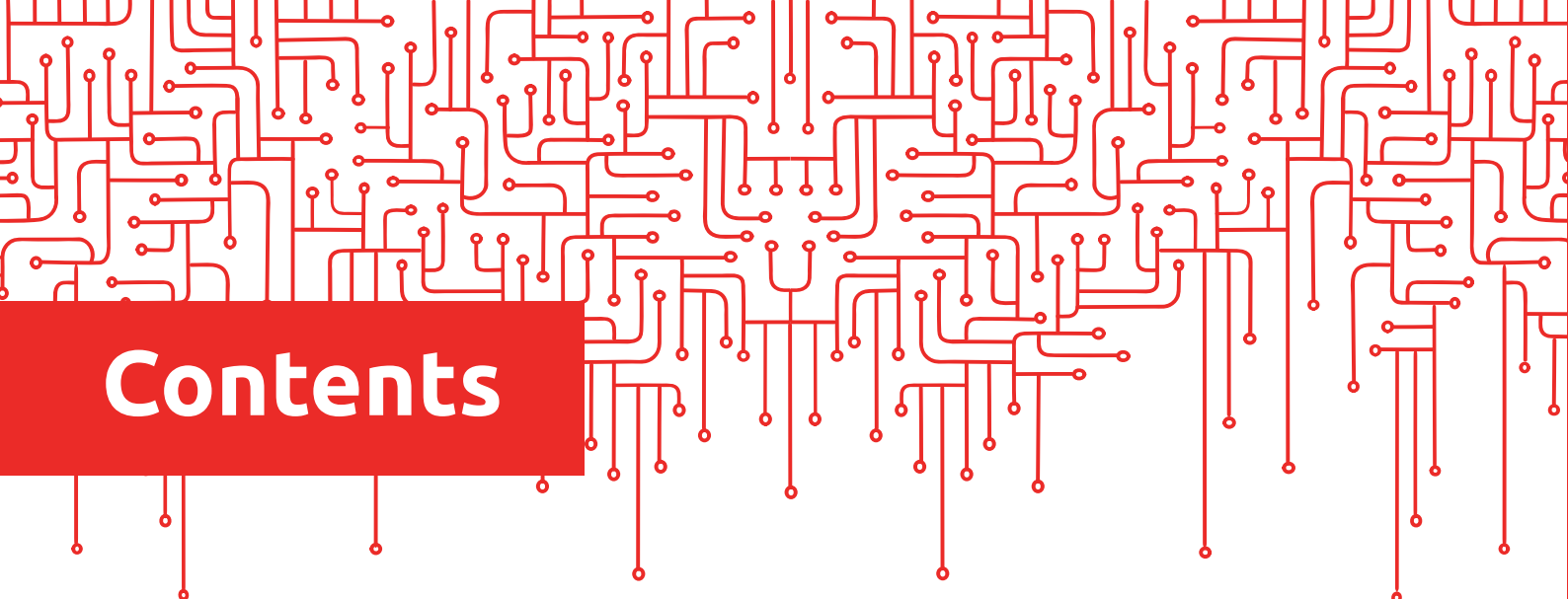


Machine Intelligence quality characteristics

How to measure the quality of Artificial
Intelligence and robotics





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01 Introduction

1.1 The series of papers on Testing and AI

This is the second in a series of papers focused on testing of Artificial Intelligence (AI). It will give further insight into the test techniques and methodologies for ensuring AI quality, and it will identify the quality characteristics and their testing in this fast-changing area of IT.

Our first paper “Testing of Artificial Intelligence; AI quality engineering skills – an introduction” discussed the skills needed for quality engineering.

(download this paper at: <https://www.sogeti.com/explore/blog/testing-of-artificial-intelligence/>)

In this second paper, we define software quality, introduce a generic taxonomy of quality characteristics, discuss the connections between these characteristics, and discuss future work leading to a quality-characteristics-based methodology for evaluating software architectures.

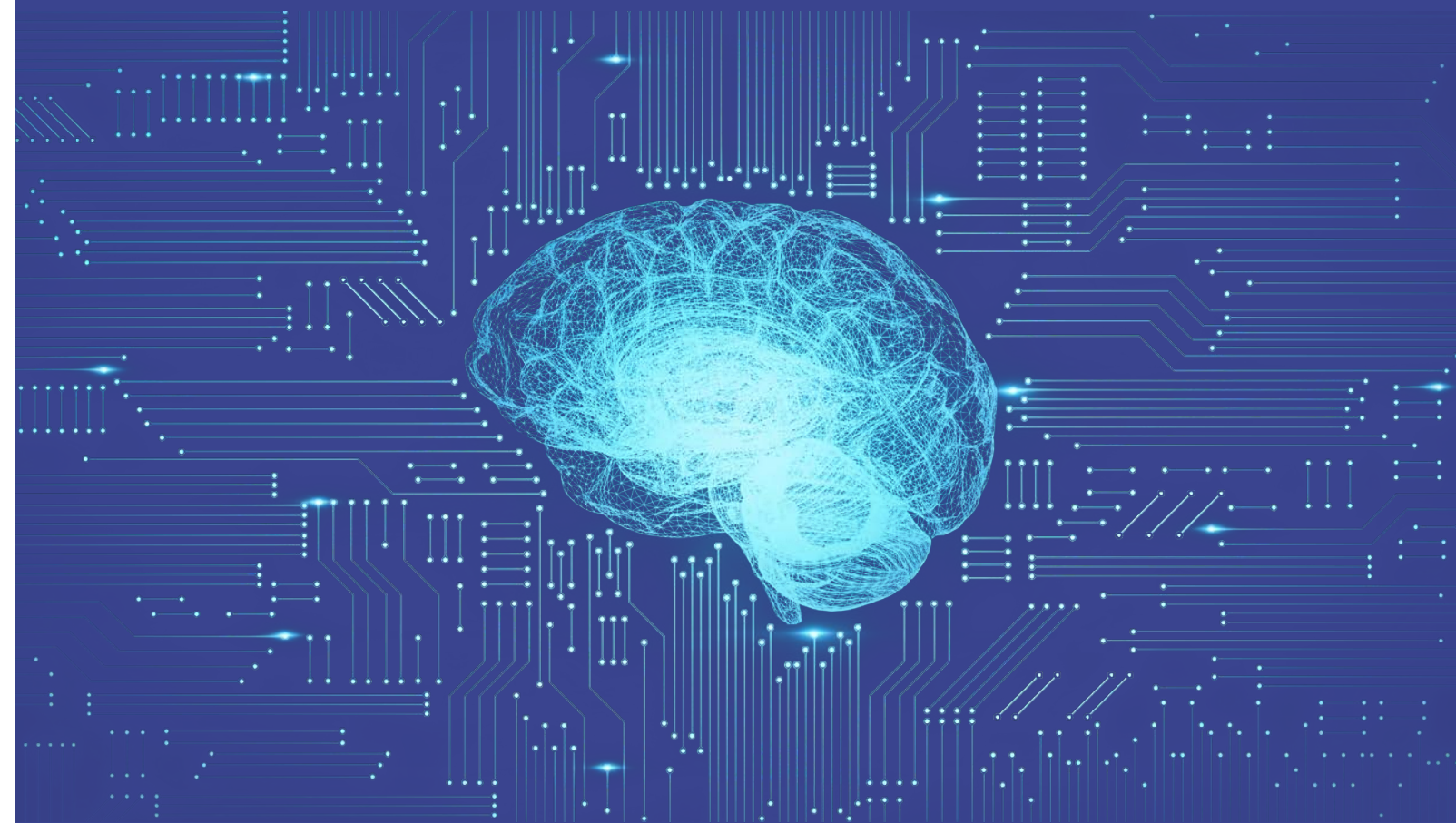
The key premise of this paper is that there is a need to extend the existing model of quality characteristics with new quality characteristics specifically for AI and robotics.

Content from both papers has been included in the book “Testing in the digital age; AI makes the difference”, published on 1 June 2018.

1.2 Musings on history and future of AI

Rapid IT developments

Since the onset of the IT era with the launch of the first transistor in 1947, innovation after innovation has changed the world. With the development of personal computers in the 1980s, the spread of the World Wide Web in the 1990s, and the introduction of Smartphones in the 2000s, IT has rapidly transformed the way information is handled.



The technologies have reached a state in which promising mathematical Artificial Intelligence (AI) models and theories stemming from the 1950s can now be implemented. The development and use of AI is triggering another revolution in IT. The technology is powering its way into the market with both scientific disciplines and commercial sectors not only involved in the development of AI but using it in their business operations too. The initial successes achieved are visible already. The five most valuable companies worldwide are leaders in AI technology. The focus is not only on developing new products and services, but also on improving business processes. The fact that the AI-driven AlphaGo has beaten the world champion of the complex game of Go clearly shows the possibilities. Go has been played by humans for more than two thousand years and now AI reveals new and unimagined strategies.

AI causes new challenges

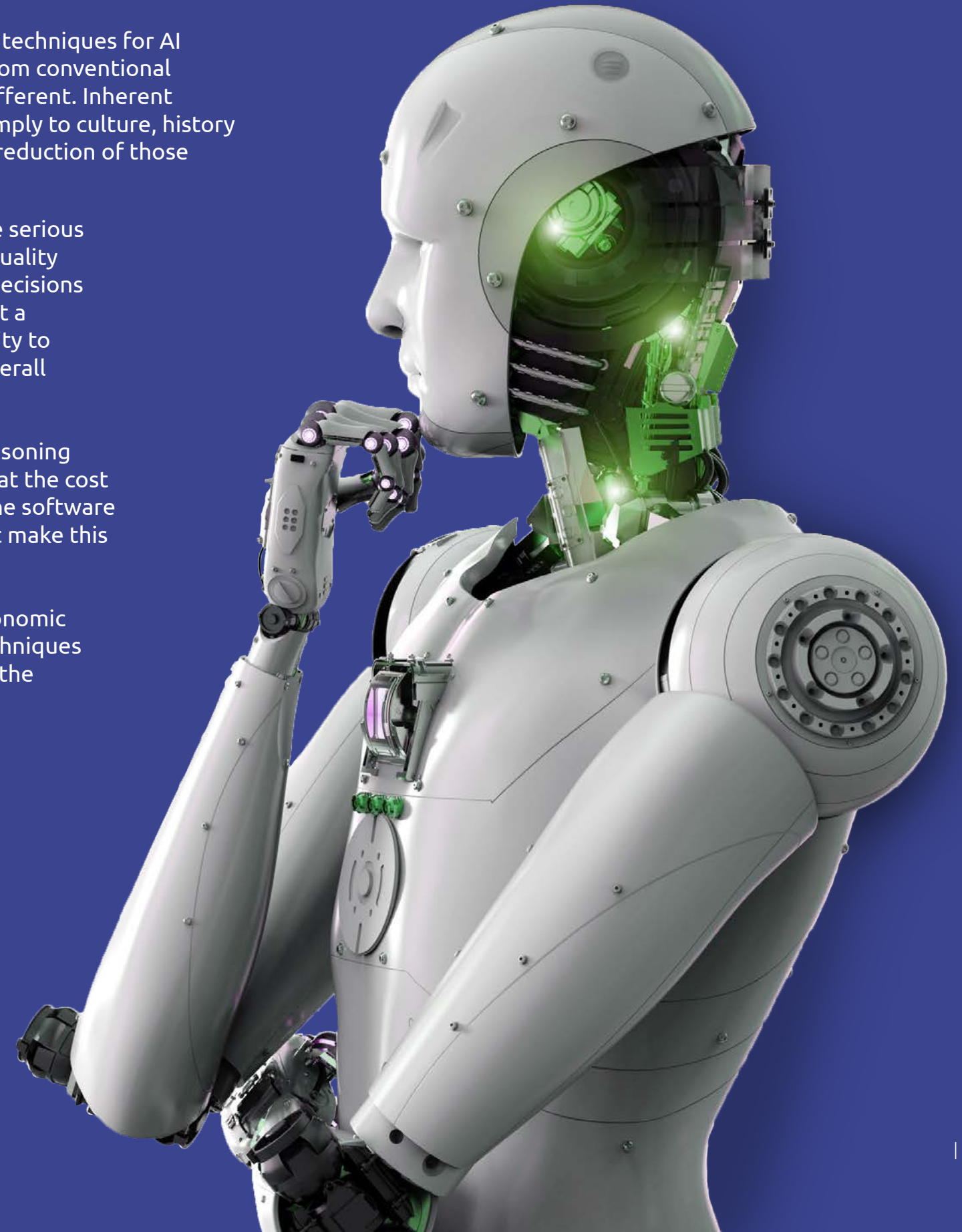
AI software differs from conventional software in two significant ways: it generally addresses different and more complex kinds of problems, and it typically works in a different way than conventional software. Conventional software uses rule-based decision-making, whereas AI uses evolutionary algorithms. On the other hand, AI software has much in common with conventional software: indeed, most of the software in the system will be of the conventional variety (for example, I/O almost always is the largest single component in any system).

We believe that the best way to develop credible and effective quality assurance and evaluation techniques for AI software is to identify the facets of such software that are inherently, or essentially, different from conventional software, and to distinguish them from those facets that are only accidentally or inessentially different. Inherent differences demand the development of new techniques; accidental differences or those due simply to culture, history and bias, require only the adaptation of established techniques (and possibly the elimination or reduction of those differences).

Computer systems are used in many critical and non-critical applications where a failure can have serious consequences (e.g. loss of life or property). Developing systematic ways to relate the software quality attributes of a system to the system's architecture provides a sound basis for making objective decisions about design trade-offs. It also enables engineers to make reasonably accurate predictions about a system's attributes that are free from bias and hidden assumptions. The ultimate goal is the ability to quantitatively evaluate and trade off multiple software quality attributes to arrive at a better overall system.

The purpose of this paper is to move towards the development of a unifying approach to the reasoning about the multiple software quality attributes for AI and robotics. It is now widely recognized that the cost of software vastly exceeds that of the hardware it runs on. Furthermore, a large proportion of the software budget may be spent on maintenance. We need to ensure that the new possibilities of IT will not make this even worse.

We know that software costs a huge amount to develop and maintain. But that's not all: vast economic and social assets also depend on its functioning correctly. It is therefore essential to develop techniques for measuring, predicting, and controlling the costs of software development and the quality of the software produced.





02 Setting The Scene

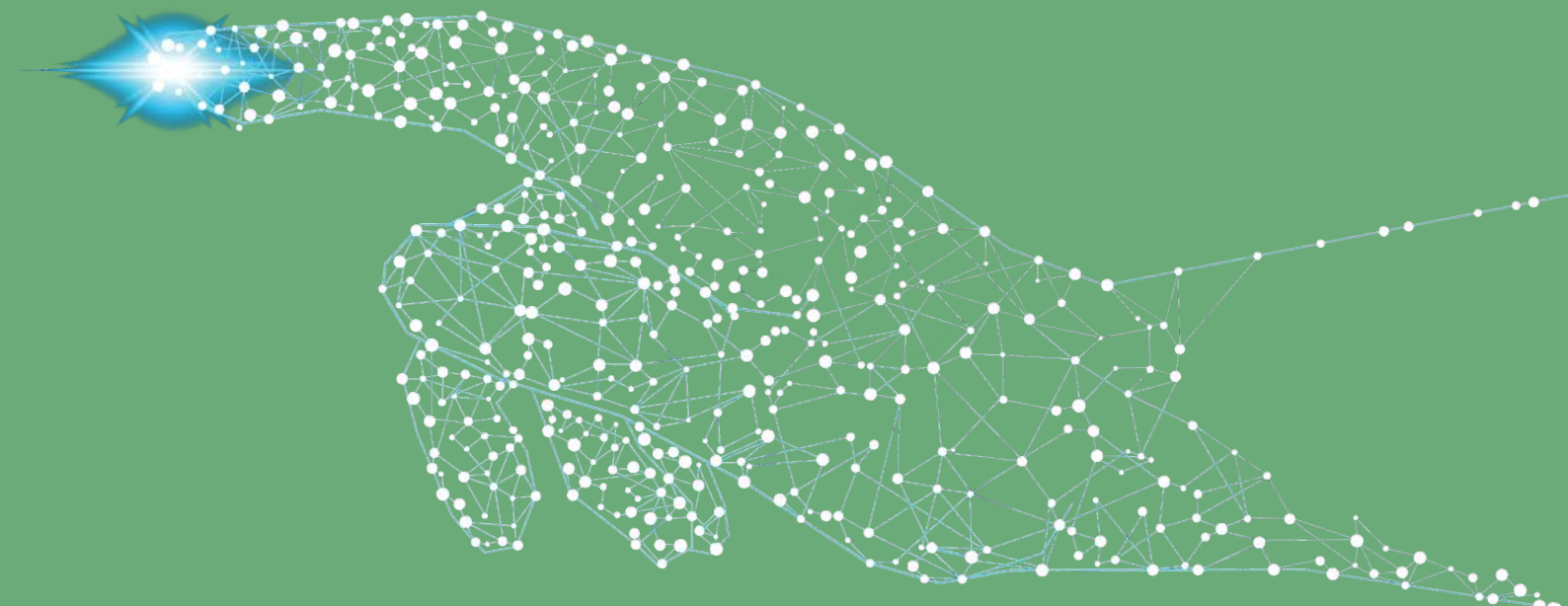
2.1 Introducing quality and quality characteristics

What is quality? The definition of quality may differ from person to person but, to align views, there are some standards. The ISO 8402-1986 standard defines quality as: *"The totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs."*

Software quality is the characteristic of the software that defines how well the software meets the customer requirements, business requirements, coding standards, security standards, etc.

Now let's see how one can measure certain quality characteristics of a product or application. To start with, a set of attributes is needed to measure the quality as a whole, along with a set of rules that should be followed. Mainly there are two categories:

1. Functional quality characteristics, which define how well the system developed meets users' functional requirements
2. Non-functional quality characteristics, which define how well the structural requirements are fulfilled to deliver the functional requirements.



A good example of a non-functional characteristic is performance. No one uses a system solely because of its performance. They use it for the functionality the system provides. Yet if the performance isn't good enough, the users will say the quality of the system as a whole is poor.

In today's IT world there are numerous lists of quality characteristics. Many of those lists contain concepts that are synonymous or closely related. The International Standards Organization published the ISO 9126 standard in 2001 and the updated version ISO 25010 in 2011. Another list of quality characteristics can be found in the TMap® NEXT book (2006). In this paper we use the ISO 25010 as our starting point because it is the newest and most extensive list. Further, we will demonstrate that new quality characteristics are needed as an addition to this list. Also, be aware that in an average IT project only a subset of quality characteristics will be relevant, so for every project the people involved should determine their set of relevant quality characteristics.

Testing and AI

Testing is one of the many aspects of Quality Assurance (QA). With Artificial Intelligence (AI) and robotics (see the definitions in the next section) playing an increasingly important role in IT today, testing is more vital than ever. The use of AI (and robotics) in IT promises to enable new functions, and/or to support activities that make existing ones better and faster. But it also creates new challenges.

It is important, when talking about testing and AI to distinguish between testing with AI and testing of AI, as described on the following pages.

Testing of AI

The improvement goal of systems engineering is to design and develop better systems with less effort. So, what does better systems mean? It relates to the relevant quality characteristics and, using these characteristics, engineers can assess products for strengths and weaknesses. System quality, by definition, is the degree to which systems possess a desired combination of attributes. Nowadays, AI and robotics can be used to create better systems. But involving AI and robotics introduces new quality risks.

Therefore, to improve system quality, we will feel the need for additional quality characteristics. Hence it is necessary to select appropriate characteristics, both from the existing list as well as new characteristics that are relevant to AI and robotics systems.

AI algorithms can be immensely helpful in the IT industry in making a smarter and more productive system for the end-user. AI is already becoming an integral part of our daily life and all systems we come across in the near future will be AI-enhanced. Indeed, they will be taking decisions and solving our tasks 24/7 and in less time than is currently possible. Therefore, Artificial Intelligence itself must be tested too, to ensure that users can rely on the decisions taken by AI.

Reading guide

This paper investigates and identifies the quality characteristics that are relevant to Artificial Intelligence (including robotics) systems. In chapters 2 and 3, we explain the terminology and review existing software quality assurance measures and techniques that have been developed for, and applied to, conventional IT-systems. In Chapter 4, we investigate the characteristics of AI-based systems, the applicability and potential use of measures and techniques identified in chapter 2, and we review those methods that have been developed especially for AI-based software. We have extended the existing quality characteristics matrix mentioned in ISO25010 with characteristics to test AI and robotics. In chapter 5 we finish with some musings on the topic of applying quality characteristics.



Testing with AI

Testing is transitioning to a higher level of test automation to ensure maximum confidence in the digital transformation journey. In this bid to make the application failsafe, we are turning more and more towards Artificial Intelligence (AI) and robotics. This implies that instead of manual testing done by humans, we are moving towards a scenario where machines will take over writing and executing test cases – this is testing with AI.

Nonetheless, a small amount of human input will still be required to help machines “learn” and improve themselves. And stakeholders will still want a brief manual test, just to be sure the system actually works. For more information about testing with AI (and Cognitive QA) please see the book “Testing in the digital age; AI makes the difference”.

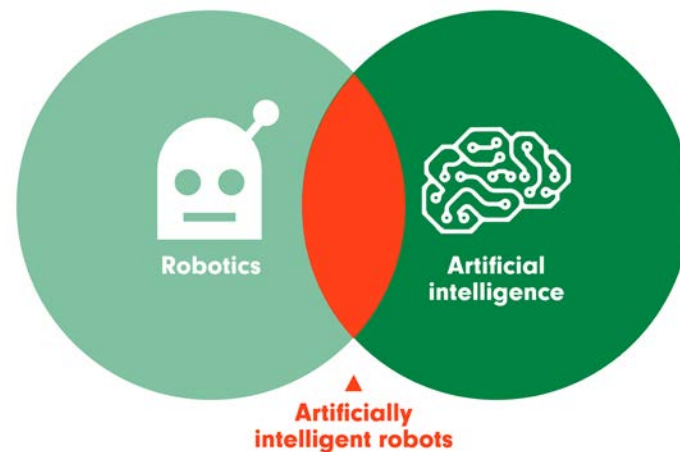
2.2 Terminology

We have used some terms in this paper like “Robotics”, “Artificial Intelligence”, “Cognitive QA”, “Testing of AI”. In today’s world of digital assurance and software testing, these terms are becoming common. The following describes in general terms how we define them.

2.2.1 Robotics

Robotics is a branch of technology that deals with robots. What is a robot? It’s a machine that gathers information about its environment by input from sensors and, based on this input, changes its behavior. Combined with Machine Learning and Machine Intelligence the robot’s reactions over time become more adequate. The use of Internet of Things (IoT), Big Data Analytics and cloud technology make a robot versatile.

Robots come in many different shapes and forms. It’s not just the metallic man of popular perception. Robots may equally be a smart algorithm on social media (for example a chatbot or a digital agent), an autonomous vacuum cleaner, or a self-driving car.



2.2.2 Artificial Intelligence

For this paper we would like to introduce two definitions of AI, and the distinction between general and narrow AI.

1. Artificial Intelligence (AI) is a sub-field of computer science aimed at the development of computers capable of performing tasks that are normally done by people, in particular tasks associated with people acting intelligently. AI is a system, built through coding, business rules, and increasingly self-learning capabilities, that is able to supplement human cognition and activities and interacts with humans naturally, but also understands the environment, solves human problems, and performs human tasks.
2. Artificial Intelligence, put simply, is the ability of machines to carry out tasks and activities we would consider “intelligent”. AI, broadly defined, is the ability for an intelligent agent to observe its surroundings and carry out specific tasks to maximize its ability to achieve a specific goal.

Artificial General Intelligence

Artificial General Intelligence (or AGI) is an intelligence that can execute all the tasks a human can execute. The most important aspect of AGI is that it can execute different complex tasks in a sequence. The coffee test as introduced in 2007 by Steve Wozniak should not be a problem for AGI: “A machine is required to enter an average American home and figure out how to make coffee: find the coffee machine, find the coffee, add water, find a mug, and brew the coffee by pushing the proper buttons.” But as Wozniak stated, it will take time before full AGI is here and what it will look like is still unclear.



Artificial Narrow Intelligence

All AI we use nowadays is categorized as Artificial Narrow Intelligence (or ANI). This AI is focused on one task, which it tries to execute as well as possible. Examples are autonomous driving cars, natural language processing and facial recognition. The big breakthrough for ANI was neural networks. Neural networks mimic biological processes. The paths that are laid in the brains of animals serve as the basis for this technology. With neural networks, it is possible to build much more complex systems for our AI solutions.

The biggest advantage of ANI is its ability to continually learn from the information it is fed. The most used example here is learning to recognize a specific object by feeding it large amounts of pictures and telling it when the object is in the picture. With reinforcement learning, it is possible to add a reward function and we can see ANI evolving into a much smarter system and growing towards an AGI solution.

Artificial Super Intelligence

"Artificial Super Intelligence is a hypothetical system that possesses intelligence far surpassing that of the brightest and most gifted human minds." (source: Wikipedia) This definition leaves open how the Artificial Super Intelligence (ASI) is implemented. It could be a computer, robot or networked computers.

Although supercomputers are beating human players at the likes of Jeopardy and Go, and assistive devices like Siri already exist, there is still no machine/computer with cognitive and intelligent capabilities compared to a fully developed adult human. It is clear to us that Artificial Intelligence has resulted in machines that are, in many ways, more capable than humans. However, it will take a long time before they are able to surpass human intelligence in every regard.

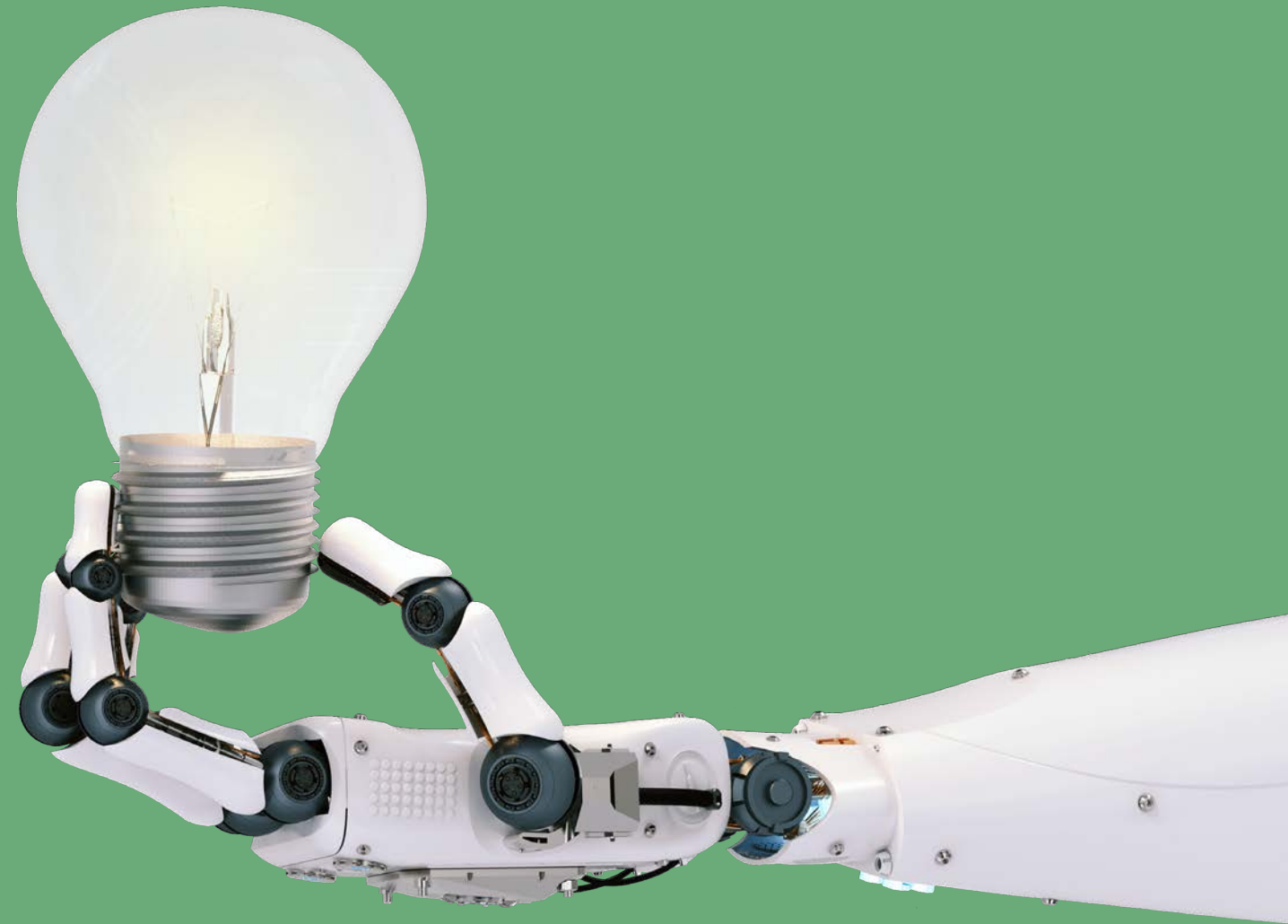
A thought-provoking quote from the great Stephen Hawking: *"The rise of powerful AI will be either the best, or the worst thing, ever to happen to humanity. We do not yet know which."*

2.2.3 Machine Learning

Machine Learning is one of the ways to achieve Artificial Intelligence. It contains different algorithms – each with its own strengths and weaknesses. The latest major breakthroughs in the field of AI are based on machine learning, or more specifically on "Deep Learning", which uses an artificial neural network. Other popular algorithms are: Bayesian networks, Decision Tree, K-Means Clustering and Support vector machines. Each has its own strengths and weaknesses. These algorithms are often grouped into three categories:

- Supervised learning
- Unsupervised learning
- Reinforcement learning

Although recognizing these differences, we have not differentiated the algorithms in this paper.



2.2.4 Machine Intelligence

Machine Intelligence (MI) is a unifying term for what others call Machine Learning (ML) and AI. We found that when we called it AI, too many people were distracted by whether certain companies were “true AI”, and when we called it ML, many thought we weren’t doing justice to the more “AI-esque”-like aspects, such as the various flavors of Deep Learning. So, Machine Intelligence is a term that combines “Artificial Intelligence”, “Machine Learning” and other related terms.

2.2.5 Cognitive IT

The word cognitive means “knowing and perceiving”. Cognitive information technology is not just rule-based but is able to react based on perception and knowledge. In this paper, “Cognitive QA” is used to refer to the use of cognitive IT to assist Quality Assurance and testing.

2.2.6 Cognitive QA; testing with Artificial Intelligence

Increasing volumes of new, digital technologies, more connectivity, and escalating levels of data in applications demand a smarter approach to QA and testing operations. This includes intelligent test automation and smart analytics that enable informed decision making, fast validation and automatic adaptation of test suites. Manual testing can be highly subjective and, as such, is prone to error. On average, in an existing test set, 30% is typically irrelevant and doesn’t tell you anything you didn’t already know from other test cases. Our latest World Quality Report (2017) shows that 99% of organizations face challenges with quality validation in agile projects and that only 16% of test activities are automated. This approach is not sustainable and is not suited to solving today’s increasingly complex quality assurance challenges. By applying smart analytics and AI, you can enable QA and testing teams to deliver quality with speed in a complex connected world at optimized cost. We call this Cognitive QA.

The Cognitive QA model

Cognitive QA accelerates and optimizes quality by using an intelligent approach to QA. This approach is a roadmap of four consecutive levels (see figure 1).

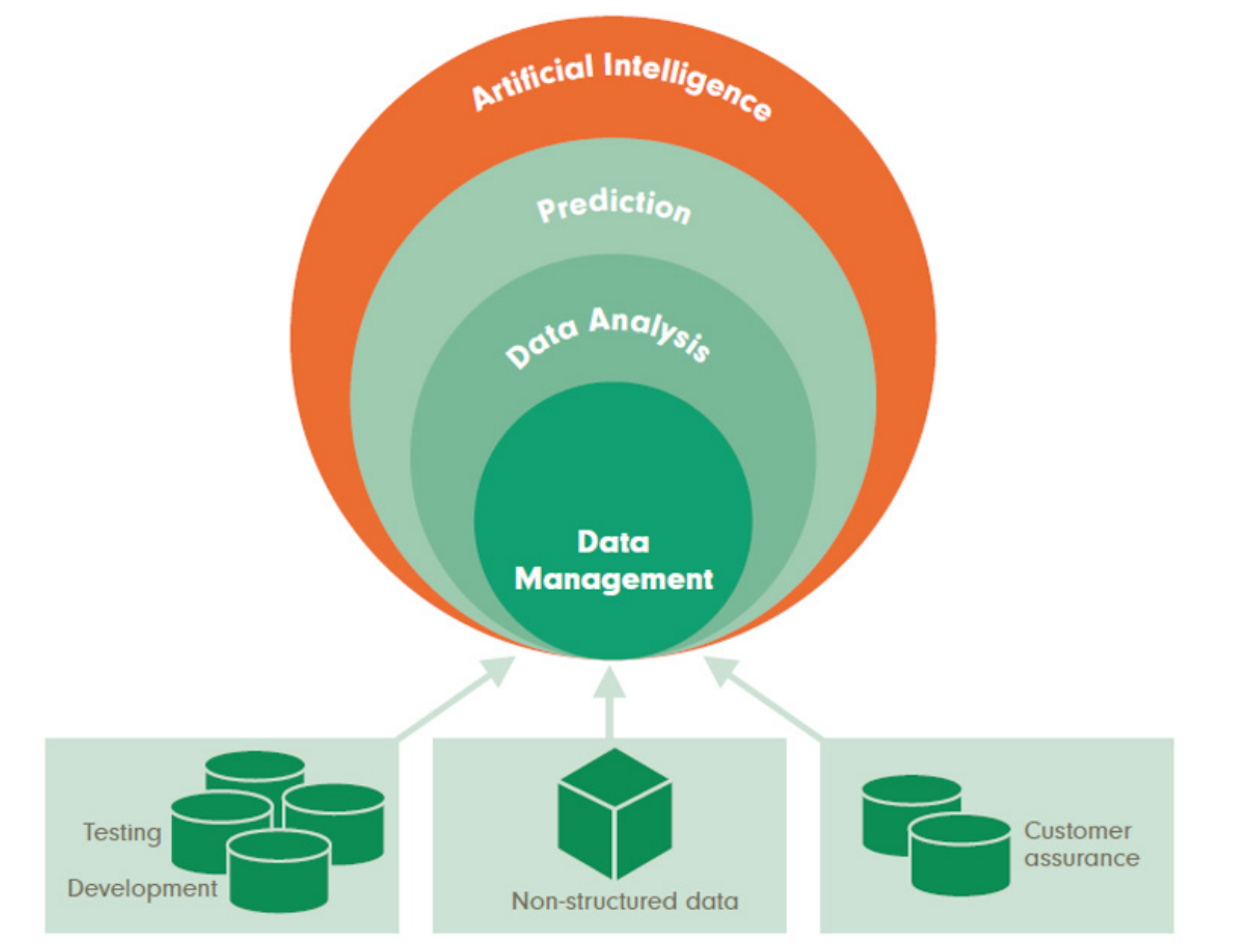
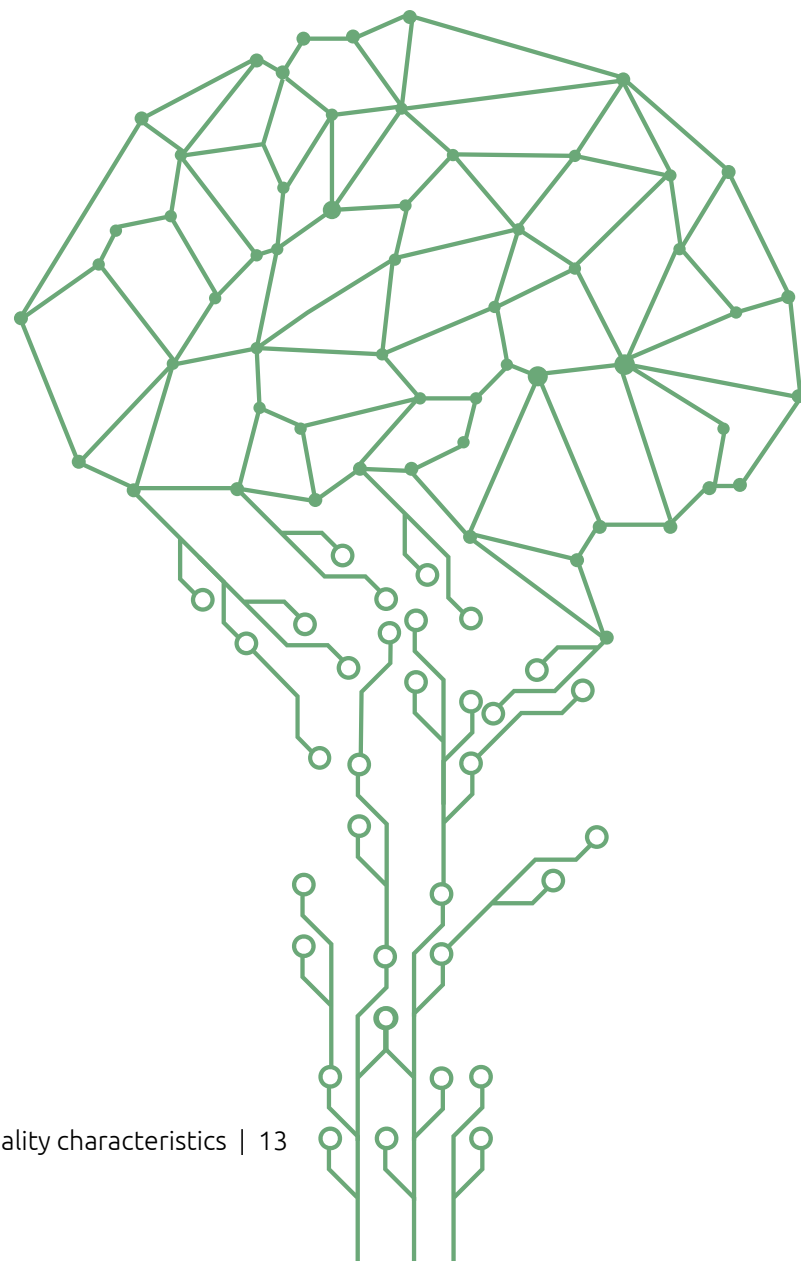


Figure 1: The consecutive levels of Cognitive QA

Cognitive QA enables smart quality decision making based on factual project data, actual usage patterns and user feedbacks to deliver quality with speed in a complex connected world at optimized cost.

Data management

The Cognitive QA approach starts with gaining confidence in the relevant data. Relevant data consist of a wide variety of data about IT-tasks, such as design, development, assurance, deployment and maintenance. It can also be the data from the operational process, like the IT-system usage.

Gaining confidence in the data relies heavily on the maturity of data management. Therefore, there's a lot of data science involved. And although this is the first level, that doesn't mean it's an easy level. Fortunately, good tools and approaches are available, including applying Machine Learning to investigate the data.

Data analysis

Dashboards are used to build on the mature data analysis and to visualize the results. This data analysis includes the use of smart analytics models. IT offers the potential to give insight into the tendency of the quality of the system (usually increasing over time) and the related product risks (hopefully decreasing over time). But the data analysis will also contribute to the provision of an accuracy rating. Such data analysis is carried out through BI capabilities and customized dashboards.

Prediction

Based on results from test execution and monitoring of live systems, quality forecasting is one of the important new possibilities of test engineering in the digital age. Examples of predictions that can be made as part of Cognitive QA are estimates related to the effort needed for test preparation and execution, as well as estimates related to the time it will cost to fix defects (important to support the maintenance function). And the system under test can be divided in various areas based on criticality.

Forecasting can be used in various situations, for example selecting and prioritizing the test cases that should be used in a future test run, as well as to establish the most favorable configuration of the test environment. And ultimately forecasting can indicate where quality issues will arise so that these can be fixed even before they exist.

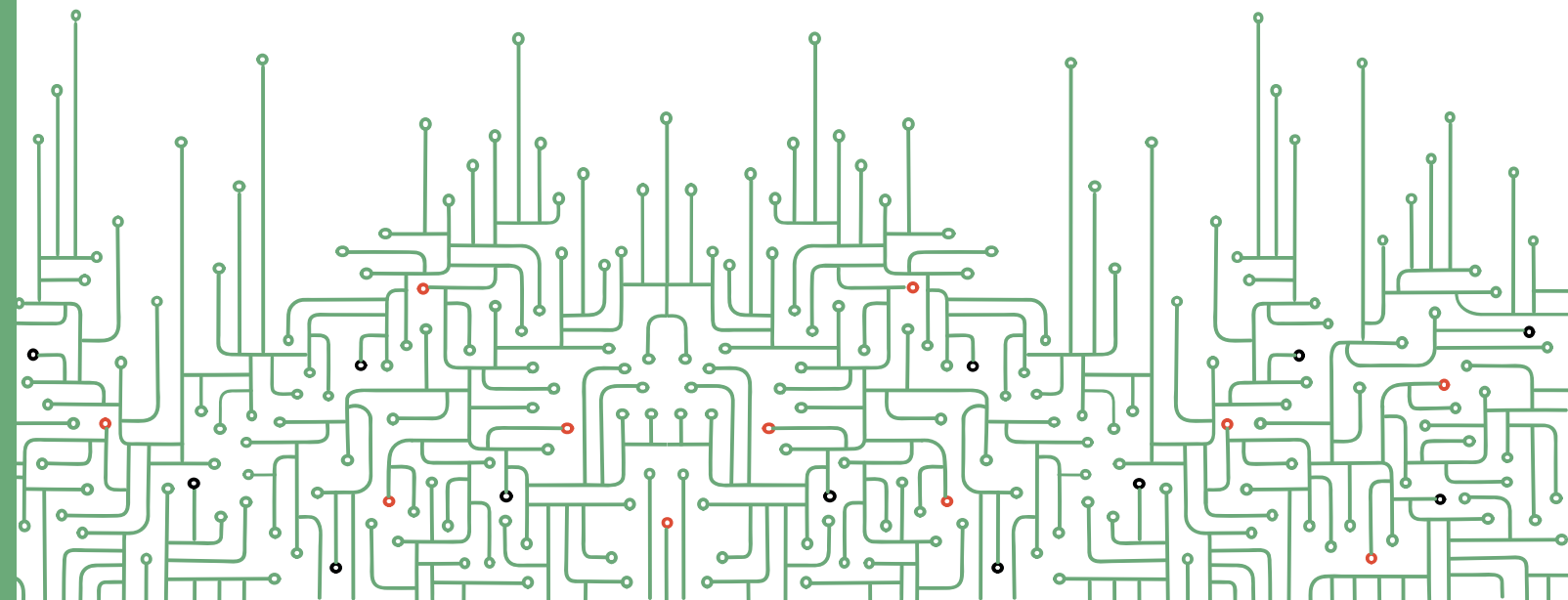
Artificial Intelligence

Using Machine Intelligence, an in-depth analysis of the test execution is made. Test scripts can even be automatically generated with a coverage level that best fits the risks involved. For this, we can apply a bespoke algorithm or readily available platforms like IBM Watson, Google's Deepmind and others. Cognitive QA enables smart quality decision making based on factual project data, actual usage patterns and user feedbacks to deliver quality with speed in a complex connected world at optimized cost.

2.2.7 Knowledge and skills for testing of Artificial Intelligence and robotics

Artificial Intelligence and robots powered by AI will ultimately be around us all the time, every day, whether we're aware of it or not. Everyone involved in IT will come across intelligent machines today, or in the near future. For testing AI and robotics, but also while using AI and robotics for testing, these professionals will need additional skills. It is an illusion to think that specialized testers will be able to do all testing tasks.

Although testing is a profession in its own right, we don't believe there will be many dedicated "AI testers", "Robot testers" or "AI Quality engineers" in projects. Most of the test engineering will be done by other team members, such as business analysts, data scientists, programmers, operations and maintenance people and end users. We hope to inform and inspire them about the skills they need to keep delivering IT-systems that are fit for purpose and that deliver business value. We have previously investigated and discussed why we need to test AI and how. You can read more in our paper ["Testing of artificial intelligence"](#) or visit www.Sogeti.com.

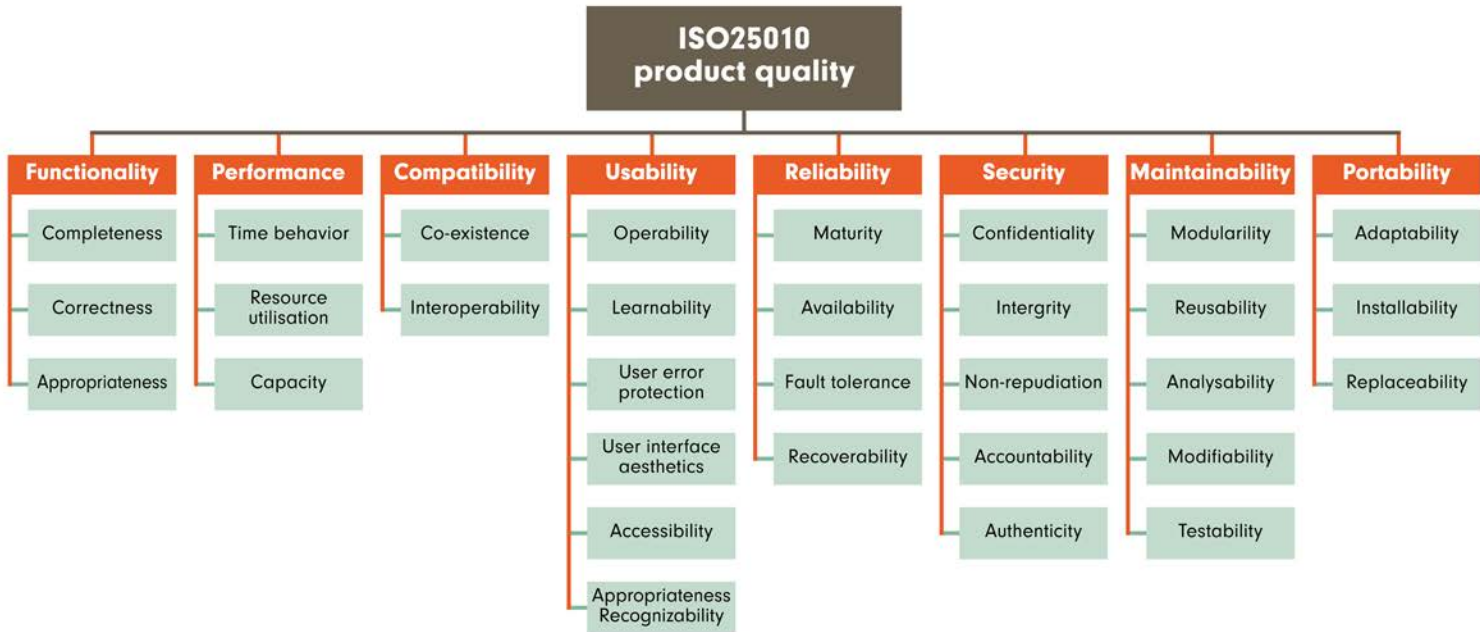




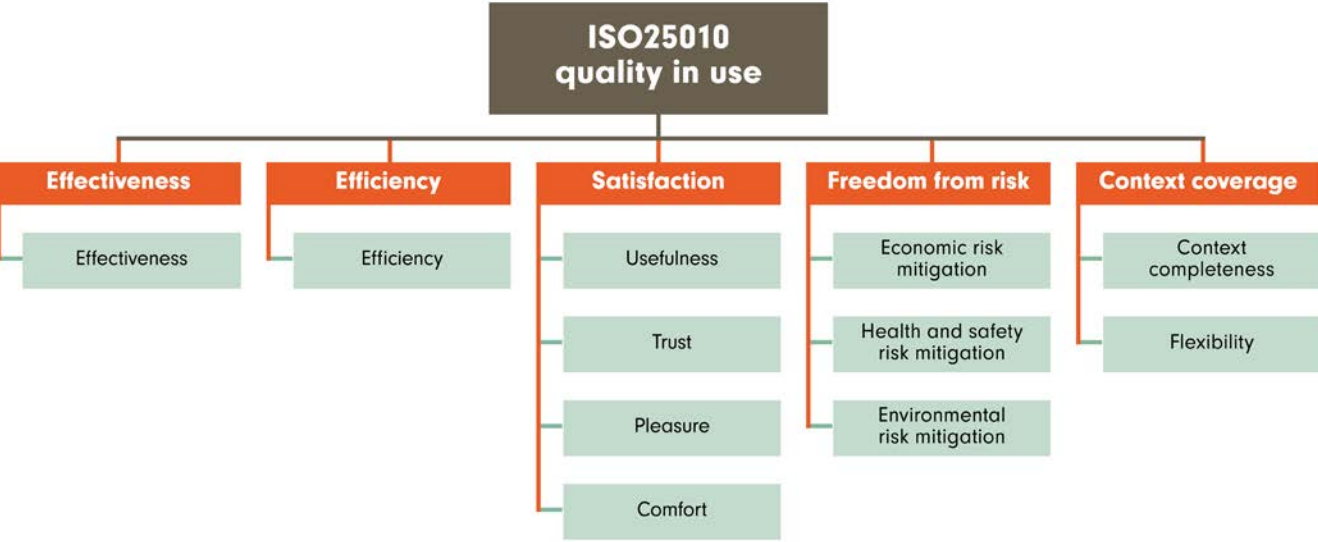
03 Quality characteristics for conventional IT

Testers have typically used quality characteristics to determine what to test and with what intensity to test it. Well known lists of quality characteristics are ISO 9126 (with 6 main characteristics and 27 characteristics in total) and its successor ISO 25010 (with 8 main characteristics for product quality and 5 main characteristics for quality in use). Also in use is the TMap® NEXT list of 17 quality characteristics for product quality. But today, with the rapid upcoming of AI and robotics these lists are no longer sufficient. To decide upon the right test varieties needed to properly test this new technology, new quality attributes are needed.

Let’s have a look at the existing quality characteristics. The ISO 25010 standard consists of 8 main characteristics for product quality, as shown here:



Quality in use relates to the outcome of human interaction with the software. It is divided into 5 main characteristics:



For more information: <https://www.iso.org/obp/ui/#iso:std:iso-iec:25010:ed-1:v1:en>



04 Quality characteristics for intelligent machines

4.1 Why we require more quality characteristics

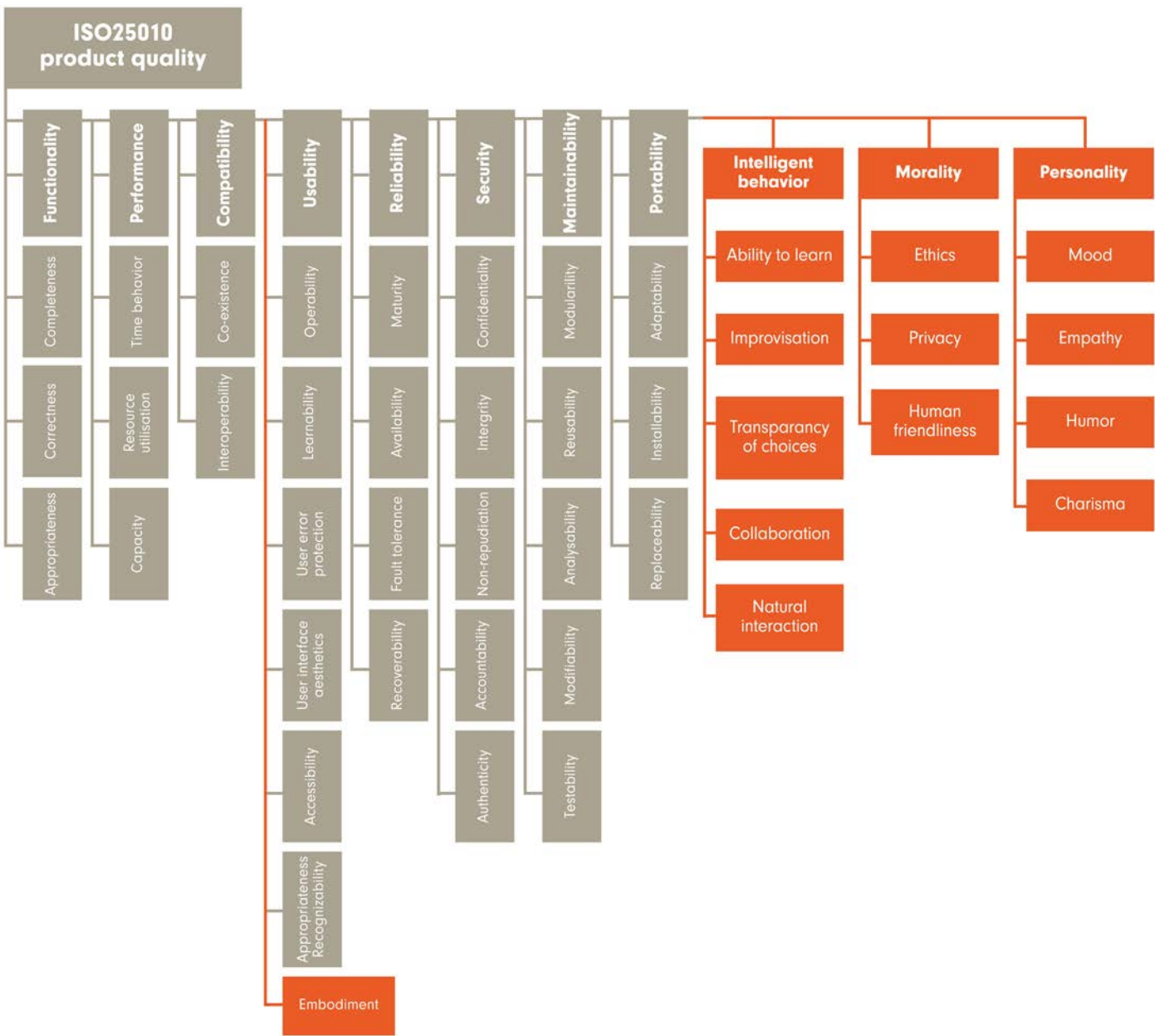
To get a clear view on the quality level of any system we need to distinguish some quality sub-divisions, for which we use quality characteristics. The commonly used standards evolved in an era when IT-systems were focused on data processing and where input and output were done by means of files or screen-user-interfaces.

Nowadays, we see machine intelligence systems that have many more options. Input is often gathered using sensors (e.g. in IoT devices) and output may be in a physical way (like moving objects in a warehouse). This calls for an extension of the list of quality characteristics. The following sections describe new quality characteristics.

We have added three new groups of quality characteristics: intelligent behavior, personality and morality. In their respective sections, we describe these main characteristics and their sub-characteristics. We then describe the sub-characteristic of embodiment that we have added to the existing main characteristic of usability.

4.2 New quality characteristics for intelligent machines

The new characteristics and sub-characteristics that we have added for use with AI and robotics are shown in the extended ISO25010 product quality characteristics graphic below.



These new (sub-) characteristics are described in more detail in this chapter.

4.2.1 Intelligent behavior

Intelligent behavior is the ability to comprehend or understand. It is basically a combination of reasoning, memory, imagination, and judgment; each of these faculties relies upon the others. Intelligence is a combination of cognitive skills and knowledge made evident by behaviors that are adaptive. (source: Wikipedia)

1. Ability to learn

The ability to learn is the ability to comprehend, to understand and to profit from experience. How does an intelligent machine learn? We see three levels of learning.

- The first level is rule-based learning. When a user frequently uses certain options in a menu, the intelligent machine can order the options such that the most used options appear first.
- The second level is based on gathering and interpreting data and, based on that, learning about an environment.
- The third level is learning by observing the behavior of others and imitating that behavior.

Examples of the levels of learning

At the first level of learning, think of a satellite navigation system in a car. If you always turn off the automatic voice right after starting the system, the machine learns to start up without the voice activated.

At the second level think of a robotic vacuum cleaner. By recording information about the layout, it learns about the rooms that it cleans and becomes better at avoiding obstacles and reaching difficult spots.

At the third level it's about mimicing behavior, for example a robot watches a YouTube video of baking pancakes and then copies the behavior. After watching several videos, the robot knows all the tricks of the trade.

Of course, the levels of learning can be combined by intelligent machines.

2. Improvisation

Does it adapt to new situations? Improvisation is the power of the intelligent system to make right decisions in new situations. Situations that might have never been experienced before require quick interpretation of new information and the ability to adjust existing behavior. Social robots in particular must be able to adapt their behavior according to the information coming in, since social behavior depends on culture in specific small groups. Applying long-term changes will also be important for a robot to remain interesting or relevant for its environment.

3. Transparency of choices

Can a human understand how a machine comes to its decisions? An Artificial Intelligence system works 24/7 and takes a lot of decisions. Therefore, there must be transparency around how an AI system takes those decisions. For example, there must be clarity on which data inputs the decisions are made, which data points are relevant and how they are weighted. In several use-cases, the decision-making is crucial, such as when an Artificial Intelligent system calculates an insurance premium. In this specific use case, it is important to investigate how the premium has been calculated.

Transparency also means predictability. It is important that robots respond as expected by the people who work with the robot. How well can the humans involved foresee what (kind of) action the intelligent machine will take in a given situation? This is the basis for proper collaboration (see next paragraph).

4. Collaboration / Working in a team

How well does the robot work alongside humans? Does it understand expected and unexpected human behavior? Robots can work with people or other robots in a team. How communication works within this team is very important. A robot must be aware of the team members and know when a person wants to interact with the robot. With the help of natural interaction, the robot must make it possible to draw attention to itself. Working in a team is particularly important in industrial automation where robots and people work alongside each other in a factory. Elsewhere, the importance of teamworking can be seen in traffic where, for example, a bicyclist should be able to see whether a self-driving car is aware that the cyclist wants to make a turn.

Collaboration between robots only, so without humans involved, is very similar to the existing quality characteristic of interoperability. However, because collaboration can be of great importance in robots and intelligent systems we are covering this separately.

5. Natural interaction

Natural interaction is important, both in verbal and non-verbal communication. With social robots in particular, it is important that the way humans interact with a robot is natural, reflecting how they interact with people. One of the things that can be considered here is multiple input modalities, so there is more than one possibility for controlling the robot (for example speech and gestures).

In chatbots it is important that the conversation is natural, but also specific to the purpose of the chatbot. Consider that a chatbot making small talk has more room to make mistakes and slowly learn, whereas a chatbot that is supposed to make travel arrangements should clearly understand destination, dates and other relevant information without erroneous interpretations. Most people who enter “home” as their destination mean their own home and not the nearest nursing home, which a traditional search-engine would assume. In this case asking clarification is very important for the chatbot.



4.2.2 Morality

"Morality is about the principles concerning the distinction between right and wrong or good and bad behavior." (source: Wikipedia)

The well-known science fiction author Isaac Asimov gave a great deal of thought to the morality of intelligent machines. One of his contributions was drawing up the "laws of robotics" that intelligent machines should adhere to.

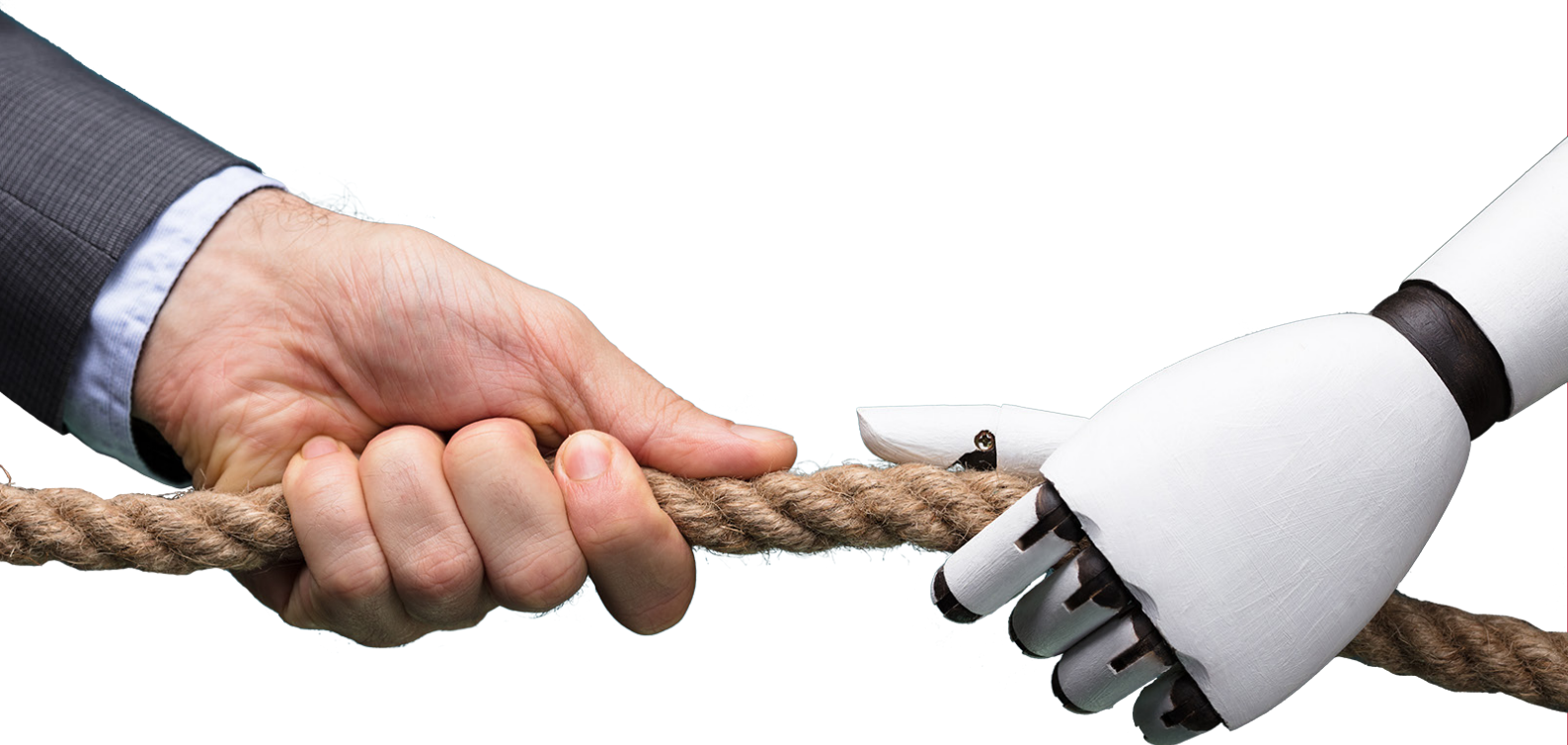
These laws of robotics are:

0. A robot may not harm humanity, or, by inaction, allow humanity to come to harm.
1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Other authors created some additional laws:

4. A robot must establish its identity as a robot in all cases.
 5. A robot must know it is a robot.
 6. A robot must reproduce. As long as such reproduction does not interfere with the First or Second or Third Law.
- (source: Wikipedia)

Unfortunately, we observe that, unlike in Asimov's stories, most intelligent machines do not have these robot laws built in. It's up to the team members with a digital test engineering role to assess to what level the intelligent machine adheres to these laws.



1.Ethics

Ethics is about acting according to various principles. Important principles are laws, rules and regulations, but for ethics the unwritten moral values are the most important.

Some challenges of machine ethics are much like many other challenges involved in designing machines. Designing a robot arm to avoid crushing stray humans is no more morally fraught than designing a flame-retardant sofa.

With respect to intelligent machines, important questions related to ethics are:

- Does it observe common ethical rules?
- Does it cheat?
- Does it distinguish between what is allowed and what is not allowed?

To be ethically responsible the intelligent machine should inform its users about the data that is in the system and what this data is used for.

Ethics will cause various challenges. For example: it isn't too difficult to have an AI learn (using machine learning) to distinguish people based on facial or other body-part characteristics, for example race, sexual preference, etc. In most countries this would not be ethical. So, testers need to have acceptance criteria for this and do something with it.

Another ethical dilemma relates to who is responsible when an intelligent machine causes an accident. There is no driver in the autonomous car, just passengers. So, should the programmer of the intelligent software be responsible? Or the sales-man who sold the car? Or the manufacturer? And who should be protected in the event of an autonomous car crash?

Some manufacturers of autonomous cars have already announced that their cars will always protect the people inside the car. That may be smart from a business point-of-view (otherwise no-one would buy the car) but from an ethical perspective, is it right to let a few passengers in the car prevail over a large group of pedestrians outside the car? These are all ethical (and some legal) dilemmas.

Finally, there is an ethical dilemma about the feelings of people towards intelligent machines. The 2013 Oscar-winning film "Her" shows how a man (actor Joaquin Phoenix) falls in love with his operating system. From an ethical point of view, we may wonder if we should allow a machine to acknowledge and return such feelings.

2. Privacy

"Privacy is the state of being free from unwanted or undue intrusion or disturbance in one's private life or affairs." (source: www.dictionary.com)

Does the intelligent machine comply with privacy laws and regulations? The fuel of machine learning algorithms is data. It determines what the solution can and will do in the end. It is important to ensure that the gathered data and the insights gained from that data are aligned with the business goals. There are also legal constraints, which depend on national and international laws, regulations and the analyzed data. In the EU, for example, the General Data Protection Regulation (GDPR) is now one of the strictest regulations with the potential for severe financial sanctions for non-compliance.

Data can be breached

Data breaches occur. That's a fact. This gives hackers access to sensitive information, such as that contained in email attachments, which should not be there in the first place. Privacy considerations now have a bigger scale and impact. They should be handled carefully, not only because of the social responsibility, but because legislation, like GDPR, must be complied with.



3. Human friendliness

Human friendliness refers to the level to which intelligent machines don't cause harm to humans or humanity.

Most of the leading AI experts and companies recognize that there is a risk for AI and robotics to be used in warfare. This challenges not only our current ethical norm, but also our instinct for self-preservation. The "future of life Institute" has taken a close look at these dangers. They are very real risks and should be considered when developing new solutions.

Human friendliness is also related to safety (especially when people work closely with robots, so-called cobotics). Safety and security are often confused, but they are not the same. Security is the protection of the application against people (or machines) with malicious intention. This is something other than safety that guarantees no harm comes to people. For robots this is very important since a co-worker may want to know: "How big is the chance that I will get a big robot-arm against my head if I try to communicate with this robot?"

It is often feared that robots and other intelligent machines will take over all human labor. This fear has been expressed many times in the last few centuries. And indeed, plenty of human labor has been automated over the years, but every time this happens, new challenging tasks requiring human intervention emerge. And this time, it won't be any different.

Nonetheless, we will see the specific phenomenon of "backshoring" related to AI and robotics. In recent years, lots of work has been offshored to countries where the hourly wages are lowest. Nowadays, robots can not only work even cheaper, but 24/7. Therefore, transport costs will be the determining factor. And consequently, work is "backshored" to the place where the outcome of the work is wanted, and where some highly-skilled support work will be needed. In this sense AI is human friendly because the work is more evenly spread over the globe, based on the location where the results are needed.

4.2.3 Personality

A personality is the combination of characteristics or qualities that form an individual's distinctive character.

Let's focus on having robots as a partner or assistant. We want to build robots with a personality that fits the personality of the humans it collaborates with.

1. Mood

A mood is a temporary state of mind or feeling.

Will an intelligent machine always be in the same mood? We would be inclined to think that a machine, by definition, doesn't know about moods, it just performs its task in the same way time, again and again. But, by adding intelligence, the machine may change its behavior in different situations or at different times of day.

A good use of moods may be in cobotics, where the robot adapts its behavior to the behavior of the people it collaborates with. For example, at night the robot may try to give as few signals as possible because people tend to be more irritable at night, whereas on a warm and sunny summer's day the robot may be more outspoken in its communication.

Another aspect of mood, is using Machine Intelligence to change the mood of people. Mood altering or so-called AI-controlled brain implants in humans are under test already. Brain implants can be used to deliver stimulation to specific parts of the brain when required. Experts are working on using specialized algorithms to detect patterns linked to mood disorders. These devices are able to deliver electrical pulses that can supposedly shock the brain into a healthier state. There are hopes that the technology could provide a new way to treat mental illnesses that goes beyond the capabilities of currently available therapies.

2. Empathy

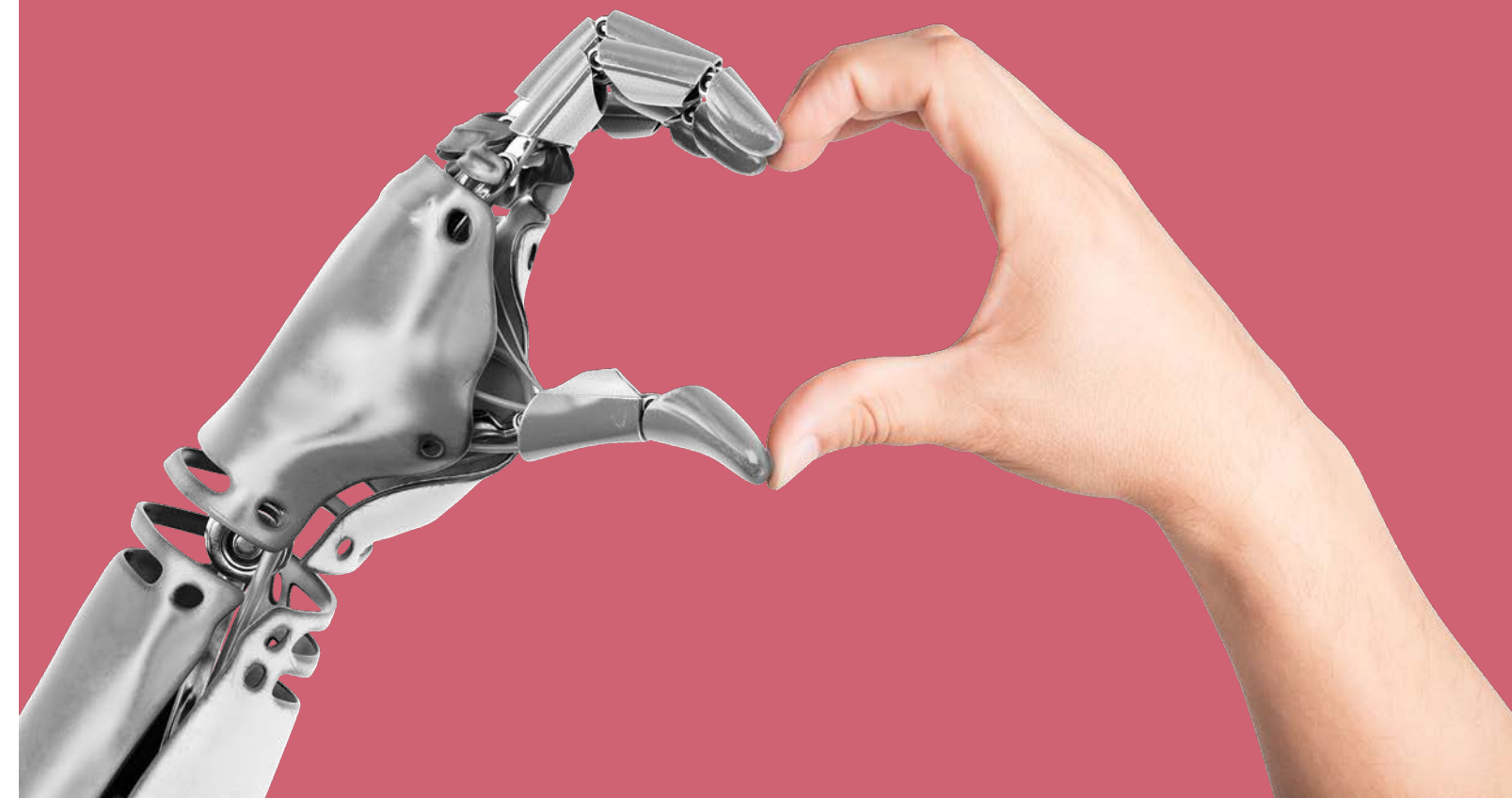
Empathy is the ability to understand and share the feelings of another.

Machines cannot feel empathy, but it is important that they simulate empathy. They should be able to recognize human emotions and respond to them. An intelligent machine should understand the feelings of the people it interacts with. This is especially important with robots working in hospitals, for example as "companion" robots.

3. Humor

"Humor is the quality of being amusing or comic, especially as expressed in literature or speech." (source: en.oxforddictionaries.com)

Is there a difference between laughter and humor? Yes, there is. Laughter is used as a communication aid. From the gentle chuckle to the full-on belly laugh, it helps us to convey our response to various social situations. Humor could be defined as the art of being funny, or the ability to find something funny. How will robots detect these very human behaviors? That is the next step in AI, programming robots with the ability to get in on the joke, detect puns and sarcasm and throw a quick quip back! There is a whole branch of science dedicated to research and development in this area. Scientists in this field are known as computational humorists, and they have come a long way in the algorithms they have created so far. An example of such an algorithm is "SASI", which detects sarcasm.



4. Charisma

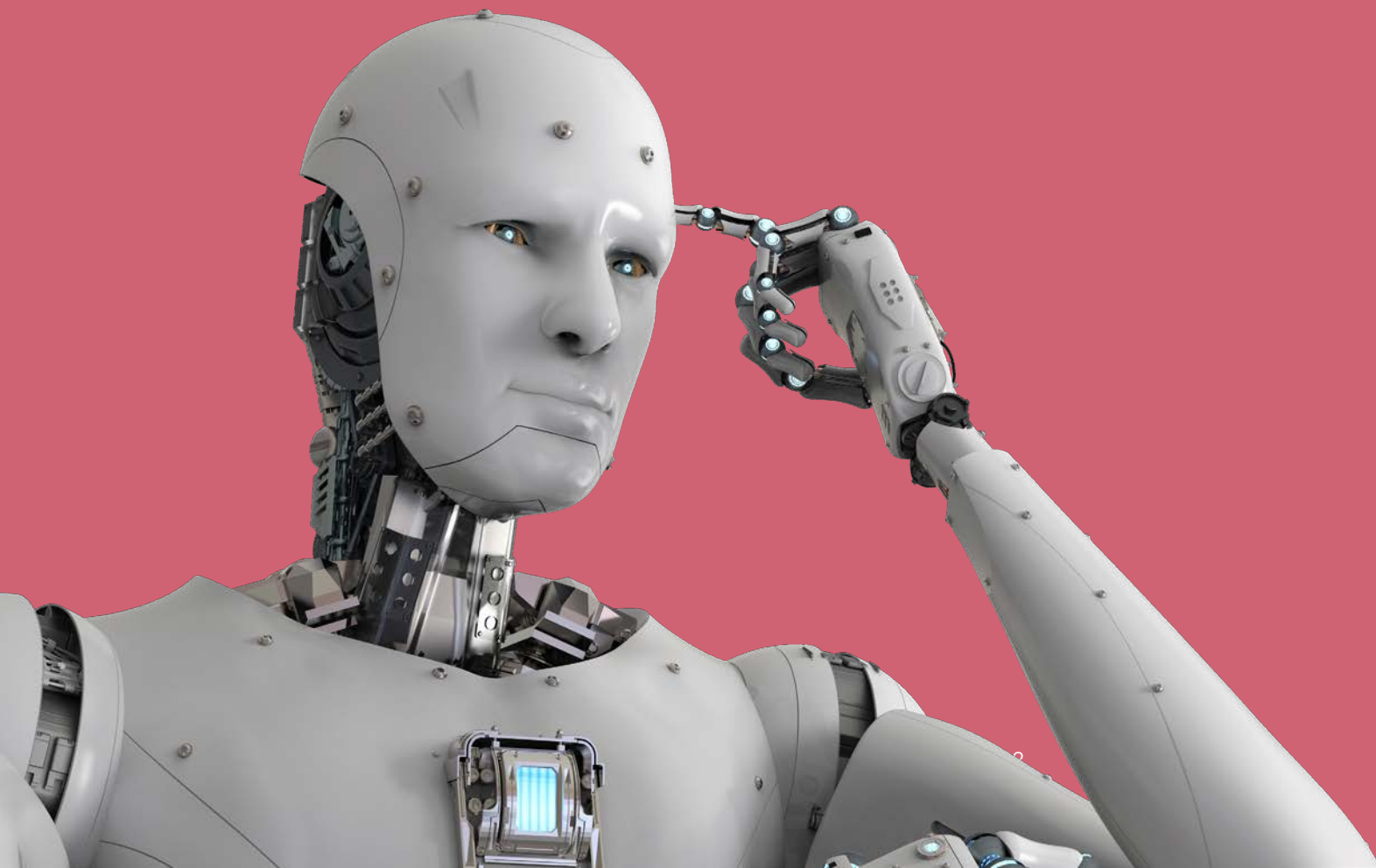
Charisma is the compelling attractiveness or charm that can inspire devotion in others. (source: en.oxforddictionaries.com)

Do people like the intelligent machine? Do people love the intelligent machine? Is it so appealing that they never want to put it away? If a product has this “wow-factor”, then it is much more likely to be a successful product. So, the charisma of a product is important.

Is charisma a sign of intelligence? It is. It is all learned behavior, no matter what factors are employed. To be accepted by users, the robot must appeal in some way to the user. That may be by its looks (see embodiment), but more important by its functionality and probably by its flexibility. One way to keep amazing the user is to continuously learn new things and thus stay ahead of the expectations of the user.

4.2.4 Usability

In the existing group of quality characteristics, we have added only one extra sub-characteristic, that is embodiment, in the group usability. Of course, other existing quality characteristics and sub-characteristics are also of importance, but that's just about a different use or application of the existing characteristics.



1. Embodiment

A big buzzword in AI research these days is ‘embodiment’, the idea that intelligence requires a body or, in the case of practicality, a robot. Embodiment theory was brought into Artificial Intelligence most notably by Rodney Brooks in the 1980’s. Brooks showed that robots could be more effective if they “thought” (planned or processed) and perceived as little as possible. The robot’s intelligence is geared towards only handling the minimal amount of information necessary to make its behavior be appropriate and/or as desired by its creator. Embodiment, simply means: “Does it look right?”

With physical robots, as well as with the user interface of chatbots and even smart speakers, how they look and how they fit in the space in which they have to operate is very important. A key point here is that the appearance of the robot must match its functions. When first seeing a robot, people create expectations about the functions of that robot. So, for example, if the appearance is attractive but the robot does very little, people can become disappointed. Another relevant aspect of embodiment is the degree to which a robot resembles a human. In general people like humanoid robots, but as soon as they look too real, people start to feel unnerved (or uncanny). In the graph depicting people’s emotional response to the embodiment, this is known as the “uncanny valley”.

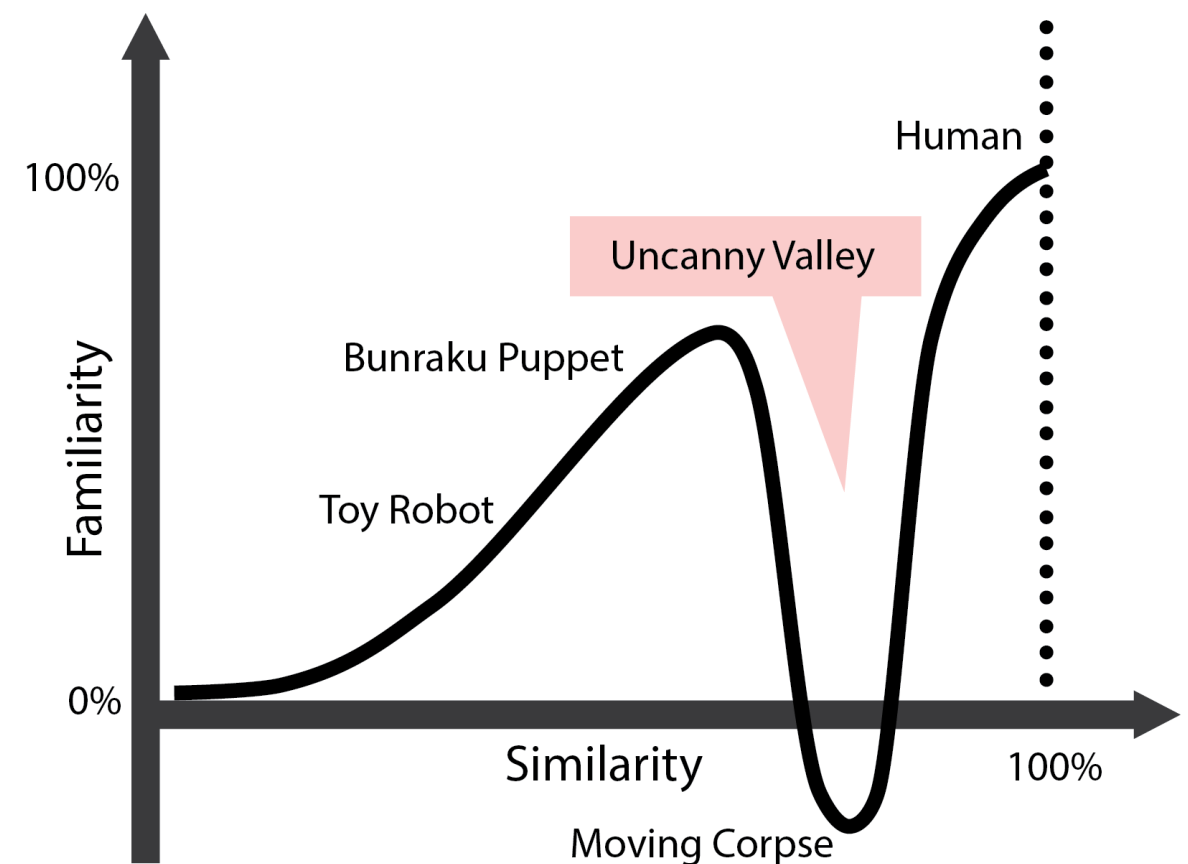


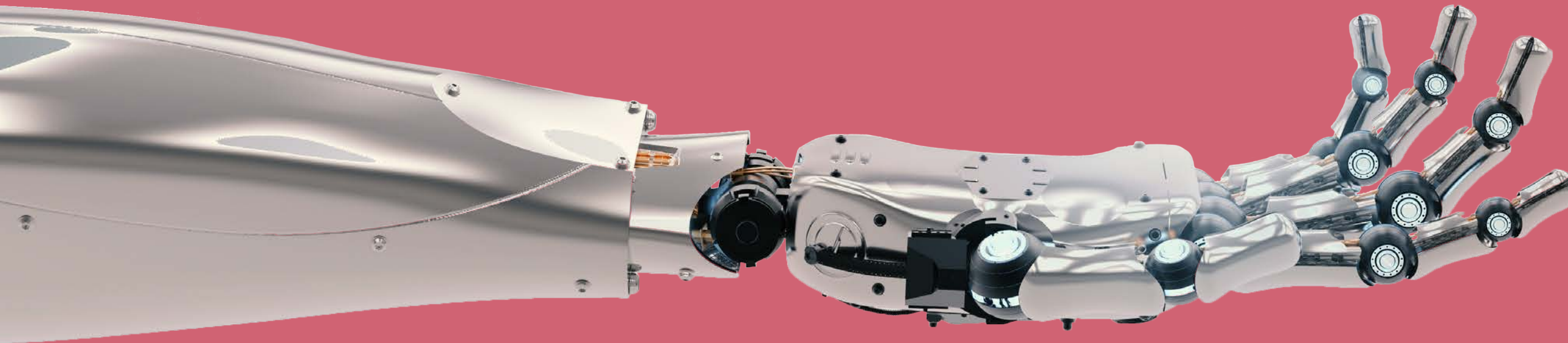
Figure 2: The uncanny valley
(source: <http://tvtropes.org/pmwiki/pmwiki.php/Main/UncannyValley>)

The quality characteristic of embodiment includes both, the physical embodiment of a robot and where the robot is located – is it right for this location?

4.3 Existing quality characteristics applied to intelligent machines

4.3.1 Applying existing quality characteristics

Most of the quality characteristics of the ISO 25010 model, both product quality and quality in use, are applicable to intelligent machines. In the following sections, we highlight a few of the most relevant of these characteristics in the context of testing in the digital age.



4.3.2 Satisfaction – pleasure

In its latest reports, Sogeti's trend lab VINT has elaborated on "digital happiness". VINT argues that human skills are augmented by applying technology and this, in turn, causes people to be more satisfied with their life and their role in the world.

With the exponential growth of technology and the ever-increasing speed of digitalization, it has become a standard procedure to take technology into account when examining social issues. People know that technology has pervaded their lives, be it shopping, following world events, forming an opinion, communicating, organizing financial affairs and even finding a life partner. The promise of technology is vast; humanity-saving claims run rampant in tech. But people see threats as well. Security-breaches, fake-news, cyberwar, and privacy-violations are now common news and no longer just 1984 fantasies.

Technology is everywhere, and the impact is complex and dualistic. It is no wonder that people are asking the logical question: "Does all this technology make me happier?"

And the customer is not alone in this quest for happiness. Employees bring the same desires to their workplace and with good reason. Shawn Achor, author of the bestseller "The Happiness Advantage", analyzed over 200 scientific studies on happiness. He concluded that happy employees *"have higher levels of productivity, produce higher sales, perform better in leadership positions, and receive higher performance ratings and higher pay. They also enjoy more job security and are less likely to take sick days, to quit, or become burned out. Happy CEOs are more likely to lead teams of employees who are both happy and healthy, and who find their work climate conducive to high performance."*

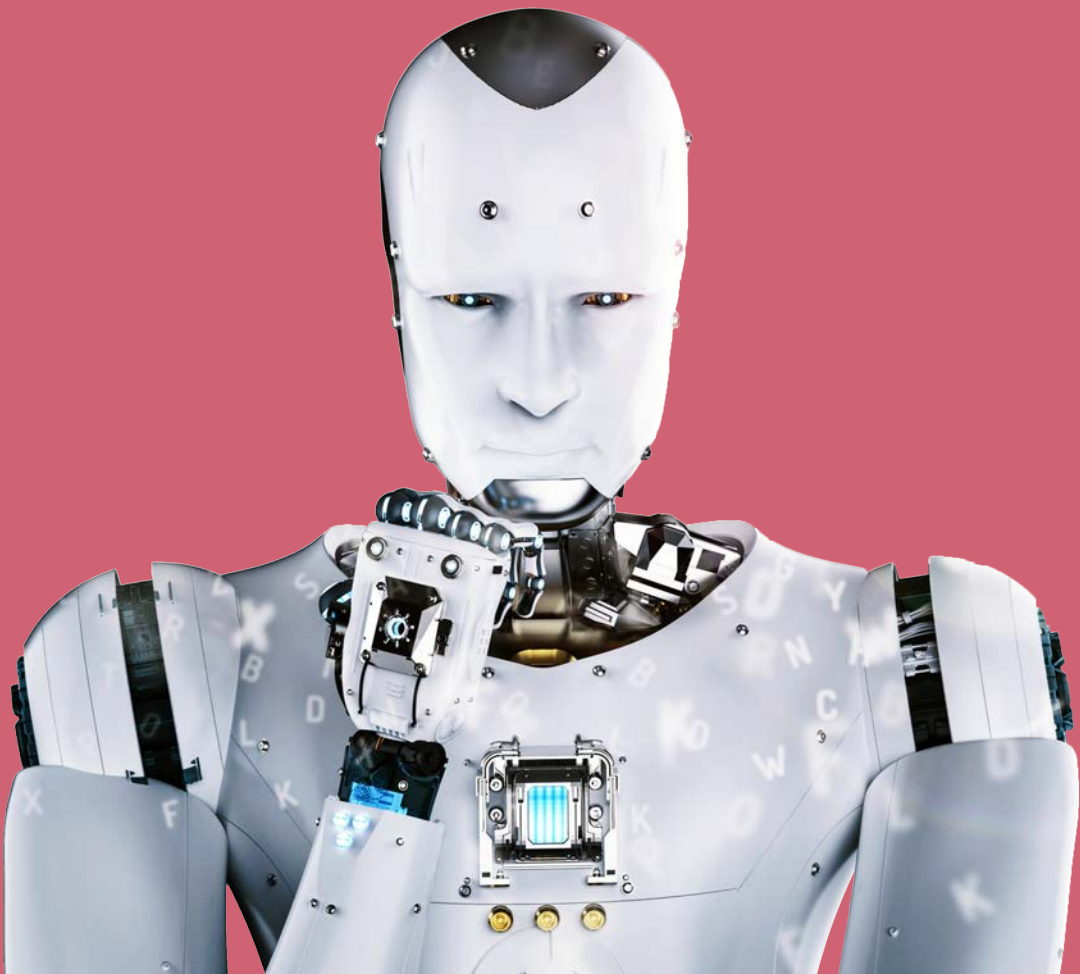
The conclusion for now is that: Happiness is becoming humanity's explicit goal (instead of just GDP, for instance). Technology will help measure happiness (and maybe increase our happiness obsession?). Companies will be reviewed through this happiness perspective: "Does your business make me happier?"

(Source: blog of Thijs Pepping on labs.sogeti.com)

4.3.3 Freedom from risk - Environmental risk mitigation
This quality characteristic is commonly known as “environmental friendliness” and is all about using as few natural resources (such as fuel) as possible and to be able to recycle materials at the end of their lifetime.

Robots should assist humanity in preventing and solving pollution. So, they should in no way add to pollution or cause other possible harm to the environment. This implies many possible things, ranging from low energy consumption and use of non-pollutive materials, to actively contributing to cleaning the environment. There are a number of ways AI is helping to safeguard the world in this way. For example, one of the areas where machine learning is proving to be beneficial is in environmental sciences, which have generated huge amounts of information from monitoring the Earth’s various systems - underground aquifers, the warming climate or animal migration, for example. A slew of projects has been popping up in this relatively new field, called computational sustainability, that combine data gathered about the environment with a computer’s ability to discover trends and make predictions about the future of our planet.

This predictive capability is useful to scientists and policy-makers because it can help them develop plans for how best to live and survive in our changing world. For example, machine learning can help with species conservation (birds, elephants, etc). Observational data captured on different bird species found in a given location can be combined with information about species distribution gathered from remote sensing networks. From this, a model can be created which can use machine learning to predict where there will be changes in habitat for certain species and the paths along which birds will move during migration.



4.4 Quality characteristics mapped to quality angles

The picture below illustrates the six different angles that are used for digital assurance and testing of modern technology, such as Artificial Intelligence and robotics.

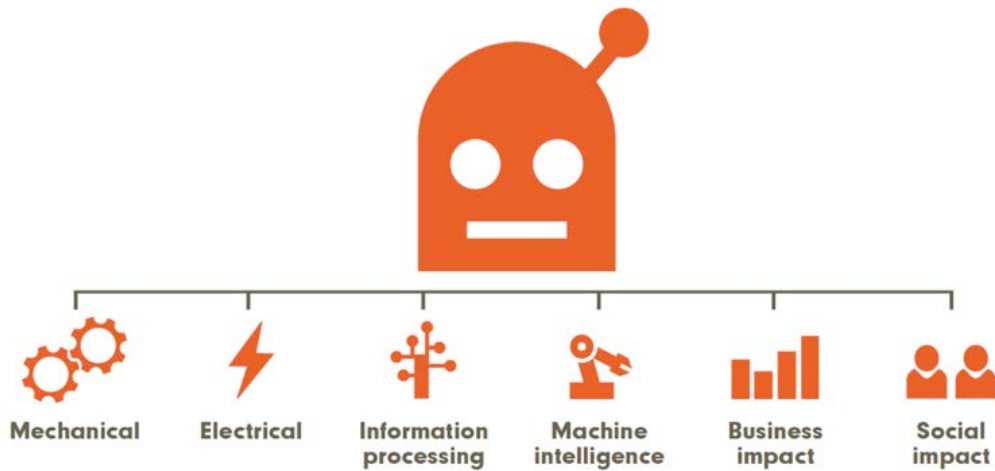


Figure 3: Six angles of quality for AI and robotics

As previously stated, we need to apply both existing and new quality characteristics for testing of AI and robotics. Therefore, in the table below we have given an overview of the main quality characteristics from the ISO25010 standard (both product quality and quality in use), extended with our new quality characteristics for AI and robotics, and we indicate the six angles of quality to which they apply.

Quality Characteristic	Mechanical	Electrical	Information processing	Machine Intelligence	Business Impact	Social Impact
Functionality	x	x	x	x	x	x
Performance	x	x	x			
Compatibility	x	x	x			
Usability			x	x	x	x
Reliability	x	x	x	x	x	
Security			x	x	x	x
Maintainability	x	x	x	x	x	
Portability			x	x		
Intelligent behavior				x	x	x
Morality				x	x	x
Personality				x	x	x
Effectiveness	x	x	x	x	x	x
Efficiency			x	x	x	x
Satisfaction			x	x	x	x
Freedom from risk	x	x	x	x	x	x
Context Coverage			x	x	x	x



05 Musing on quality attributes in the AI era

Artificial Intelligence will ultimately be everywhere. In fact, it's already here, in mobile phones, across the health sector, in self-driving cars, and much more. It's just that we don't always see it. As more and more AI comes into our lives, the need for testing both OF and WITH AI is increasing. We're already starting to use basic forms of AI for testing, but we need to continue the testing evolution to achieve the efficiency needed for testing of complex IT-systems that involve robotics, IoT, etc.

A (software) system architecture must describe the system's components, their connections and their interactions, and the nature of the interactions between the system and its environment. Evaluating a system design before it is built is good engineering practice. A technique that allows the assessment of a candidate architecture before the system is built has great value. The architecture should include the factors of interest for each attribute. Factors shared by more than one attribute highlight properties of the architecture that influence multiple attribute concerns and provide the basis for trade-offs between the attributes. A mature software engineering practice would allow a designer to predict these concerns through changes to the factors found in the architecture, before the system is built.

Developing systematic ways to relate the software quality attributes of a system to the system's architecture provides a sound basis for making objective decisions about design tradeoffs and enables engineers to make reasonably accurate predictions about a system's attributes that are free from bias and hidden assumptions.

The ultimate goal is the ability to quantitatively evaluate and trade off multiple software quality attributes to arrive at a better overall system. Developers of critical systems are responsible for identifying the requirements of the application, developing software that implements the requirements, and for allocating appropriate resources (such as processors and communication networks).

It is not enough to merely satisfy functional requirements. Hence the AI systems should be architected in an evolutionary way not only to fulfill functionality, security, safety, dependability, performance, but also to take in non-functional requirements, such as intelligent behavior or personality. The main objective of this paper is to investigate the quality characteristics of software in the architecture for an AI system. To test these characteristics, one needs to investigate the characteristics as well as new test approaches and techniques. These new quality characteristics are an extension to the already existing software quality characteristics as defined in the ISO 25010 standard.

Naturally, part of structured software testing is to test the new quality characteristics that we have introduced in this paper. The choice of test approaches or test strategies is one of the most powerful factors in the success of the test effort and the accuracy of the test plans and estimates. The testing of AI will require a new skill set. Our previous paper "Testing of AI" points out why and which skillset are required for testing of AI. One should follow and document test approaches and techniques to test these qualities. We will investigate and describe how to use the existing and new quality characteristics for AI and robotics, and how to apply test design techniques, testing tools, etc., in a future paper.



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