and better performance. Therefore, improved performance over LCDs will have the greatest impact in the midrange to high end, while the cost savings will most affect lower-end devices.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: BOE Technology Group; LG Display; Samsung Display Solutions; Tianma Micro-electronics; Visionox Technology

Recommended Reading: "Market Trends: Advancements in Immersive See-Through Technologies Will Differentiate Augmented Reality Glasses"

Head-Up Displays

Analysis by: Masatsune Yamaji

Definition: A head-up display (HUD) is a transparent display using light-emitting diode or other display projection technology to display customizable information and images (for example, speed data and warnings). It displays such content within a driver's line of vision onto a windshield or other surface viewed by passengers (such as side windows).

Position and Adoption Speed Justification: HUDs are beginning to be offered on large-volume vehicle brands and models, and not exclusively as optional features. Recent R&D work is focusing on combining augmented reality (AR) with HUD technology to enable enhanced information management in the driver's view, including social and point-of-interest data. Automakers are also working on offering aftermarket solutions to retrofit existing vehicles with the technology. This work emphasizes HUDs' role in providing broader driver information features. Vendors are also developing emerging and advanced HUD technologies that use laser technology to directly project images onto a surface, and that provide higher resolutions and more color choices. The growing importance of human-machine interface (HMI) solutions for connected vehicle applications and the desire for distraction-minimizing technologies will continue to elevate the importance of HUDs in automobile applications.

High-definition (HD) video will also be used for AR navigation in the automotive space.

The technology is already mature enough to reach plateau, but the adoption rate is still not high.

This is because automakers provide HUDs as an option, and not many car owners use the HUDs.

The situation remains in 2020, so we did not change the position of this technology in the Hype Cycle this year.

User Advice: Automotive companies should increasingly develop and deploy HUDs as a potential HMI solution in automobiles. HUDs will create differentiated and less-distracted customer experiences — especially when combined with other user interface technologies, such as speech recognition and haptics.

Application developers can make HUD technology more compelling to users by adopting AR.

Business Impact: HUDs can address driver distraction issues by:

- Keeping drivers' eyes on the road
- Providing better information management
- Creating better user experiences for consuming vehicle-specific performance data and digital content in automobiles

These benefits are critical to automotive companies, because they help to meet legislative mandates regarding driver distraction. HUDs can also create differentiation and revenue opportunities as automakers can charge for these technologies as vehicle options.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

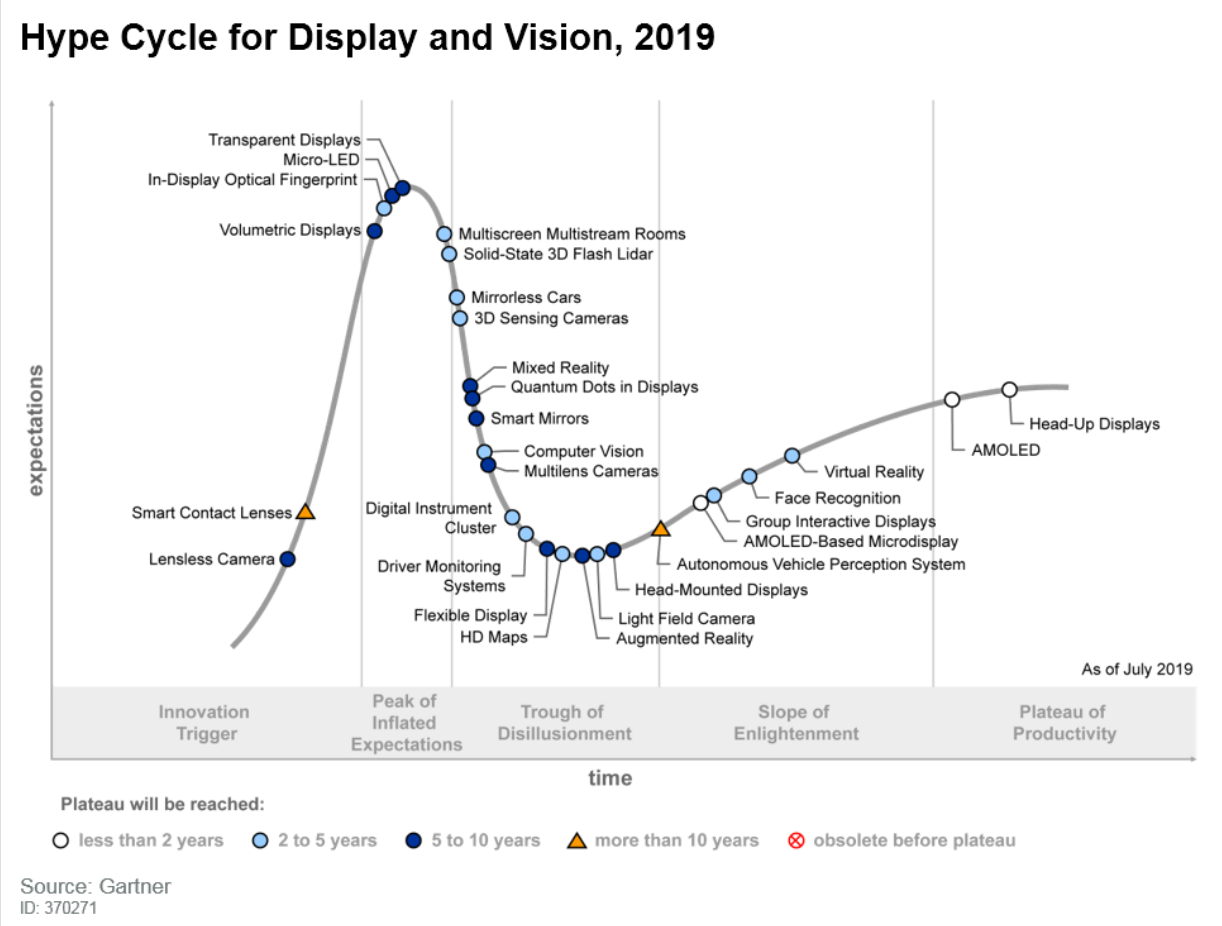
Maturity: Early mainstream

Sample Vendors: Bosch; Continental; Delphi Technologies; Garmin; Making Virtual Solid; Pioneer; Texas Instruments

Recommended Reading: “Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest”

Appendixes

Figure 3. Hype Cycle for Display and Vision, 2019



Source: Gartner
ID: 370271

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 1: Hype Cycle Phases

(Enlarged table in Appendix)

Phase ↓	Definition ↓
Innovation Trigger	A breakthrough public demonstration, product launch or other event generates significant press and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the technology is pushed to its limits. The only enterprises making money are conference organizers and magazine publishers.
Trough of Disillusionment	Because the technology does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the technology's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the technology are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the technology to reach the Plateau of Productivity.

Source: Gartner (July 2020)

Table 2: Benefit Ratings

Benefit Rating ↓	Definition ↓
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2020)

Table 3: Maturity Levels

(Enlarged table in Appendix)

Maturity Level ↓	Status ↓	Products/Vendors ↓
Embryonic	▪ In labs	▪ None
Emerging	▪ Commercialization by vendors ▪ Pilots and deployments by industry leaders	▪ First generation ▪ High price ▪ Much customization
Adolescent	▪ Maturing technology capabilities and process understanding ▪ Uptake beyond early adopters	▪ Second generation ▪ Less customization
Early mainstream	▪ Proven technology ▪ Vendors, technology and adoption rapidly evolving	▪ Third generation ▪ More out-of-the-box methodologies
Mature mainstream	▪ Robust technology ▪ Not much evolution in vendors or technology	▪ Several dominant vendors
Legacy	▪ Not appropriate for new developments ▪ Cost of migration constrains replacement	▪ Maintenance revenue focus
Obsolete	▪ Rarely used	▪ Used/resale market only

Source: Gartner (July 2020)

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Recommended by the Authors

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Understanding Gartner's Hype Cycles

Top 10 Strategic Technology Trends for 2020: Multiexperience

Market Trends: Top 5 Technologies Driving the Evolution of Consumer Devices, 2020

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