Computer Vision

Fundamentals for Business Leaders
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Foreword

Welcome – this publication is designed to provide business leaders an introduction to Computer Vision, as they commence their journey to utilise this new form of business intelligence.

Computer Vision powered by machine learning will change the way we see the world. New computer vision techniques allow organisations to collect unprecedented intelligence about the most important aspects of their business: their people, products, assets, and documents that form the backbone of their processes. Accompanying the new possibilities from this exciting new technology is a different spectrum of risks to be understood and managed, which we also explore in this document.

With multiple channels of perception and greater visual capabilities, the potential impact computer vision will have on our world will be **significant**.

Sathesh Sriskandarajah
Senior Manager, Risk Assurance

Introduction

2020 Vision – Seeing is believing

The human senses are our connection to the world around us. The human brain combines our five senses of seeing, hearing, smelling, tasting, and touching into something meaningful; providing us humans the information we need to trigger an action. We perceive up to 80 per cent of all impressions by means of our sight.[1]

It's important to note that 'Sight' and 'Vision' are different things. Sight is physical – it is a sensory experience in which light reflects off of shapes and objects and the eyes then focus this light. Signals are sent to the brain to be converted into images. Vision is how the mind interprets these images. Sight may allow a person to witness an event, but vision helps the person understand the significance of that event and draw interpretations.[2]

Computer Vision powered by machine learning will change the way we see the world. With multiple channels of perception, machines can see things that humans could not and have far greater visual capabilities. Given this superhuman seeing power, the potential impact computer vision will have for organisations and our lives will be significant. Yet with this extraordinary capability to serve us positively, new risks arise which need to be understood and addressed.

1. Introduction to Artificial Intelligence

1.1. What is artificial intelligence?

Before we explore Computer Vision, let's define Artificial Intelligence.

Artificial intelligence (AI) may be defined as a collection of interrelated technologies used to solve problems autonomously and perform tasks to achieve defined objectives, in some cases without explicit guidance from a human being. Subfields of AI include machine learning, computer vision, human language technologies, robotics, knowledge representation and other scientific fields. The power of AI comes from a convergence of technologies.

In practice, AI can help automate tasks, help do things better and more quickly, assist with better decisions and ultimately, automate decision-making processes that can be done entirely without people.

Often, AI technologies mimic humans' ability to Sense, Think and Act (see Figure 1)

AI works in three basic ways[3], providing:

Assisted Intelligence – where AI is assisting humans to do the same tasks faster or better where these tasks are typically "narrow" in scope.

Augmented Intelligence – where AI is performing more general actions to assist humans. Often involving feedback loops and machine learning, where humans and machines "learn" from each other and increase the efficiency of what they do together.

Autonomous Intelligence – where AI is operating with much less human intervention (i.e. fully autonomous self-driving cars), operate in complex and open-ended environments with high levels of independence and self-determination.

	Action performer	Decision maker
Assisted Intelligence	AI	Humans
Augmented Intelligence	AI & Humans	AI & Humans
Autonomous Intelligence	AI	AI

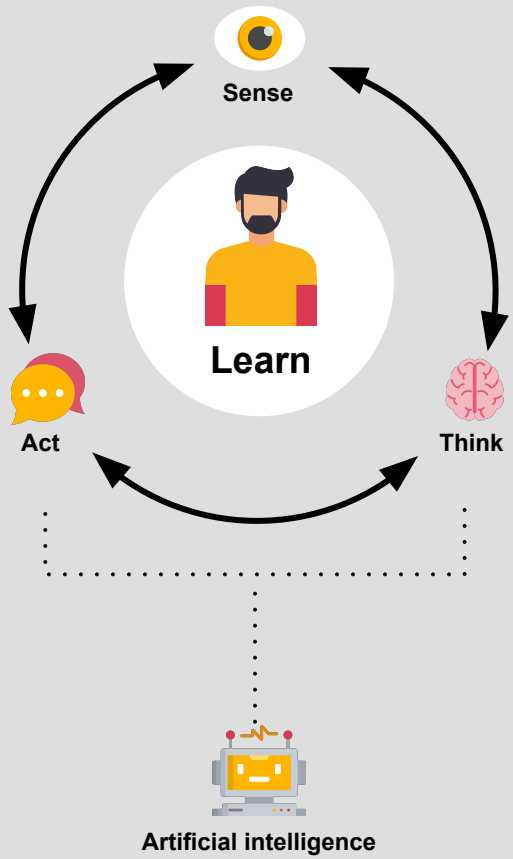


Figure 1 AI Technologies Mimic Humans' Abilities to Sense, Think, and Act[4]

Sense: sensory AI
- Image and video analysis
- Facial recognition
- Speech analytics
- Text analytics

Think: cognitive AI
- Machine learning platforms
- Deep learning platforms

Act: executable AI
- Natural language generation

Sense, think, and act: artificially intelligent solutions
- AI-enhanced analytics solutions e.g. churn forecasting
- Conversational service solutions e.g. digital agents
- Intelligent research solutions e.g. content summary
- Intelligent recommendation solutions e.g. next best offer

2. Computer Vision Fundamentals

2.1 What is Computer Vision?

Computer Vision (CV) is a field of artificial intelligence that trains computers to interpret and understand the visual world. Using digital images from cameras and videos and currently typically applying the technique of “deep learning”, machines can more accurately than ever before identify and classify objects or data within an unstructured format — and then react to what they “see.” As amazing as this technology is, we must remember that computers don’t “see” in the same way we do, so it’s imperative that the AI is trained sufficiently to ensure optimal accuracy; the risk of misclassifying something or someone could be disastrous.

Computer Vision seeks to automate classification tasks that the human visual system performs as well as trigger appropriate actions based on that classification. It can work with digital image data in the form of photographs, videos, views from multiple cameras, laser scanning (LIDAR) or multi-dimensional data from a medical scanner (i.e. medical imaging), and of course direct/drive self driving vehicles.

2.2 Why is Computer Vision important now?

Technology is progressing at an exponential pace where computer vision has moved into mainstream commercialisation. This is due to the following factors:

1. **Computing Power** – Hardware designed for computer vision has become cheaper, faster, better and easily accessible
2. **Big Data** – Availability of large training data sets due to mobile technology with built-in cameras saturating the world with photos and videos
3. **Open Source** – Availability of new deep learning frameworks that can take advantage of hardware and software capabilities

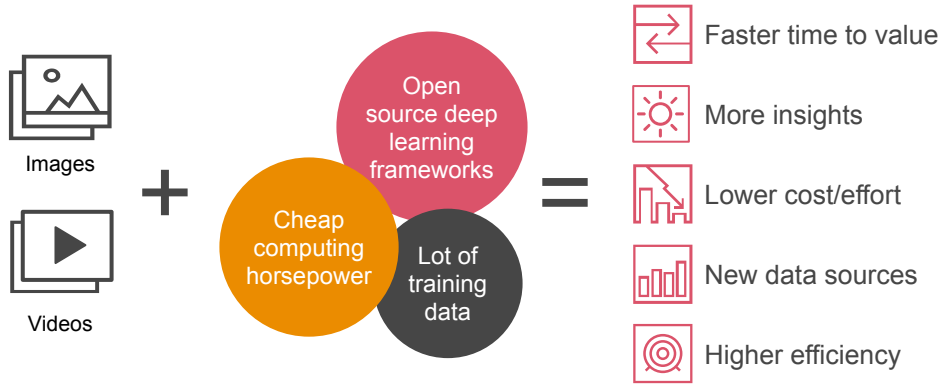


Figure 2 Why is computer vision important now[5]

2.3 Key applications of Computer Vision

Objects

- Object Classification – What broad category of object is in the image?
- Object Identification – Which type of a given object is in the image?
- Object Verification – Is the object in the image?
- Object Detection – Where in the image is a specific object?
- Object Recognition – What objects are in the image and where are they?
- Object Tracking – Tracking a specific object across a series of images
- Semantic/Instance Segmentation – Breaking down the object into its components including counting

Documents

- Object Character Recognition (OCR) – What is written in a particular image (i.e. text and numbers)
- Document Analysis – Analyse a document and provide me the information I enquired about

People

- Facial Recognition – Identify gender, age, cultural appearance, emotions, etc.
- Action Recognition – Identifying a specific action/gesture of a person
- Mood and Sentiment - Forecasting someones reactions or current mood
- Crowd Dynamics – Counting people and tracking their density / direction

2.4 Computer Vision Framework for Business

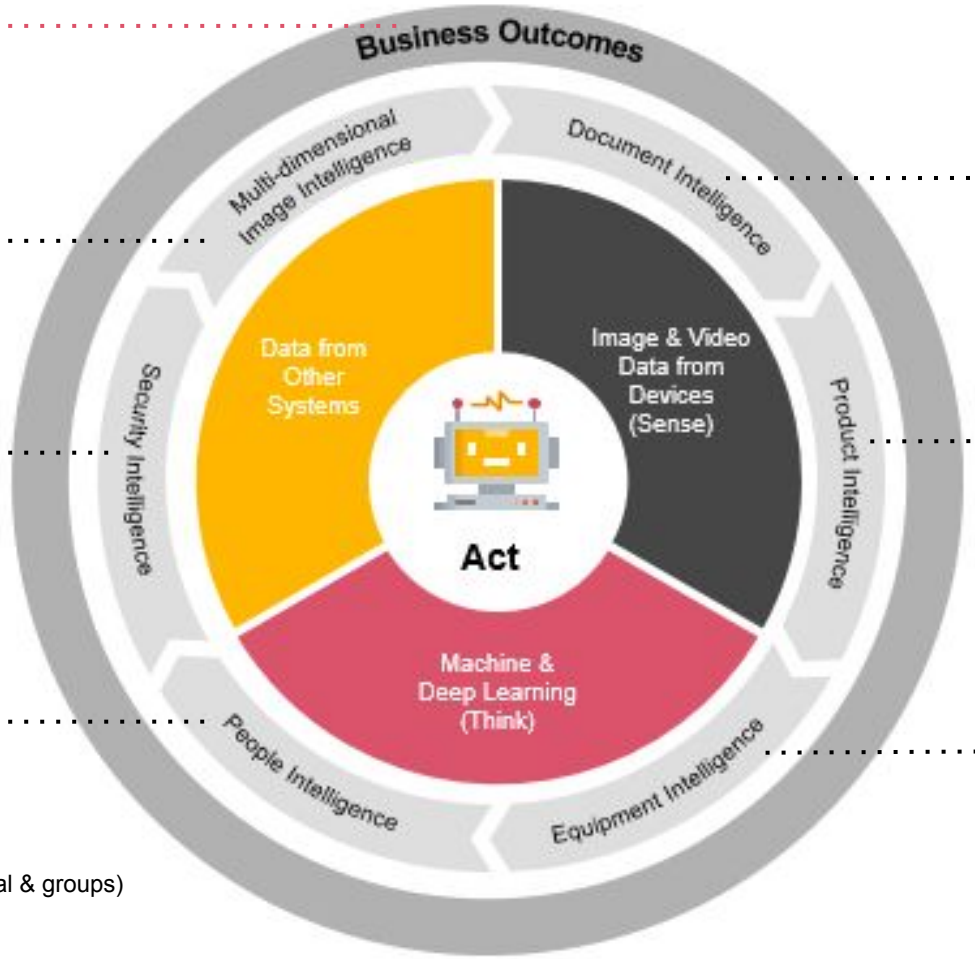
Computer Vision unlocks new intelligence and drives new business outcomes at scale.[6] The following diagram depicts where Computer Vision technology can be used within the business landscape:

- Strategic
- Augmentation
- Automation
- Compliance
- Innovation

- Medical Imaging Analysis
- Patient Diagnosis

- Surveillance
- Facility Management
- Emergency Response
- Public & Workplace Safety
- Assisted Living

- Facial Recognition
- Demographics
- Emotion Recognition
- Behaviour (specific actions)
- Movement Tracking (individual & groups)



- Optical Character Recognition (OCR)
- Document Research & Analysis
- Autonomous regulatory compliance

- Visual Search
- Product Assembly
- Quality Inspection / Defect Management
- Inventory Management & Audits
- Asset & Product Tracking
- Shelf Management

- Self-driving vehicles
- Predictive maintenance
- Optimisation of maintenance and repairs

Figure 2 PwC Computer Vision Technology Framework

3. Applications of Computer Vision

What use cases are most applicable to your organisation?

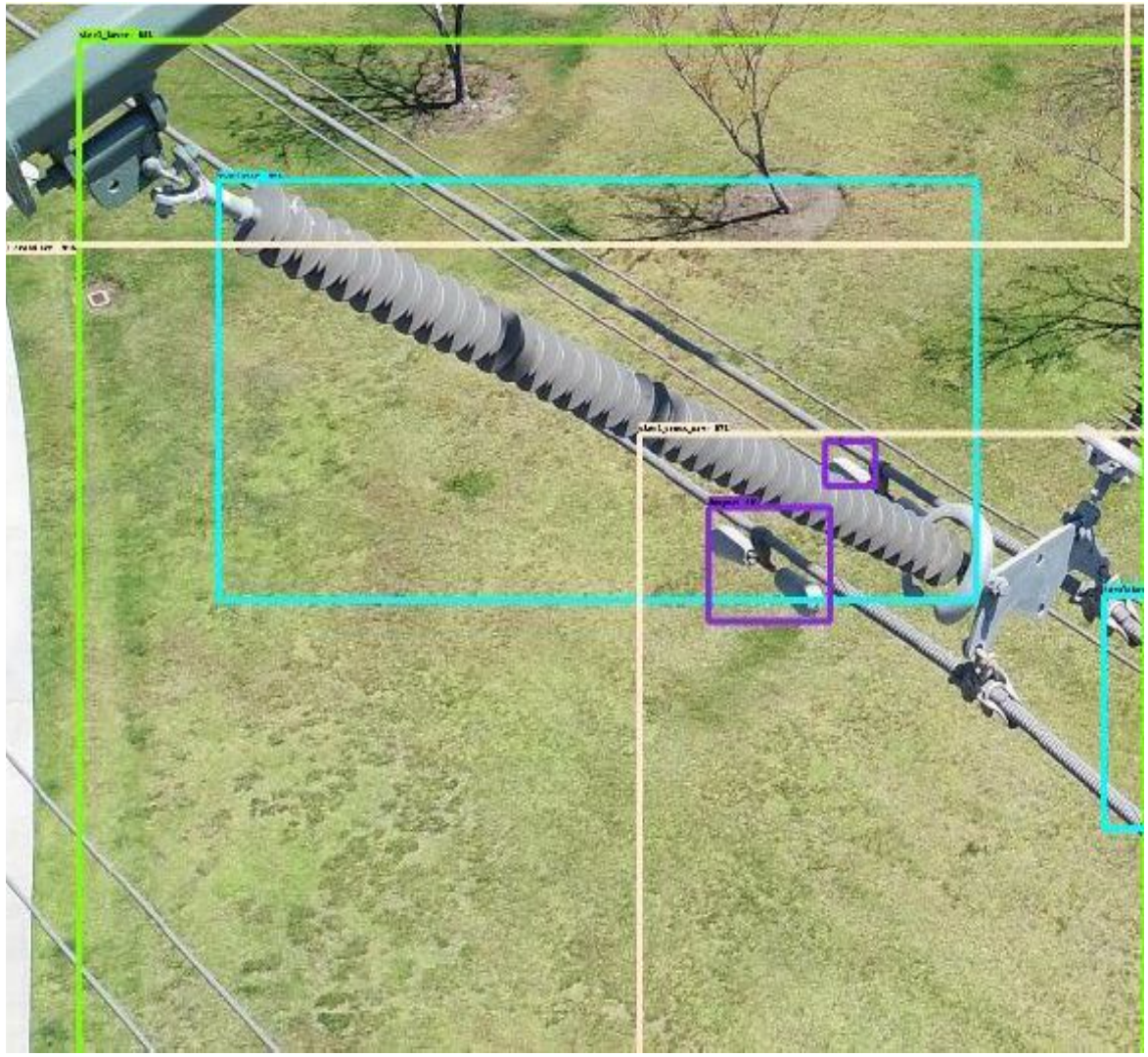
Let's explore some "interesting" use cases on how computer vision is changing the world

3.1 Equipment Intelligence

Energy providers are continually seeking to improve the management of their transmission network through efficient network investment opportunities, more cost effective maintenance practices and potential industry innovations. A key element of their vision is to efficiently maintain and manage their network through best practice asset management and new technologies which will also enable planning for more complex power quality, dynamic stability and network reliability with a changing generation mix. Asset inspections, vegetation management, works delivery and capital projects represent a large part of an energy providers spend and involve managing a number of critical operational risks.

Thanks to advanced sensors and a combination of image data processing and analytics, energy providers have been able to increase their productivity and manage risk more effectively. Such advanced technologies will play a vital role in delivering accurate and timely data needed to enhance the inspection and management of assets, construction project monitoring and vegetation management.

Using drones powered by computer vision, PwC have assisted energy providers in hard to reach places by enhancing their maintenance schedules and workforce as well as material and equipment allocation to jobs. We have provided structural assessment of technical conditions of various infrastructure elements, structural alignment validation, detection of overheating elements and identification of corrosion. These operational risks, put great weight on the image classification of the drone mounted computer vision device, so it is imperative that the solution has undergone a rigorous and well governed development process and is retrained on a frequent basis.



3.2 Product Intelligence

Amazon Go is a new kind of store with no checkout required and utilises the world's most advanced shopping technology so customers never have to wait in line. The store concept uses several technologies similar to those found in self-driving cars, including computer vision, deep learning algorithms, and sensor fusion to automate the purchase, checkout, and payment steps associated with a retail transaction.

Cameras within the store recognise individuals, track them around the store, know which account is linked to each customer, understand exactly which product and how many of each are put into their bag, and tally it all up with high confidence.[8]

As a second step of security and verification, the store is equipped with pressure sensors allowing the computer to detect when and from where an item is removed.[8] The next layer of confidence is built on customer history. The more you shop at Amazon Go, the more informed the computer will be on your shopping habits and history.[8] It will gain additional confidence that the items in your bag are correct because it can verify that you've had a similar transaction in the past.[8]

While Amazon Go provides a shopping experience we haven't seen before, consumer groups have raised significant concerns about privacy, namely because the stores use cameras to extensively track a person from the time they enter the store until they leave and combine this with every other dataset they have on the customer. This is the same idea as an employee following you around the entire store, watching what you pick up and writing it down!

Amazon Go was first launched to the public in 2018 by online retailer Amazon with a plan to launch more stores in the future. The future of retail is here!

> "I have no doubt in the next 10 years, customers will be able to take the product off the shelf, put it in their basket, walk out and have it all paid for"[15]
>
> ***Greg Davis***
> *Coles Chief Executive of Commercial and Express*

3.3 Document Intelligence

The digitisation of enterprise data is a requirement for organisations when on their digital transformation journey and to comply with increasing regulatory requirements. As the vast majority of enterprise data is unstructured – emails, invoices, receipts, handwritten notes, contracts, forms, etc., this provides a major hurdle for organisations. Transferring unstructured or semi-structured data into a digital format that can be searched, manipulated, and processed is key to digital transformation.

Where traditional Object Character Recognition (OCR) fails to accurately extract specific content from image-based documents, Computer Vision's enhanced approach overcomes this gap by accurately detecting and narrowing down target objects within image-based documents.

Many organisations across industries are undertaking their digital transformation journey through the digitisation of physical documents and forms, driving productivity and efficiency outcomes.

Recently, it was identified that artificial intelligence could potentially be used to automate new scientific discoveries, as researchers from the U.S. Department of Energy's Lawrence Berkeley National Laboratory recently found out when they let an unsupervised AI loose to analyse millions of old scientific papers.[9]

Amazingly, the algorithm – which had no previous training in materials science, was able to predict now-known thermoelectric materials in advance, suggesting that it could be used to review past scientific papers in order to uncover new knowledge that might have been missed by human experts.[9]

Computer Vision, OCR and Natural Language Processing (NLP) have made a huge impact in the healthcare sector across the globe. Using CV in conjunction with NLP has increased the accuracy of doctors and nurses handwritten notes, significantly reducing the number of errors made when categorising patients, and helping predict high risk individuals. However, the variability in handwriting means that no matter how well a model is trained, there is likely to be handwriting it cannot classify correctly, which increases the risk of errors and omissions.

3.4 People Intelligence

A facial recognition system uses biometrics to map facial features from a digital image or video source and is capable of identifying or verifying a person by comparing the information to a database of known faces. There are number of commercial applications using facial recognition from surveillance to marketing however, through identifying a person raises many privacy concerns.

Facial recognition can be seen as intrusive and discriminatory that destroys our human rights and forces people to change their behaviour. It may decrease criminal activity but on the other hand stop people expressing their views (i.e. peaceful protests) and change the way people live their lives to avoid unwarranted surveillance.

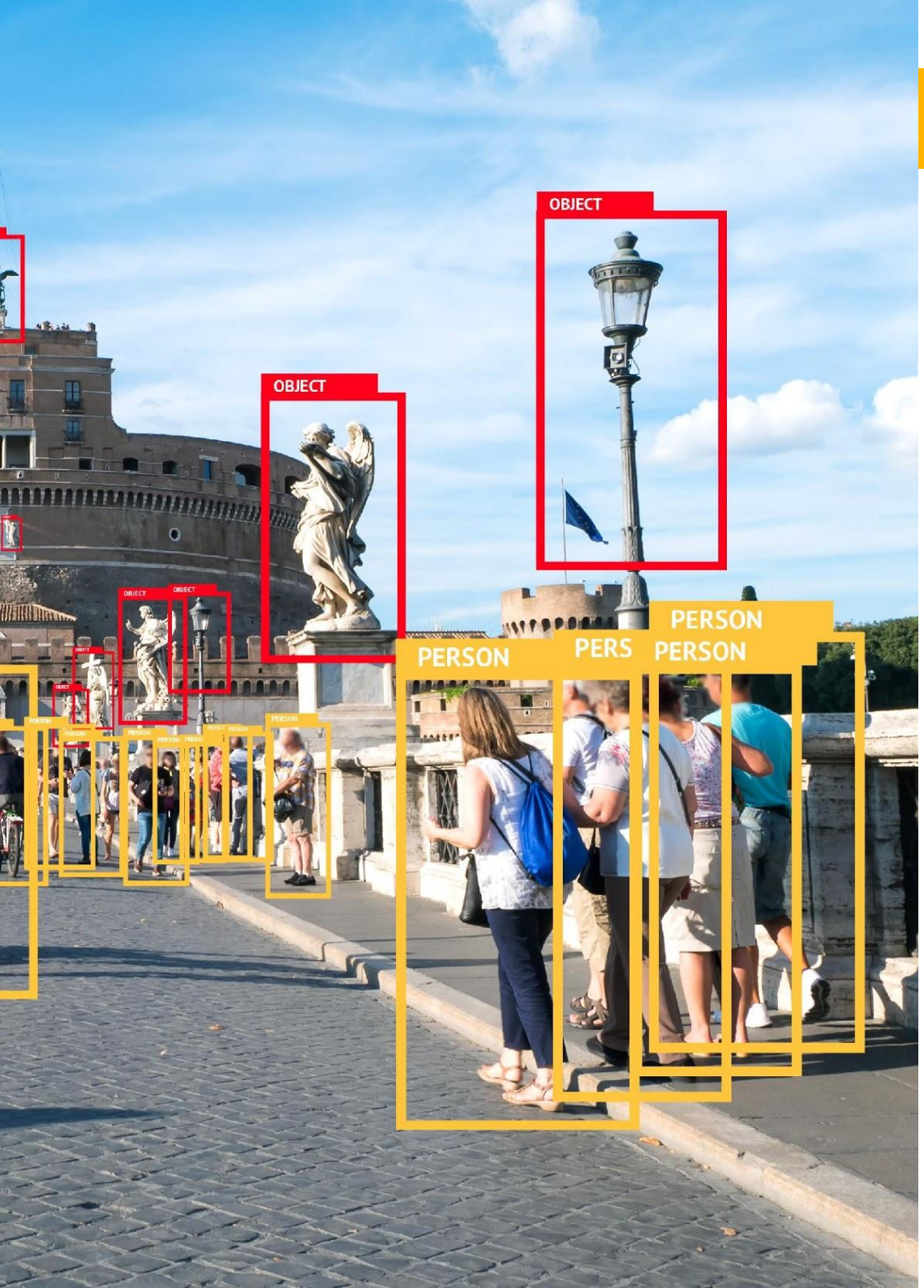
Studies have shown that machine learning systems reflect the racial and sexist prejudices of the society that programs them. In a surveillance use case, if we train AI surveillance system using old footage, like from CCTV or police body cameras, then biases that exist in society are likely to be perpetuated.[12]

Chinese authorities have gone one step further and begun deploying a new surveillance tool called "gait recognition" software that uses people's body shapes and how they walk to identify them, even when their faces are hidden from cameras.[10]

Already used by police on the streets of Beijing and Shanghai, "gait recognition" is part of a push across China to develop artificial intelligence and data-driven surveillance that is raising concerns about how far the technology will go.[10]

Watrix chief executive officer Huang Yongzhen said its gait recognition system can identify people from up to 50 metres away, even with their back turned or face covered. He says, "Gait analysis can't be fooled by simply limping, walking with splayed feet or hunching over, because we're analysing all the features of an entire body.“[10]

The technology is not capable of identifying people in real-time yet however this will improve in time with the ever increasing nature of computer power. It is envisioned that gait recognition will be used alongside facial recognition software for superior results.



3.5 Security Intelligence

Computer Vision is giving surveillance cameras autonomous intelligence, letting them analyse live video with no human involvement. This could be good news for public safety, helping police and first responders more easily spot crimes and accidents.

Computer Vision applications in the security space have been implemented to identify:

- Foreign objects in a public place (i.e. unattended bag, litter, etc.)
- Hazards (i.e. spills, etc.)
- Disorderly behaviour (i.e. violence)
- Crowd control
- Individuals in distress (i.e. injured, panic, etc.)
- Workplace safety breaches
- Theft
- Unauthorised access
- Other crimes and accidents

The above list is not exhaustive and new use cases are being explored each day. It's important to note, that with the appropriate infrastructure in place, authorities can be alerted in real-time to address public safety issues before anything eventuates.

Furthermore, applications are now available that can recognise hundreds of thousands of natural language queries, enabling authorities to search footage to find clips showing people wearing clothes of a certain colour, or even individual car makes and models.

IC Realtime CEO Matt Sailor explains a scenario, "Let's say there's a robbery and you don't really know what happened. But there was a Jeep Wrangler speeding east afterward. So we go in, we search for 'Jeep Wrangler,' and there it is."[11] On-screen clips begin to populate the feed, showing different Jeep Wranglers gliding past. This will be the first big advantage of combining AI and CCTV – making it easy to find what you're looking for. Sailor went on to say, "Without this technology, you'd know nothing more than your camera, and you'd have to sift through hours and hours and hours of video."[11]

The quality with which the AI/CV application was developed, trained and maintained has a huge impact on authorities being able to do their job - can they trust the AI? If little is known about the application and it is treated as a black box, confidence in the technology is likely to be lower.

3.6 Multi-dimensional Image Intelligence

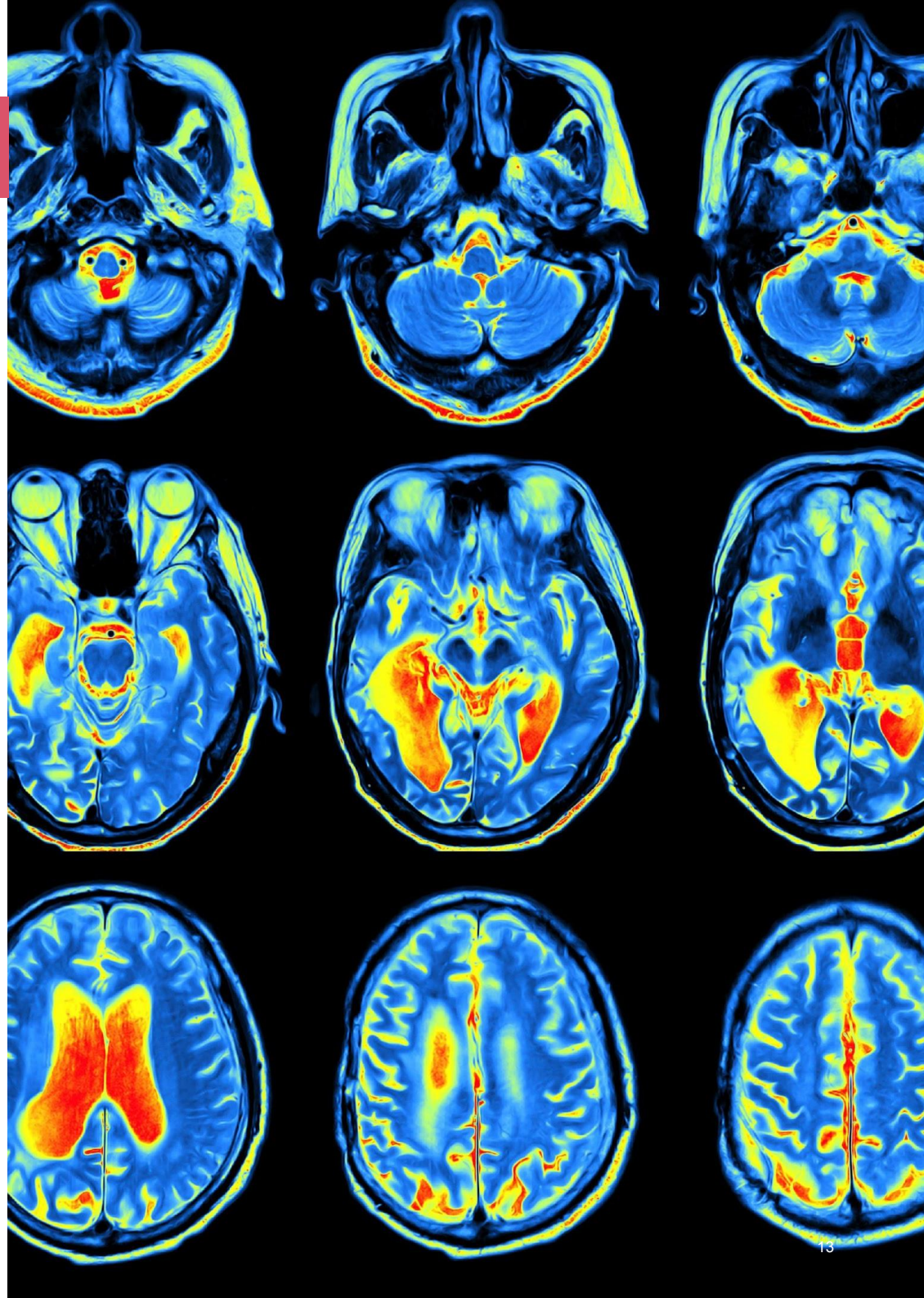
Multi-dimensional image data are images that are produced from specialist equipment (i.e. medical imaging). One advancement in the healthcare industry is to use computer vision to help healthcare professionals diagnose patients – known as ‘Computer-aided Diagnosis’.

Currently, the most viable use case for computer vision in healthcare seems to be in radiology. AI solutions for radiology generally involve aiding radiologists in diagnosing diseases and conditions from X-ray, MR, or CT- scans.

MaxQ AI is a US and Israel-based company that offers a device and accompanying software which it claims can help physicians identify rare anomalies in brain scans using computer vision. MaxQ AI claims emergency room physicians can use the company’s software to identify anomalies in patient brain scans and quickly suggest treatment options to patients and their families.[12] For example, in the event of a stroke, patients recover faster if physicians administer aggressive, targeted treatment to the patient’s brain. Stroke patients that receive treatment sooner experience better outcomes.[12]

Microsoft offers a software called InnerEye, which it claims can visually identify and display possible tumours and other anomalies in X-ray images.[12] Microsoft claims radiologists can upload three-dimensional patient scans into the software.[12] The software could then generate area measurements for various parts of the organ or ligament shown in the scan.[12] Then, InnerEye colours areas it believes contain tumours or other anomalies white.[12] A physician could then pay closer attention to these white areas.[12]

It is important to note that computer-aided diagnosis is a hard market to crack with business leaders in healthcare wary of being the guinea pig, and looking for validation of successful AI implementations. One of the issues with AI is that people hold AI and CV applications to a much higher standard than they would a human. While a talented surgeon might be able to detect 70% of tumors, and the AI 95%, people are still inherently suspicious of the AI. This will change over time through demonstrating a validated process to develop AI and CV applications. Once real results are obtained and validated, it will only be time when healthcare professionals and patients begin trusting AI and we see this technology throughout the healthcare industry.



3.7 Taking computer vision to the next level

Health

Deep learning algorithms have been able to spot genetic disorders better than doctors by analysing a patient's facial features.[13]

A photograph of the face of four-year-old girl Yael who is smiling and looking as healthy as can be was analysed by a computer which detected something was not right. The computer had detected she had MR XL Bain Type – a very rare syndrome that causes a wide range of health problems and it turned out that the computer was right.[13]

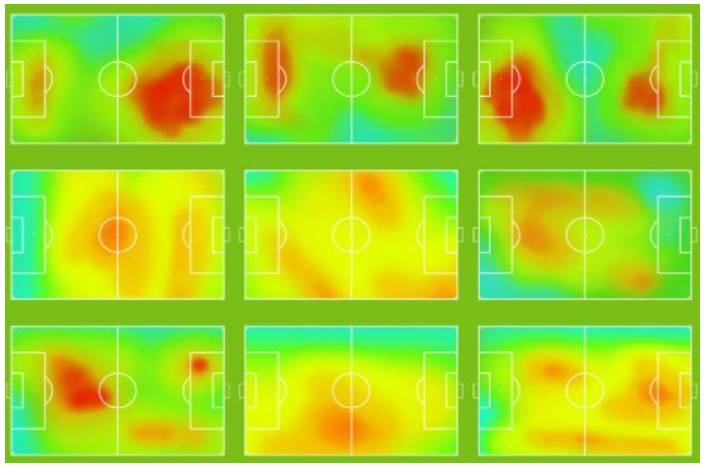
Yael is one of thousands of children who have contributed to the development of an artificial intelligence system called DeepGestalt that can identify rare genetic disorders based on facial features alone.[13] The system, built by Boston-based FDNA, analyses photographs of faces using computer vision and deep learning algorithms.[13]

In an article published in the journal, Nature Medicine (January 2019), FDNA announced the results of a study of DeepGestalt involving 17,000 children, with more than 200 different syndromes among them.[13] The system outperformed clinicians' ability to identify disease in three separate experiments.[13]

Barcelona FC

As highlighted at the 2019 Sports Tech Conference in Melbourne, FC Barcelona has invested heavily in building an innovation hub to equip them for the future. Their sports technology and innovation team created empirical models that show what players are doing for the 87 minutes of a match when they don't have the ball.[14]

Hundreds of data points captured in each match are used to better understand player contributions, such as how players create space for others to score goals.[14] FC Barcelona's team of data scientists developed a method of displaying the models behind 'players making space' including tables with player ratings and dynamic heat maps overlaid on video.[14] Coaches took this data to develop tactics that could exploit opposition movement in future games, as well as better understand the contribution of players.[14] Star forward Lionel Messi, for example, has been criticised for not running enough in games. But his space and contribution metrics puts paid to this criticism.[14]



Australian Institute of Sport

"Computer vision is non-invasive, and it gives us the opportunity to extract unique and actionable intelligence from the competition domain. Insight that can be used to manipulate the outcome of the contest, and importantly, insight that our competition don't have.

Recent advances in deep learning architectures for object tracking, scene understanding and pose estimation have made it practical to offer a wider range of bespoke analysis tools for our sports at a level that was not possible just 5 years ago."

Stuart Morgan

Head of Vision & Machine Learning, in the Applied Technology & Innovation branch at the Australian Institute of Sport

The best use cases lie at the intersection of:

- Business value
- Legal and ethical compliance
- Good source data
- Technical feasibility
- Good training data
- Your organisation's capabilities

While new computer vision technologies open up a host of valuable use cases, not all of them are destined to succeed.[6] The ones that will drive the most impact at your organisation lie at the intersection of available data, technical feasibility, your organisation's capabilities, and business value.[6]

If your company hasn't been able to tackle a problem in the past, it may be a valuable problem that wasn't addressable previously or it may be a problem that wasn't worth solving.[6]

4. Getting started with Computer Vision

Some **64%** of global senior business purchase influencers say that computer vision will be very or extremely important to their firm in the coming year, and **58%** said that their firm is implementing, planning to implement, or interested in implementing computer vision in the coming year.[7]

When getting started with computer vision, ensure you consider the following:

Is it valuable?

- Business value
- Alternative solutions

Ensure upfront that your solution has the potential to generate substantial business value relative to your organisation's existing solution and other feasible solutions.[6]

Can you get good data?

- Availability of data
- Quality of data
- Variations in source data (i.e. is your data captured by different types of cameras, in different lighting scenarios, at different angles, at different distances)

The greater the variation in the source data, the harder it will be to leverage computer vision technologies effectively.[6]

Can you train it?

- Volume of labelled training data
- Cost of training
- Source of training data

The simpler the object, motion, or other phenomenon, the easier it will be to create a computer vision model to detect it. The greater the nuance and variation, the more high quality labelled training data you will need.[6]

Can you deploy it?

- Regulation
- Ethics
- Hardware constraints
- Responsiveness requirements
- Computational power
- Cloud hosting and bandwidth
- Cost

An accurate computer vision model doesn't mean you will be able to use it unless you have the right infrastructure in place, that is legal and aligned with your ethical frameworks.

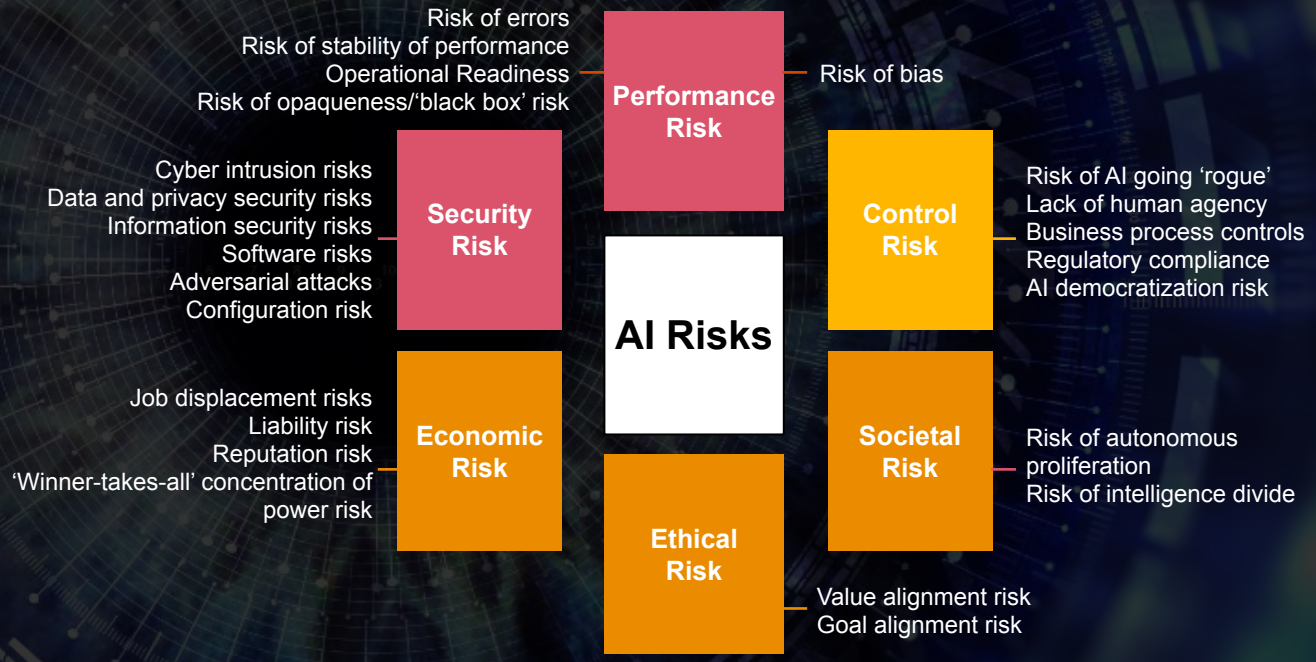
5. Challenges and risks when implementing Computer Vision

The risks of AI are not just technical risks - it takes a multidisciplinary approach to tackle them

To reap the full benefits of Computer Vision adoption, it is imperative for boards and senior management to develop a comprehensive strategic understanding of and associated plan for AI technology; including its potential uses (both intended and unintended) within their organisation, as well as the implications from a risk management perspective.

With any exciting new technology there is always a danger it could be misused if it is launched without the right checks and balances in place. It is important that these technologies are developed and implemented responsibly to ensure the technology meets its intended objective whilst minimising risk to the organisation. This can only be achieved by implementing a comprehensive end-to-end production process which ensures all risks are addressed and mitigated before the technology is put into production.

Some AI risks are technical and require technological tools and supports to overcome



Other AI risks are social, economic and ethical and need a different set of tools to manage

Technical risks

Risks with both technical and other elements

Other risks

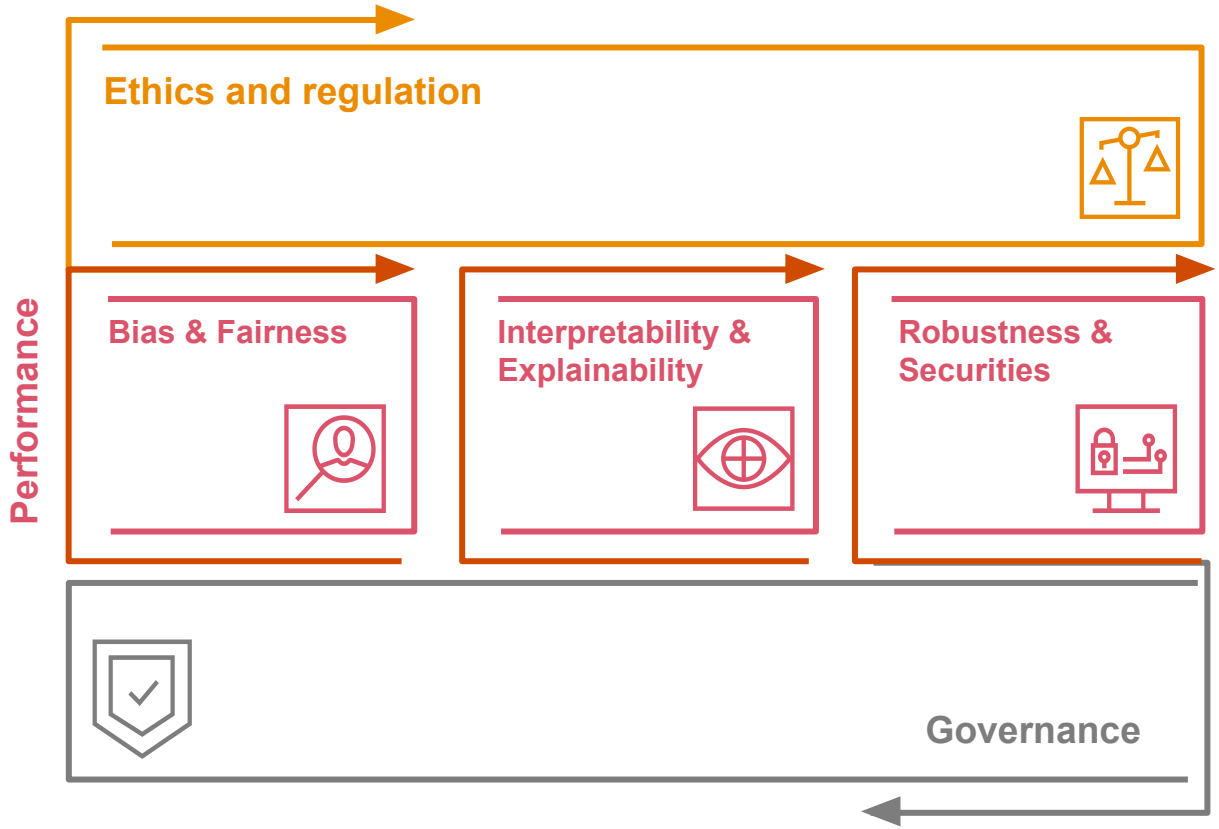
6. Responsible AI

6.2 An approach to Responsible AI for CV

Your stakeholders, including board members, customers, and regulators, will have many questions about your organisation's use of AI, data and Computer Vision, from how it's developed to how it's governed. You not only need to be ready to provide the answers, you must also demonstrate ongoing governance and regulatory compliance.

Computer Vision in particular comes with a range of considerations that some other AI applications don't. Developed and used responsibly it is a powerful AI powered technology, used or developed in a haphazard fashion leaves you exposed to a number of serious issues.

Fortunately PwC's Responsible AI Toolkit is a suite of customisable frameworks, tools and processes designed to help you harness the power of AI in an ethical and responsible manner – from strategy through to execution. It is designed to help organisations focus on and address five key dimensions when designing and deploying responsible AI applications. Visit www.pwc.com/rai to find out more, and take our diagnostic to see how you do when it comes to developing AI solutions in a responsible manner.



Ethics and Regulation – This is the moral compass for organisations looking to develop Computer Vision application i.e. is it legal? Is it 'right' to develop such an application? Could the data or observations be correlated with other data to generate an unintended outcome?

Bias & Fairness – While there is no such thing as a decision that is fair to everyone (i.e. group fairness vs individual fairness), its well known that facial recognition is highly biased against persons of colour. How does the organisation deal with this? Or if classifying other people or objects, how do you establish if the classification or classification threshold (the acceptable percentage of accuracy) is fair? Fair to who or what?

Interpretability & Explainability – Many Computer Vision applications use deep learning algorithms which are virtually impossible to explain in lay terms. Will this impact how or if you can use a CV application? Will you have to compromise CV accuracy by using a more simplistic algorithm for explainability? Who makes that decision?

Robustness & Security – It is critical that Computer Vision systems provide robust and secure performance housed in safe ecosystems impervious to attack, given the sensitive information they store and communicate.

Governance – Governance serves as an end-to-end foundation for all the other dimensions.

Conclusion

New computer vision techniques allow organisations to collect unprecedented intelligence about the most important aspects of their business: their people, products, assets, and documents that form the backbone of their processes.[6] Even with a small amount of investment, they enable organisations to drive outcomes at scale with greater employee productivity, more automation, best-practice adherence, and faster innovation.

Organisations should scan for the best computer vision use cases and assess them based on their business value, data availability, and their ability to train and deploy the necessary solutions. However, before implementing a solution, the board and senior management must increase their understanding of AI and have a plan in place to manage potential risks, regulatory and ethical implications. With the appropriate 'Responsible AI' processes in place, organisations should leverage computer vision to deliver innovative solutions to drive growth and operational efficiency for their business.

Computer Vision powered by machine learning will change the way we see the world. Given this superhuman seeing power, the potential impact computer vision will have for organisations and our lives will be significant.

Appendix A – References

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