The AHSN Network

Department of Health & Social Care

NHS

Accelerating Artificial Intelligence in health and care: results from a state of the nation survey

AUTUMN 2018

CONTENTS

FOREWORD

New technologies that harness the power of data, like artificial intelligence (AI), present huge opportunities to transform healthcare, improve the quality of people's lives, and to make the job of working within the health and care system more rewarding. We are determined to harness this potential.

While these opportunities are available to every country, the UK is well-placed to take a global advantage in this field. By virtue of our universal single-payer system, the complete longitudinal datasets the NHS holds on every citizen's health and care, and our world-leading AI and tech industries, our goal should be to bring the transformative power of AI to every corner of the NHS.

For that reason, we are delighted to introduce this 'state of the nation' report, which looks to the future of health and care and envisions what can be achieved when the vast potential of AI is unlocked. The report is based on a survey conducted by NHS England and the AHSN Network AI Initiative, and it underlines the potential for AI to contribute to improved care: 94% of the UK's AI thought-leaders cite AI as being extremely important or very important for diagnostics; 89% support this view for operational and administrative goals; and, 79% have this opinion in regard to the benefits for health promotion and preventative health. The report cites many exciting examples of pilot schemes and more developed programmes that are already delivering better healthcare for British patients.

As it stands, the NHS is primed to use AI to improve its efficiency, deliver better outcomes and prevent ill health. However, we must be realistic about the challenges. First and foremost, the public must have confidence that AI (and the health data which fuels the development of new algorithms) is being used safely, legally and ethically, and that the benefits of the partnerships between AI companies and the NHS are being shared fairly. As a consequence, realising the potential of AI in health and care requires changes to data infrastructure, organisational structures, commercial arrangements, and models of consent.

We have already made some important steps forward in this area. These include the introduction of a new national data opt-out and by the Bill, currently before Parliament, to put the National Data Guardian on a statutory footing. At the end of this report we point to, for the first time, a Code of Conduct for Digital Health Innovations and Intelligence Algorithms, which is designed to provide a national set of 'rules of engagement' for any NHS organisation entering into a partnership with an AI developer.

Inevitably, there is still more to do to seize the opportunities ahead. By working collaboratively with industry, academia, innovators and commissioners we will continuously iterate the principles and guidance contained in the Code. Together, we will work to ensure that the NHS gets the maximum possible benefits from these partnerships, both for existing use cases of AI and those that appear in the future. And, of course, these developments all take place in the context of our review of the current regulatory framework and analysis of the future needs of the health and care workforce.

A collaborative approach is important; no single partner in this endeavour has a monopoly on wisdom about what will work.

By working together we will be able to explore all potential avenues of opportunity, and risk, and to make sure that none are missed. We hope that, based on this reassurance and reflecting on the information presented in this enlightening report, you are left feeling as optimistic as we are about the ability of technology, and AI in particular, to transform health and care.

Matt Hancock

Secretary of State

Department of Health and Social Care

Lord O'Shaughnessy

Parliamentary Under Secretary of State

Department of Health and Social Care

INTRODUCTION

In recent years there have been a number of policy reports published on the potential for artificial intelligence in healthcare. In this report we are not attempting to recreate that content but rather to address some of the concerns raised and outline some of the emerging policy in this arena within the UK.

We developed a survey in collaboration with industry, academia and policy makers in an attempt to capture the reality of what technology is actually being developed within the UK health and care sector, and to understand what complexity of artificial intelligent technology is being realised. This survey went live to the nation at the start of 2018 and we have captured throughout this report the initial findings from the 131 responses.

In order to present a rich picture of the nation's ecosystem and bring to life the complex and multifaceted aspects of the industry, the report also highlights a number of case studies that set the scene for the work needed to scale up evidence-based solutions that are safe, effective and offer value going forward.

The report is split into four main sections:

1. What do we mean by AI in health and care? This section describes how AI is broadly defined and shows how, as AI evolves, it is becoming an increasingly complex landscape.
2. Results of the 2018 national survey of AI technology in health and care, and the defining characteristics of the first 131 solutions that were submitted.
3. Real world analysis of feasibility and implementation based on evidence from over 100 leaders and pioneers working in the field. This highlights the top barriers and enablers for catalysing an ethical, evidence-based market for AI-enabled solutions in health and care, and defines the issues that will set the agenda for the sector over the coming months and years.
4. A summary of proposed next steps. This includes the key themes for policy makers to develop a 'Code of Conduct' for an AI-enabled digital health and care market going forward, and the regulatory challenges that need to be addressed.

EXECUTIVE SUMMARY

Over the last few years numerous reports have been written about the opportunities and benefits artificial intelligence (AI) can offer for healthcare. These have ranged from the Reform report[1] illustrating the areas where AI could help the NHS become more efficient to the report by Future Advocacy[2] which reviews the ethical, social and political implications of AI in health and medical research.

While acknowledging these reports exist, we felt there was a need to understand what is actually happening on the ground and what is being developed. We also wanted to ask people within the health and care system who use artificial intelligence (which is summarily defined as a series of advanced technologies that enable machines to effectively carry out complex tasks that would require intelligence if completed by a human) what stage of deployment their work has reached.

The survey

The survey was developed with the input of the AHSN Network AI Initiative Core Advisory Group (individual members are listed in Acknowledgements) and sent out nationally via the AHSN Network and a number of AI and innovation networks including the AI community run by NHS Horizons. The survey results are self-reported and were compiled and analysed by a team at Kent Surrey Sussex Academic Health Science Network, supported by Health Education England Kent Surrey Sussex. This report is a collaboration between the AHSN Network, NHS England, NHS Digital and the Department for Health and Social Care.

Survey respondents included CEOs, senior managers and others working across the AI ecosystem in England. They represented both large organisations with 250 staff or more (32%) as well as micro organisations with less than 10 staff (28%) across private, public and charitable sectors as well as academia.

The results shows that AI has huge potential to transform whole the health and care system. Unlocking value in data/analytics was the top category (75%) addressed by solutions submitted for the survey, followed by condition recognition (60%) and organisational processes (50%).

Whilst impressive, the survey shows that many solutions are primarily in their infancy and have a long way to go before the true potential of AI for health and care can be realised. As one survey respondent commented 'AI is still evolving... it won't solve all the problems healthcare faces at the moment' and we must avoid the trap of 'overhyping potential, unrealistic claims and poorly thought out products.'

The survey revealed that realising the truly huge potential of AI to transform health and care services will require overcoming several key barriers, and working together across the AI ecosystem to:

- ground AI solutions in real 'problems' as expressed by the users of the health system;
- engage healthcare professionals and create an ethical framework to enhance and preserve trust and transparency;
- build capacity and capability;
- ensure the regulatory framework is fit for purpose;
- explore innovative new funding and commercial models; and
- focus on building a sound data infrastructure and high quality data sets, underpinned by interoperability and sharing standards.

Furthermore, momentum is starting to build for unlocking open innovation through establishing open data ecosystems across health and care.

Showcase

To show what can be achieved as AI is embraced across health and care, this report showcases some of the emerging examples of more complex AI methodologies currently being used and which hold significant potential to deliver impact at scale in NHS, social care and, importantly, in preventative health. As the complexity and capabilities of these projects increase, it is vital that the policy and organisational contexts, processes and regulation evolve to keep pace.

Code of conduct

To address these challenges, a number of workstreams have already been initiated across the UK health and care sector. These include the Topol review on workforce; a set of principles and guidelines summarised in a Code of Conduct for digital health innovations incorporating intelligent algorithms; and a number of initiatives to understand and unlock the value of data to provide maximum benefit to citizens and UK plc.

'Focus on building a sound data infrastructure and high quality data sets, underpinned by interoperability and sharing standards'

[1]Harwich, S. and Laycock, K. (2018). Thinking on its own: AI in the NHS. Reform. Available at: http://www.reform.uk/wp-content/uploads/2018/01/AI-in-Healthcare-report_.pdf.

[2]Fenech, Matthew, Strukelj, Nika and Olly Buston (2018). Future Advocacy and Wellcome Trust. 'Ethical, social and political challenges of artificial intelligence in health'. Available at: https://wellcome.ac.uk/sites/default/files/ai-in-health-ethical-social-political-challenges.pdf.

WHAT DO WE MEAN BY AI IN HEALTH AND CARE?

AI describes a set of advanced technologies that enable machines to carry out highly complex tasks effectively – tasks that would require intelligence if a person were to perform them.

There is no single, universally agreed definition of AI, nor indeed of 'intelligence'. Broadly speaking, intelligence can be defined as 'problem-solving', and 'an intelligent system' as one which takes the best possible action in a given situation.

The 'A' of AI generally refers to one of the following:

- **Artificial** (Intelligence) – makes it possible for 'machines' to learn from new experiences, adjust outputs and perform human-like tasks. It can be thought of as the simulation of human intelligence and could include voice and visual recognition systems.
- **Augmented** (Intelligence) - outputs that complement human intelligence, emphasising AI's supplementary role. Examples include tools that support radiologists in reviewing large numbers of scans, or that support financial advisors to better understand clients' current and potential future financial needs.
- **Ambient** (Intelligence) - the application of several technologies (including Artificial or Augmented Intelligence, but also sensor networks, user interfaces, home automation systems, etc) to create proactive 'smart' environments.

AI is generally classified into the following types:

- **Narrow AI** typically focuses on a narrow task, or works within a narrow set of parameters such as reading radiology scans, or optimising hospital workflows;
- **Strong or general AI** is a hypothetical concept which can refer to an AI that can learn to perform several different types of task, or to a sentient machine with consciousness and mind.

Thanks to advances in AI and Big Data research, narrow AI technologies have the potential for wide application in health and social care, bringing benefits to individuals, families, communities, and society as a whole. While early examples from our survey illustrate that much of this work is at an early stage, current technologies support a more general shift away from reactive care models to models that are more personalised and proactive.

But this is not without its challenges in health and social care and more widely – ensuring these technologies are fit for purpose, ensuring outputs are transparent and explainable, and ensuring people are trained in the use of these new technologies.

Complexity scale in AI

There is a significant amount of effort being devoted in the research space to map machine learning and AI, but it has been challenging to categorise them according to their 'intelligence'. Thus far, attempts at categorisation have been limited to looking at their generic ability to solve new problems, and at the speed with which they adapt to these problems.

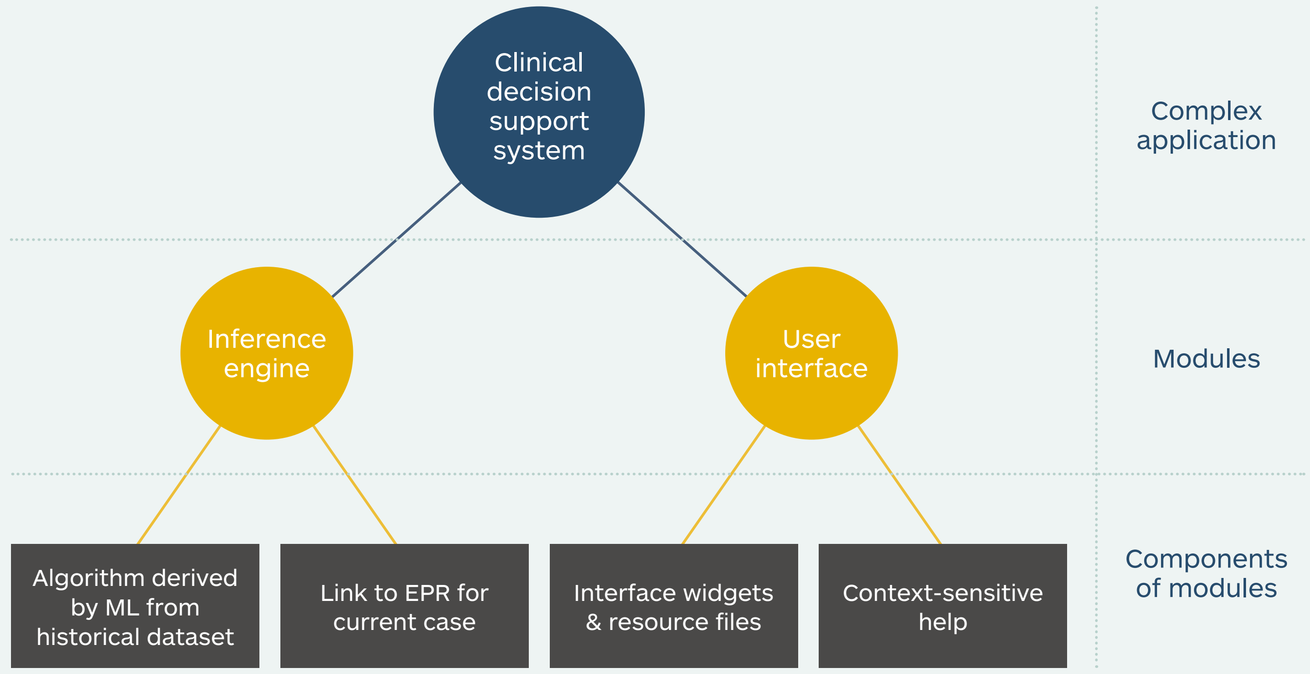
A more straightforward way of understanding AI is to classify AI systems by their complexity. A 'Complexity Scale for AI' can be seen in the boxed section and compared with methods and case studies revealed in our survey.

A glossary of AI-related terms used within the Complexity Scale for AI can be found at Appendix 3 on page 50.

High complexity AI applications	**Middle complexity** AI modules or components	**Low complexity** AI reasoning methods
• Autonomous vehicle • Machine translation tool • Care companion robot • Chat bot • Surgical or pharmacy robot • Mammogram interpretation system • ECG interpreter • Diagnostic decision support system • Speech driven radiology report tool with SNOMED coded output	• Natural language to SNOMED code processing module • Image processing module • Text to speech module • Knowledge based or expert system module • Signal processing & classification module • Recommender module	• Deep learning module • Ensemble methods (e.g. Random Forest Models) • Neural networks • Object segmentation algorithm • Signal processing algorithm / filter • Generative adversarial networks • Time series analysis • Graphical models • Decision trees, rule induction e.g. CART • Clustering algorithm • Classification algorithm • Regression – linear, multiple, logistic • Inference engine for rules or frames • Argumentation, temporal or spatial reasoner e.g. QSIM • Text generator using DCGs • Case-based reasoning algorithm

Devised by Jeremy Wyatt, Director and Professor of Digital Healthcare, Wessex Institute of Health Research, Clinical Advisor on New Technologies, Royal College of Physicians, Fellow of American College of Medical Informatics & UK Faculty of Clinical Informatics)

Example of how simple components form modules which then form a complex AI application



Devised by Jeremy Wyatt, Director and Professor of Digital Healthcare, Wessex Institute of Health Research, Clinical Advisor on New Technologies, Royal College of Physicians, Fellow of American College of Medical Informatics & UK Faculty of Clinical Informatics)

The lowest level of the complexity scale comprises single specific reasoning methods (e.g. neural networks, pattern recognition algorithms). When these reasoning methods are combined with other functions (e.g. a database or user interface), we get 'modules', which sit at the next level of complexity and are the problem-solving components of a system. At the top level of complexity, we have applications or packaged systems comprising two or more of these modules (e.g. an autonomous robot).

The above provides an example of a complex AI application.

Algorithms in healthcare are not a new phenomenon and have been deployed for decades. What we have attempted to show here is how technology utilising intelligence within its algorithms can fall under many different subsections and with varying degrees of complexity. We encourage developers and industry to be transparent as to what complexity or methodology they are utilising when they state that they use 'AI'. We would also like to encourage those investing in these technologies to understand what type of AI is being developed, how complex it is, and indeed question what the 'A' in AI truly represents.

RESULTS OF THE NATIONAL SURVEY ABOUT AI TECHNOLOGIES IN HEALTH AND CARE

This section presents key findings from 131 self-reported entries in response to our survey that began in Spring 2018. The information has been used to create an online map that illustrates what sort of problems are being solved currently, who some of the key players are, and how we can group or categorise current projects to help our understanding of the current reality of AI in health and care.

Complexity of current projects

As part of the survey we asked respondents to list some of the AI methods employed in their solutions. This enabled them to be categorised in a way that shows how solutions in the AI space vary greatly in terms of complexity.

By mapping some of the methods employed by survey respondents against Professor Jeremy Wyatt's complexity scale (see previous section), it can be seen that many of the current solutions are using 'lowest complexity' advanced statistical techniques rather than more complex AI applications. Classification and neural network machine learning methods were by far the most popular techniques, used by 60% and 51% of solutions, respectively.

At the highest end of the complexity scale, 8% of solutions employed machine translation methods. 20% of solutions indicated they used 'other' AI methods, including a range of chat bot solutions (considered 'highest complexity' solutions).

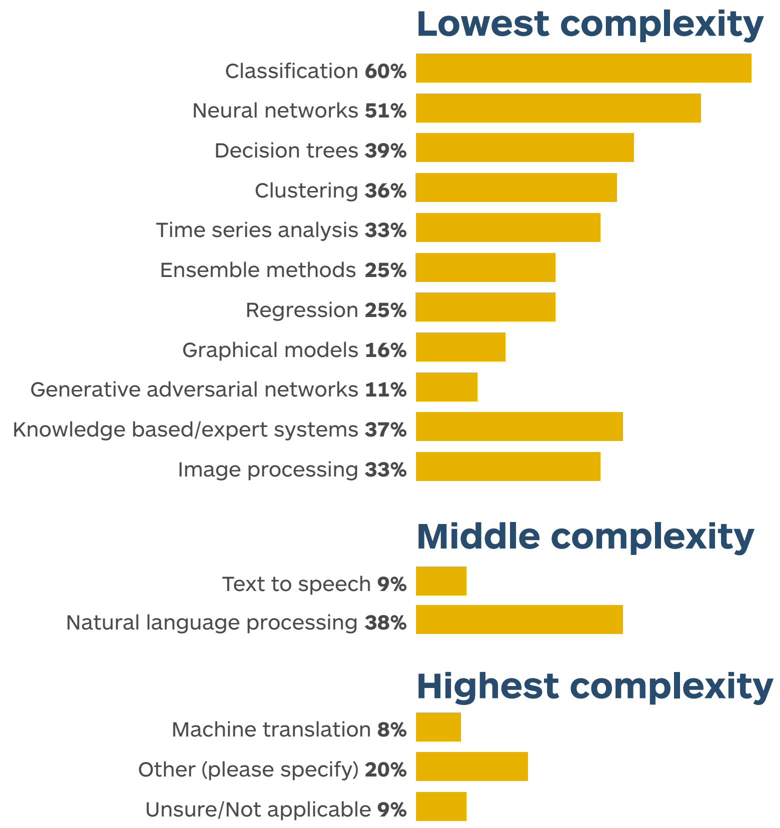
Case studies delivering value now

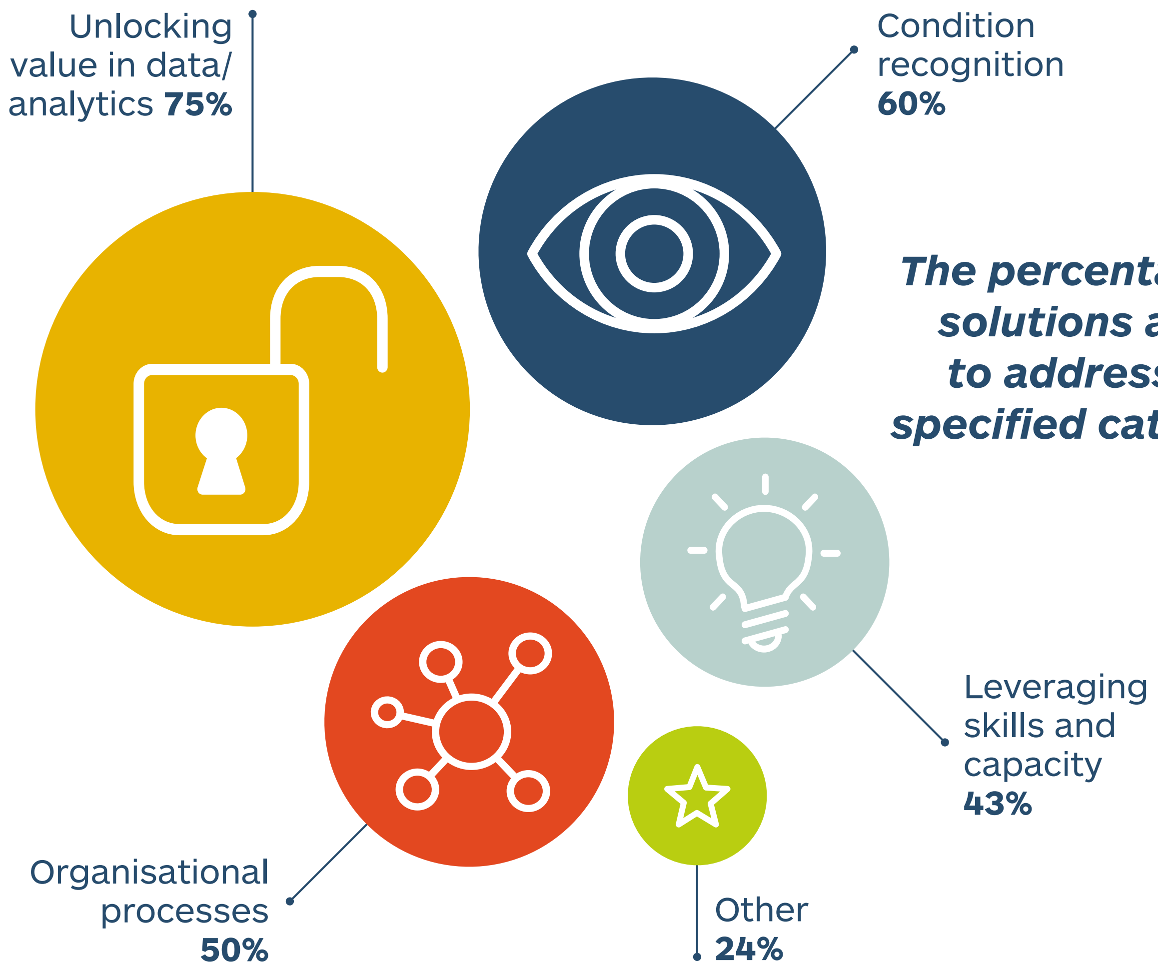
A range of case studies identified through the survey at various stages of maturity (from those at research stage through to examples with regulatory approval and/or publicly available) are listed in Appendix 1.

These solutions are delivering value to the health and care sector in the following areas:

- Unlocking value in data/ analytics
- Leveraging skills and capacity
- Organisational processes
- Condition recognition.

The percentage of solutions reporting using a method of AI





The percentage of solutions aiming to address each specified category

Key areas where AI can deliver impact

We wanted greater insight into what types of problems are being addressed across the range of solutions. Survey respondents were able to select multiple entries from a list of four categories. Results can be seen below.

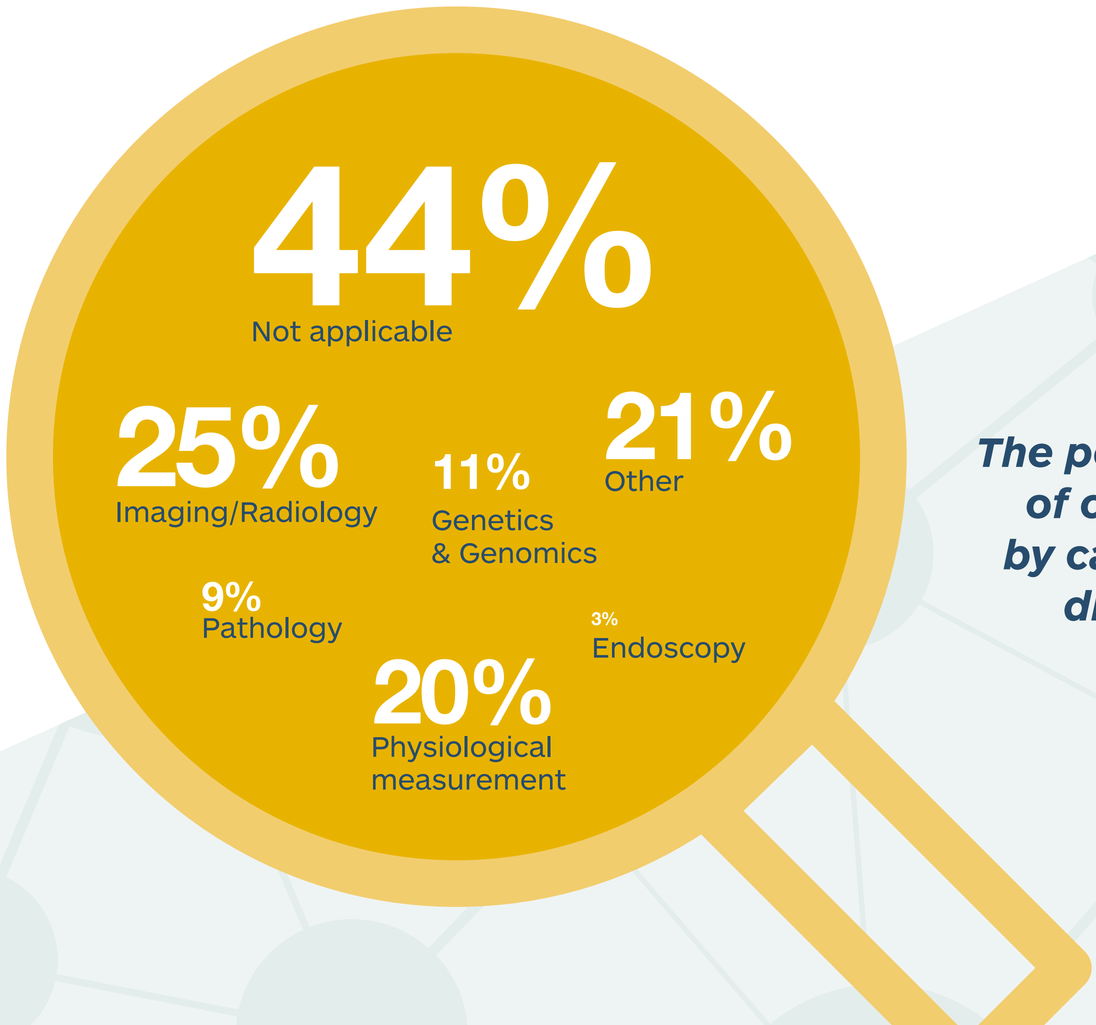
Unlocking value in data/analytics was the top category (75%) addressed by solutions submitted for the survey, followed by condition recognition (60%). Organisational processes were addressed by half of the solutions, reflecting the increasing use of AI to automate routine clinical, managerial and back office tasks (e.g. document management, paperwork and scheduling).

Diagnostics in focus

With wide consensus that diagnostics presents some of the strongest early AI use cases, we chose to make it a special focus for this first AI map and survey.

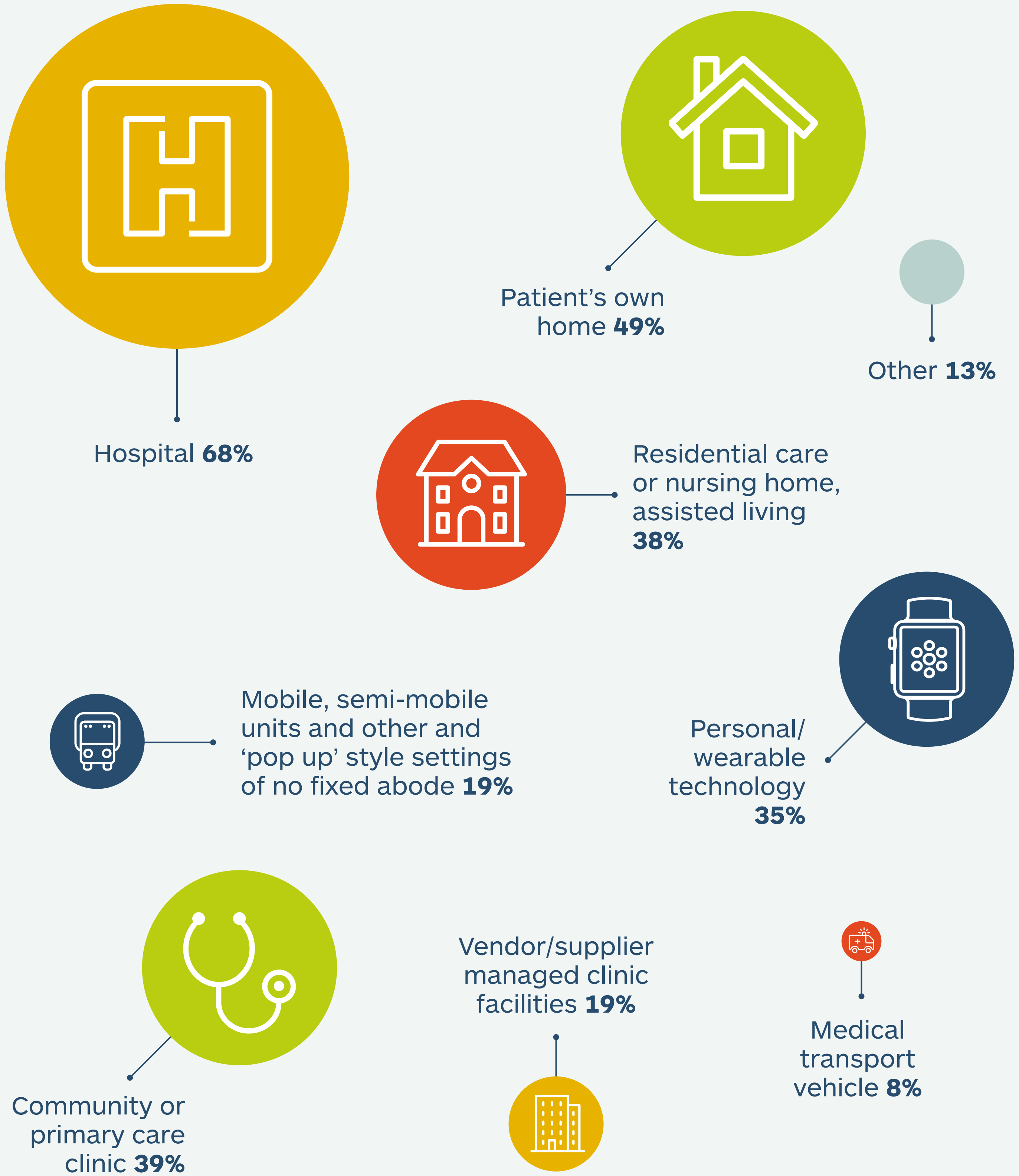
Across the range of diagnostics categories, AI is already offering opportunities to free up workforce capacity and to dramatically increase diagnostic accuracy. Taking advantage of the convergence across diagnostics, personalised medicine and data science, some organisations on the map are already seeking to mine big data sets to enable identification of individuals at the earliest stage of disease, when interventions have a higher likelihood of success.

Overall, 66% of the initial solutions featured on our map indicated they contained one or more categories of diagnostics. As can be seen below, many early solutions are in diagnostic imaging/ radiology (25%), where digital imaging has been in widespread use for a number of years. This compares to far fewer solutions listed in pathology (9%) and endoscopy (3%), where the digital and AI solutions are only recently starting to emerge.

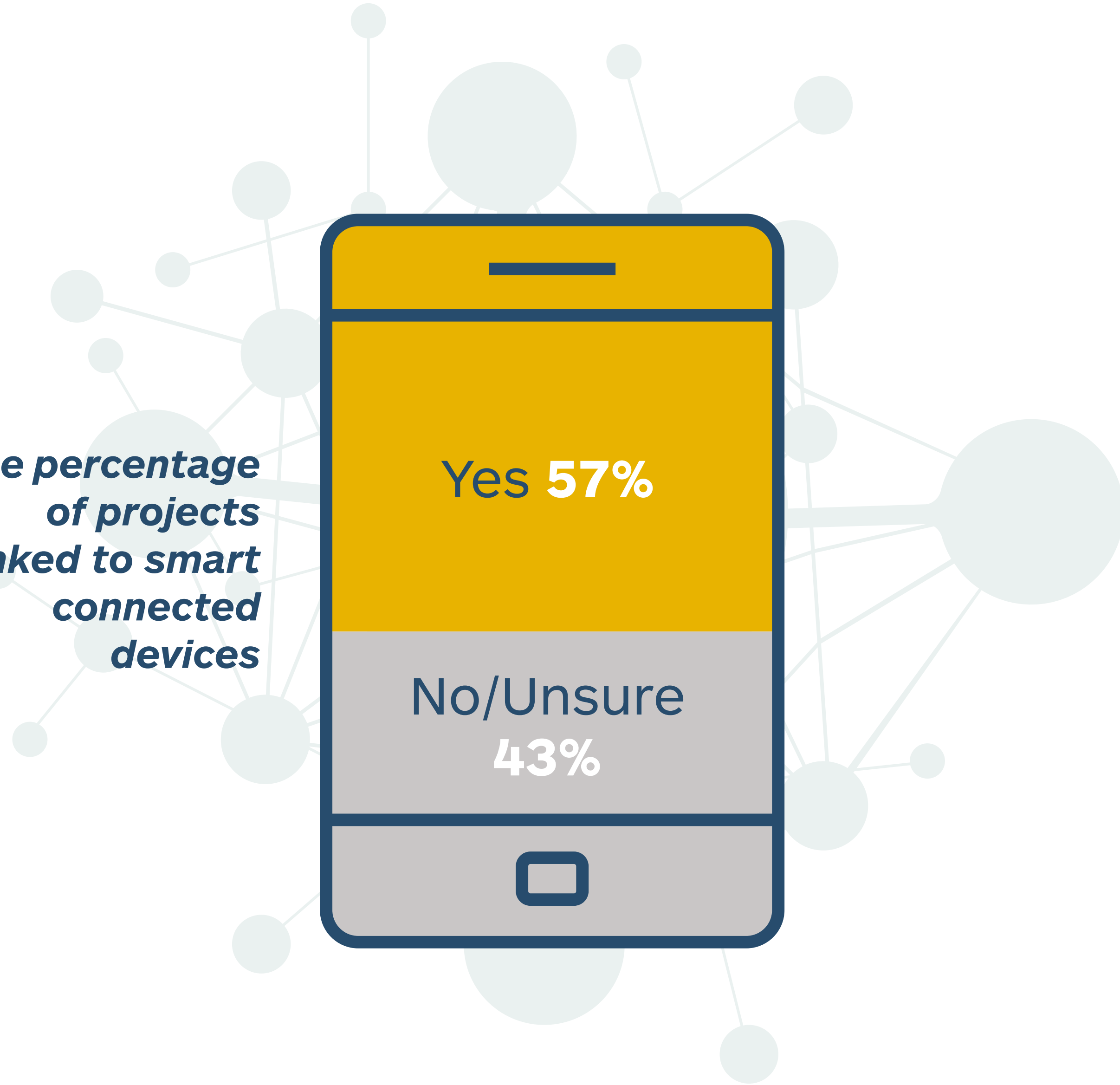


The percentage of companies by category of diagnostics

The percentage of solutions, which indicated a point of care, delivering in each point of care site



The percentage of projects linked to smart connected devices



Point of care

Another way that AI is enabling new models of care is by using remote diagnostic and monitoring capabilities to change where and how care is delivered. We asked solutions to indicate the points of care where they deliver services (multiple selections were possible).

Excluding those entries that did not indicate a point of care, the majority of solutions reported delivering services in hospitals (68%), followed by a patient's own home. Care settings such as medical transport vehicles (8%), vendor/supplier managed settings (19%) and mobile, semi-mobile units (19%), were selected by the least number of respondents.

Already, 57% of solutions within the survey say they able to link to smart connected devices (e.g. Internet of Things). With super-fast 5G broadband networks being tested this year, it is likely that the number of IoT-enabled solutions offered in non-acute points of care will increase over the coming years as 5G networks are rolled out more widely.

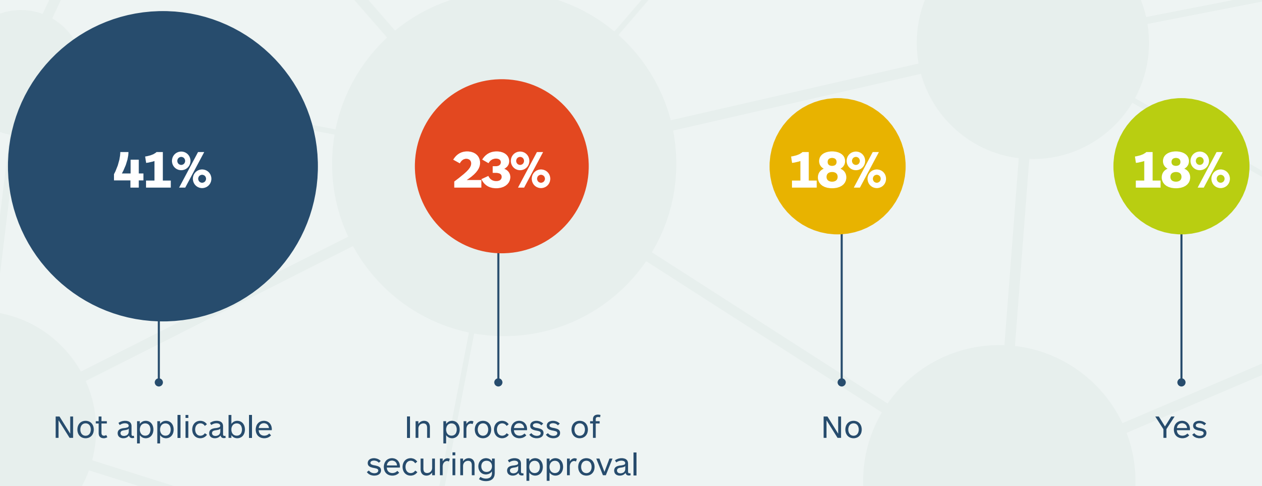
Regulation

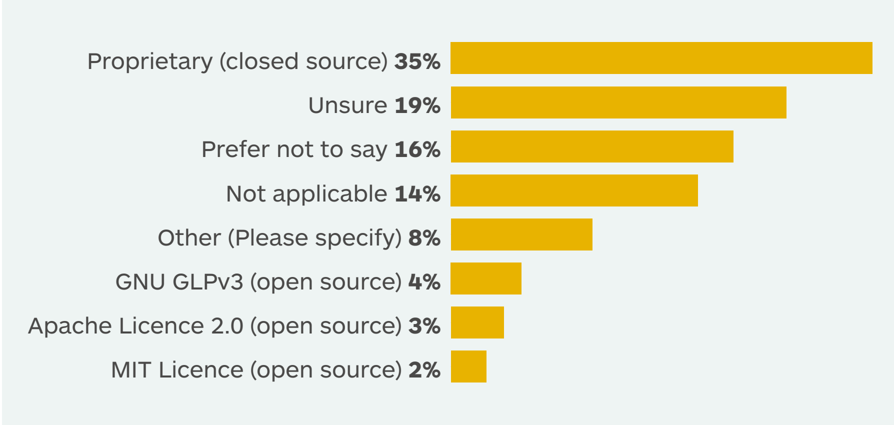
Our survey aimed to capture a full range of AI activity across the health and care ecosystem, ranging from ongoing research projects to fully scaled commercial products and services. With new solutions coming to market regularly, it is important for buyers (including commissioners and consumers) and users of AI to have mechanisms for distinguishing which solutions have the appropriate evidence base and are ready for 'at scale' adoption.

In the UK, medical devices must demonstrate that they meet the requirements set out in the Medical Devices Directive by carrying out a conformity assessment. The assessment route depends on the classification of the device. Devices meeting the requirements can place a CE mark (or logo) on their product to show that the medical device has met the requirements as set out in the conformity assessment. The CE marking also means that the product can be freely marketed anywhere in the EU. In the United States, the Food and Drug Administration (FDA) provides medical device approval.

When we asked our respondents about regulatory status, only 18% of solutions indicated they had secured approval in the UK/EU or abroad. A further 23% indicated they were in the process of securing approval.

The percentage of projects with regulatory approval





The percentage of solutions according to type of licence the computational product has

Licensing

Currently, 35% of solutions in the survey have been developed using proprietary (closed source) software, distributed under licensing agreement to named users who are given authorisation to modify, copy and republish applications. The source code for this software is not shared publicly for anyone to look at or modify. Proprietary software developers often pride themselves on product 'usability' and providing a high level of ongoing support for maintenance, security, content updates and training.

In contrast, only 9% of respondents report using one of the following three open source licences – GNU GLPv3, Apache Licence 2.0 and MIT Licence. Open platforms are vendor and technology neutral and are based on open standards, meaning that any application built on an open platform will operate on an open platform.

Proponents of open standards, such as the Apperta Foundation, a not-for-profit community interest company supported by NHS England and NHS Digital, maintain that liberating both data and applications and making them portable and interoperable eliminates lock-in, facilitates innovation and competition, and forces vendors to compete on quality, value and service. A downside can include the significant capacity and capability required to run open platform ecosystems.

A further 19% are unsure what licence their computational product uses altogether, and this needs to be explored further to understand the reasons for this.

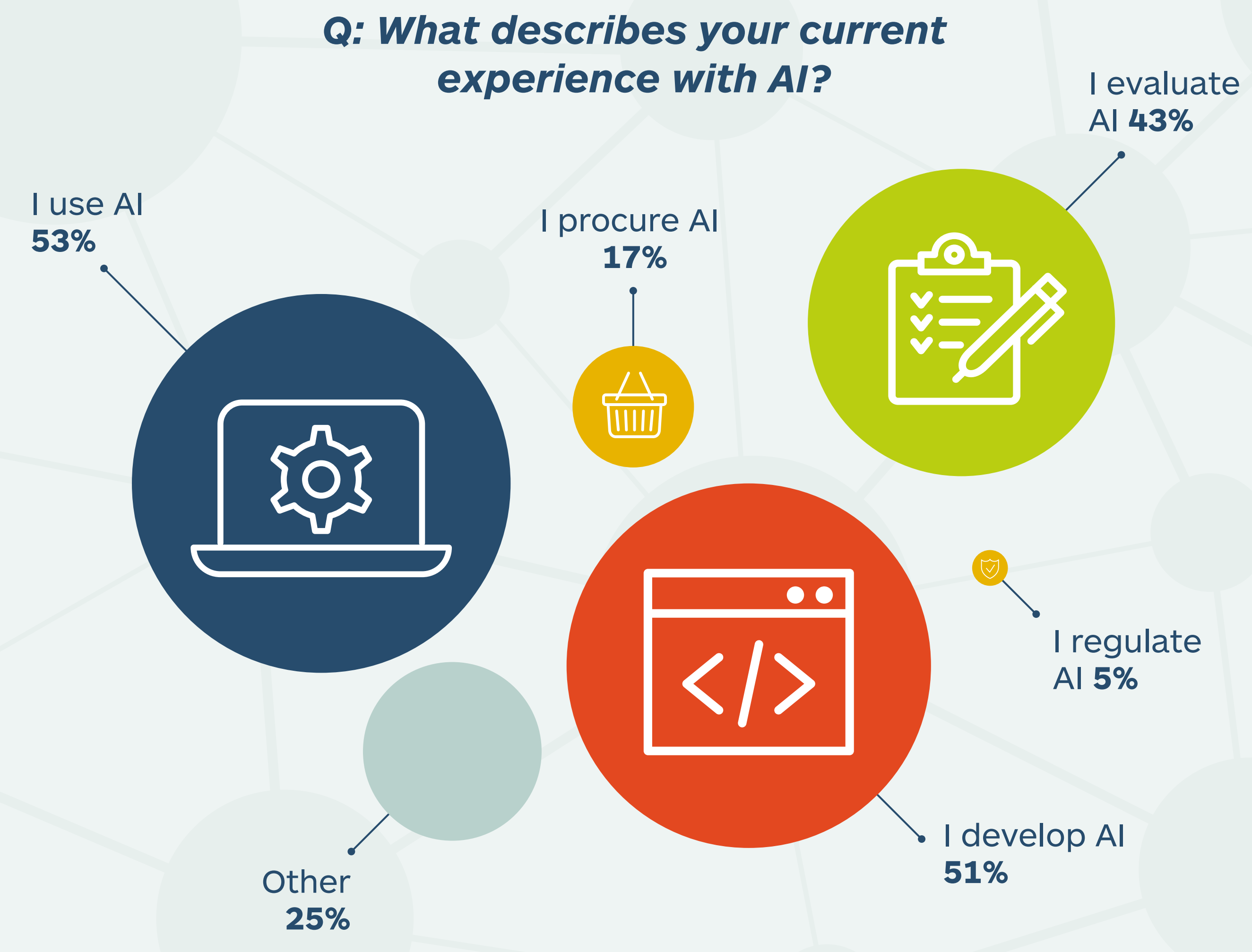
REAL WORLD ANALYSIS ON FEASIBILITY AND IMPLEMENTATION

In order to inform government policy and the AHSN Network AI Initiative offer, we conducted a survey of 106 thought leaders and AI pioneers during May and June 2018. In this section we outline survey results, highlighting top barriers and enablers for catalysing an ethical, evidence-based market for AI solutions in health and care.

Who responded?

Survey respondents included CEOs (42%), senior managers (15%) and others working across the AI ecosystem in England. They represented both large organisations with 250 staff or more (32%), as well as micro organisations with less than 10 staff (38%) across private, public and charitable sectors, as well as academia.

Respondents cite a broad range of experience with AI, with many indicating that they wear multiple hats when dealing with AI.



Game-changing use cases

The best AI-enabled solutions always solve a valuable problem or 'use case', as expressed by users - citizens, carers and professionals. Working with users to understand their needs and then working with them to prototype and test solutions iteratively is key to refining the product's value proposition and ensuring successful uptake and adoption at scale.

We asked respondents to identify the areas where the strongest early use cases are.

Overall, the views were clear that the main game-changing use cases for AI will be in three key areas in the immediate period:

- Diagnostics
- Non-clinical (operational and administrative efficiency)
- Health promotion and preventative health.

Development in drug discovery and medical research will also be hugely aided by AI.

Respondent views ranged from AI being 'ubiquitous', 'pervasive' and 'high impact' that will 'replace front line tasks' to rather less optimistic predictions. Many see AI as a tool to help doctors and all healthcare professionals become more efficient and deliver a higher standard of care at less cost to benefit patients. Most see AI having a key role in helping to make decisions across the board and in better planning for scarce resources.

	Health promotion and preventative health	Treatments and interventions (including surgery)	Diagnostics (accurate and early detection)	Non-clinical (e.g. save time with administration)	Keeping up to date with medical research
Extremely important	47%	40%	80%	66%	35%
Very important	31%	28%	14%	23%	30%
Quite important	16%	26%	5%	9%	21%
Somewhat important	5%	5%	1%	2%	10%
Not at all important	1%	2%	0%	0%	4%

'80% of all dermatology diagnoses will be done using AI within 3 years - it will be better than dermatologists at diagnosing'.

Respondent prediction

The top three use cases are explored in more depth below.

Diagnostics (accurate and early detection) was cited overwhelmingly as a strong early AI use case, with 94% of respondents citing it as either extremely important or very important. Some predictions from survey respondents include:

- *'Huge impact in radiology for assisted reporting and screening'*
- *'Increased use in radiology and other imaging applications, particularly in prioritisation/ triage of scans to ensure these are brought to human attention first'*
- *'Translation into routine practice, widespread use of clinical decision support tools for complex diagnostics, genomics and lifestyle advice'*
- *'80% of all dermatology diagnoses will be done using AI within 3 years - it will be better than dermatologists at diagnosing'.*

Use cases for **non-clinical applications, for instance saving time with administration,** were seen as extremely important or very important by 89% of respondents. AI will increasingly be used in the automation of routine clinical and managerial tasks and for back office processes (e.g. document management, paperwork and scheduling). Machine learning will increasingly be used to process images and texts.

A reduction in administrative staff overheads is expected, and a positive view on how AI will impact clinicians also emerged.

- *'AI and clinicians will work more closely as one team'*
- *'Supervised machine learning - Clinicians remain in control'.*

Some predictions include:

- *'Significant improvements in workflow management and data analysis coupled with the emergence of intelligent clinical decision support systems'*
- *'AI will become a standard part of devices and image management systems'.*

Health promotion and preventative health was cited as extremely important or very important by 78% of respondents. Overall, respondents expect AI to be used in a more predictive way, facilitating the shift from reactive care to a more preventative health model in which people are more empowered to take care of their own health.

Comments from respondents include:

- *'Move towards using AI as a tool for early prevention and diagnosis using large population level datasets i.e. identifying individual risk. Use of AI in demand management and predictive modelling'*
- *'Better allocation of resources by earlier detection of patterns and thus disease, with better targeted preventative strategies as a result'*
- *'AI will take a large amount of the early identification of disease, allowing clinicians to focus on the complicated cases'*
- *'AI will be instrumental in detecting minuscule changes in individual's records (data), making it possible to detect and catch problems even before they actually form. It will enable prevention in the most literate sense of the word'.*

For an excellent overview of AI use cases, refer to Future Advocacy's Ethical, Social and Political Challenges of Artificial Intelligence in Health and Care (April 2018)[3], a report produced with the Wellcome Trust.

[3] *Ibid.*

'Better allocation of resources by earlier detection of patterns and thus disease, with better targeted preventative strategies as a result'

Respondent feedback

Overall AI enablers

To gauge what factors might support the development of AI in health and care, we asked respondents to consider the extent to which the following actions or policies were important in realising the potential of AI in health and care.

The numbers below highlight actions or policies that respondents viewed as very or extremely important:

- **92%** Engagement of healthcare professionals
- **88%** Ethical framework to build/preserve trust and transparency
- **87%** Capacity and capability to deliver scope
- **82%** Clarity around ownership of data
- **81%** Education of healthcare professionals

AI enablers specific to diagnostics

We then looked at the relative importance of factors impacting diagnostics, building on potential actions suggested by our AHSN Network AI Initiative core advisory group members.

The percentages below show the key factors that pioneers believe are very or extremely important to address in order to realise the potential of AI in health and care:

- **93%** Data sharing for medical imaging for AI training
- **93%** Support the spread of proven innovations
- **85%** Consistent labelling methods for imaging data
- **82%** Reviewing governance models (eg ST 11-7) in light of machine learning algorithms
- **78%** Work with commissioners to help them understand how to buy AI-enabled products and services

Trust, privacy and ethics

According to survey respondents, the top two factors enabling the realisation of AI in health and care are 'engagement of healthcare professionals' and establishing an 'ethical framework to build/ preserve trust and transparency'.

Overall, respondents agreed with the need for a clear governance structure to guide decisions and build trust. This needs to be underpinned by a clear ethical framework to address such issues as transparency in algorithm development.

Comments from the respondents include:

- *'There is a need for widespread understanding of augmented intelligence, predictive analytics, deep learning and machine learning'*
- *'The speed at which AI will have an impact on healthcare will depend very much on the public's (and therefore the government's) trust in AI and the company using patient data to develop AI. This will not impact all AI products but a significant proportion'*
- *'There has to be first an enabling framework within the NHS. This would include ethical considerations, the right for human interpretation of the AI algorithms'*
- *'We need transparency of algorithm development'*
- *'[the potential of AI] is based on the governance structure developed and ability to forge trust'.*

Educating healthcare professionals and the public on the potential of AI in a balanced way was also raised as a key issue by survey respondents. This is central to achieving and maintaining trust in an environment where there is much negative media coverage on the risks of AI and its potential impact on workforce. A narrative around data sharing is needed. There is also the need to engage the public actively in order to help define the problems that need solving and co-develop solutions enabled by AI.

	Engagement of healthcare professionals	Ethical framework to build/preserve trust and transparency
Extremely important	58%	61%
Very important	33%	26%
Quite important	8%	9%
Somewhat important	0%	3%
Not at all important	1%	0%

	Education of healthcare professionals	Education of public
Extremely important	50%	37%
Very important	31%	28%
Quite important	17%	25%
Somewhat important	2%	10%
Not at all important	0%	0%

Key comments include:

- *'We need a narrative around data sharing and trust …'*
- *'We need public education and enabling regulatory frameworks'*
- *'It's not enough to 'educate' the public- we need active participation of patients and other interested parties at all stages of the development process'*
- *'Much more needs to be done to educate healthcare professionals, listen to/ understand their concerns, and get their buy in. At the moment the conversation is too polarised between naysayers who say, "AI will never change healthcare significantly" and techno-utopians who say, "AI will replace all doctors and nurses" - the reality is of course much more nuanced than that.'*

Predictions for the future include:

- *'Greater public support for AI due to better understanding [of] how AI works'*
- *'There will be a new cohort of healthcare professionals that will be educated to think how to empower their human abilities with AI driven tools'.*

'We need a narrative around data sharing and trust …'

Respondent feedback

Workforce knowledge of AI

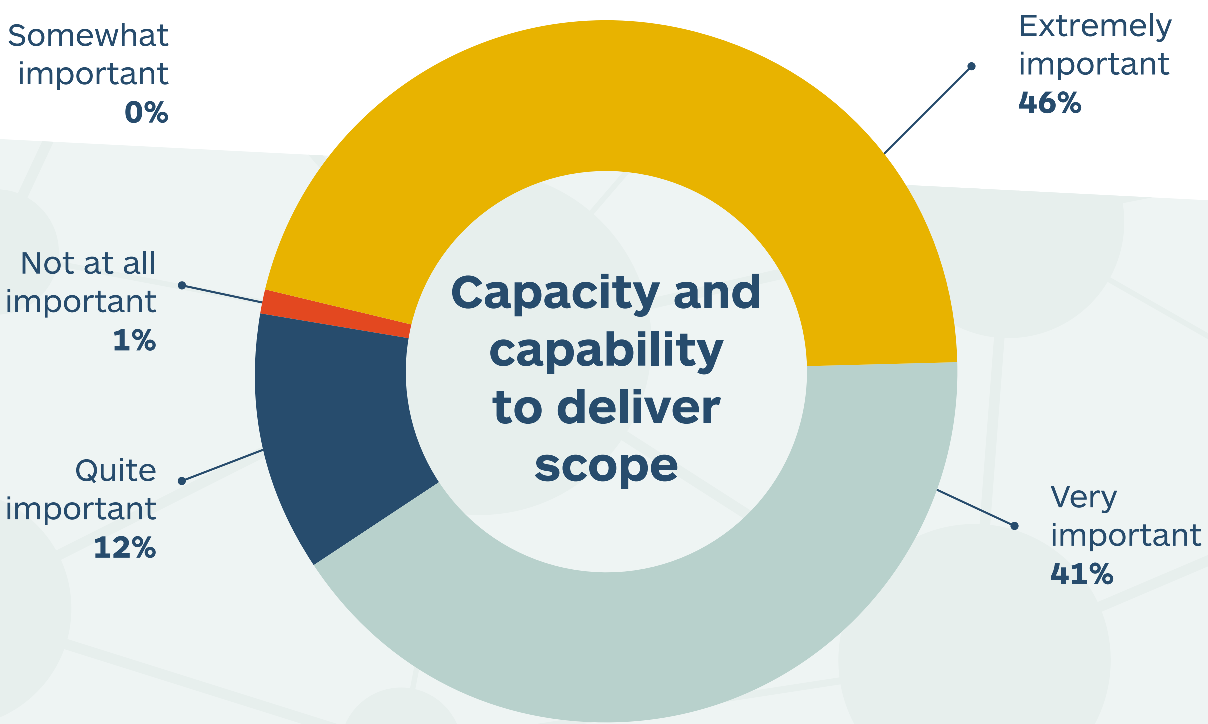
Workforce opportunities will be addressed in detail in the Topol Review (being led by Dr Eric Topol and facilitated by Health Education England), but it is important to note that at a high level, education has come out as a clear enabler.

87% of respondents indicated that building capacity and capability is extremely important or very important to achieving AI's potential. This includes basic education on AI and its potential applications for senior managers and directors in clinical, management, commercial and procurement roles. Training in areas such as user-driven design, change management, ethics and having difficult conversations in the new era of AI will also be essential, along with training in technical and legal aspects of AI.

Above all, securing clinical understanding, engagement and buy-in to the co-design and use of AI will be important to leverage the potential of the technology. This will not only assuage clinicians' fears and concerns, but will ensure that the AI algorithms developed augment (rather than replace) and increase the accuracy of human clinical decision making. Helping senior decision-makers to understand and have realistic expectations of what AI has to offer will also be important.

Key points to consider from our survey participants include:

- *'Ability for enough people to understand the back end of AI, and even perhaps learn the coding within hospitals to help internal management'*
- *'We need to understand and design the human computer interaction and how algorithms are used in practice'*
- *'Understanding financial and clinical pathways in more detail will be important…'*
- *'Helping to build interdisciplinary teams so that clinicians with good ideas can have these realised by people with computer programming skills'*
- *'Having highly skilled data scientists involved is crucial'.*



Evidence of effectiveness and regulation

Linking strongly with the theme of trust, the requirement for evidence of effectiveness of the digital health innovations and intelligent clinical decision support (algorithms) was a topic that ran throughout respondents' comments.

A number of respondents called for the ability to explain the algorithm and providing enough information to allow regulators to independently replicate results on a similar set of data, ensuring algorithms are safe and unbiased. Representative comments include:

- *'Many AI-based tools will struggle to get used through lack of evidence and/or clinical conservative behaviour'*
- *'Clinical support should be gained by discussion of the scientific case and justifying the technology. Just offering an algorithm lacks scientific credibility'.*

78% of respondents felt that regulation was extremely important or very important in realising the potential of AI in health and care. Gaps in regulating AI-enabled products and services, and uncertainty about the roles of the various regulators and when a product, service or algorithm should be subject to regulation were also strong themes. There is a clear need for a new regulatory framework to keep up with advances in AI.

Comments included:

- *'Legacy regulations will limit widespread adoption of diagnostics and health prevention applications'*
- *'[Government should] address barrier of regulation and the ability to rapidly iterate, prototype, and validate prospectiveiy'*
- *'Regulation needs to be light touch, to allow patient confidentiality but at the same time allowing the industry to flourish so we can achieve efficiencies in the fast time possible'*
- *'Regulation is important, but it would be better to find a global solution rather than country by country. Particularly concerned if the UK decides to go its own way post-Brexit, as the NHS market isn't large enough to be worth separate certification beyond FDA [United States] & CE [EU]'.*

Regulation of AI

Extremely important	44%
Very important	34%
Quite important	17%
Somewhat important	5%
Not at all important	0%

Funding and commercial models

Despite the financial challenges experienced in the NHS, 'funding and budget restraints' featured only tenth on the list of thirteen factors affecting the potential of AI in health and care, with 68% of respondents indicating that funding was extremely important or very important. Featuring even lower on the overall list of key factors were 'NHS internal market and procurement' and 'lack of clarity over appropriate business models for AI development and deployment', which came in at 12th and 13th (last) on the list respectively.

This result could be reflective of the early stage of the development of the AI market in health and care. In contrast, in diagnostics, where the early AI use cases are strongest and where we are already starting to see products come to market, 92% of respondents said they believed 'supporting the spread of proven innovations' is extremely important or very important to realising the potential of AI in diagnostics.

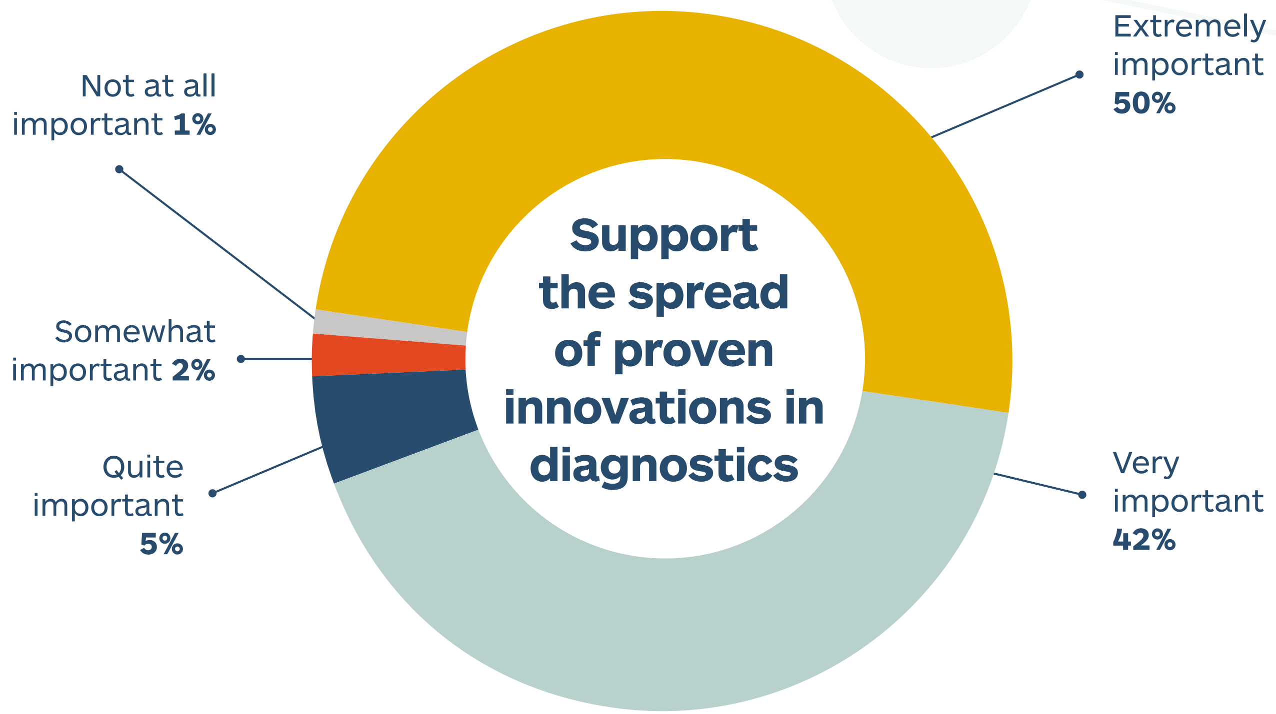
	Funding/budget restraints	Lack of clarity over appropriate business models for AI development and deployment	NHS internal market and procurement
Extremely important	45%	34%	29%
Very important	23%	25%	34%
Quite important	27%	33%	21%
Somewhat important	4%	8%	13%
Not at all important	1%	0%	3%

Given AI's potential for system wide impact, with funding flows and incentives crossing organisational boundaries and hierarchies, some respondents also commented on the opportunity to reimagine commercial models in the new era of AI:

- *'Understand 'value' of public/ NHS data and how this can be sold to developers or used to generate additional income'*
- *'Evaluate cross department business models - who owns hospital-wide clinical efficiency? For example, will radiology purchase an AI product whose benefit is realised by reduced drug cost in neurology? How do those dots get joined up?'.*

'Understand 'value' of public/ NHS data and how this can be sold to developers or used to generate additional income.'

Respondent feedback



Data quality, sharing and interoperability

The importance of a sound data infrastructure with high quality data and the relevant standards on sharing and interoperability came through as key factors in realising AI's potential.

Data quality

A key concern affecting the ability of AI to deliver on its potential is that of the quality of the data itself, much of which is not digitised or in machine-readable format. 'Data readiness' (getting data ready for AI) was a key theme.

Respondents' comments include:

- *'The current datasets in healthcare are patchy, dirty and often incorrect! Garbage in garbage out. Often data are not digitised. The first action in machine learning or AI is to clean up dirty data'*
- *'We need clean labelled un-gamed datasets'*
- *'We need data compatibility through labelling and standardisation'.*

	Data sharing framework	Clarity around ownership of data	Open standards to promote data sharing and interoperability
Extremely important	56%	54%	47%
Very important	24%	28%	31%
Quite important	16%	10%	19%
Somewhat important	4%	7%	2%
Not at all important	1%	0%	1%

	Consistent labelling methods for imaging data	Data sharing for medical imaging for AI training
Extremely important	54%	69%
Very important	31%	24%
Quite important	11%	6%
Somewhat important	3%	1%
Not at all important	1%	0%

Data sharing and interoperability

Overall, the view emerged that the underlying data infrastructure is not fit for purpose for AI and requires standards to facilitate data sharing and the development of appropriate commercial models to leverage the value of public/NHS data. This is an especially pressing concern where public sector entities have entered into agreements with companies to process data. These datasets often end up in proprietary format or in difficult to access repositories. Intellectual property of algorithms developed using these proprietary data sets often rests with the companies (outside the public sector/NHS)[4].

Key points voiced by respondents were:

- *'The role of private companies and developers including ownership of and access to public and patient data and how data sharing agreements are negotiated'*
- *'The underlying IT infrastructure in the NHS is poor and not AI ready. We need a large push to standardise IT formats and data sharing'*
- *'Robust development, testing and validation of AI is key. Without appropriate governance it will be a liability'*
- *'We need distribution across public and private sectors, with patient access to any information generated and ease of sharing this'*
- *'Clarification of concepts around patients being curators not owners of the ("their") data; compliance with GDPR but still allowing retention of images/ blood results/other data to feed Big Data'.*

[4] *Naylor, A. and Jones, E. (2017). Unleashing the potential of health and care data. Future Care Capital. Available at: https://futurecarecapital.org.uk/policy/healthcare-data/.*

Towards a sustainable ecosystem

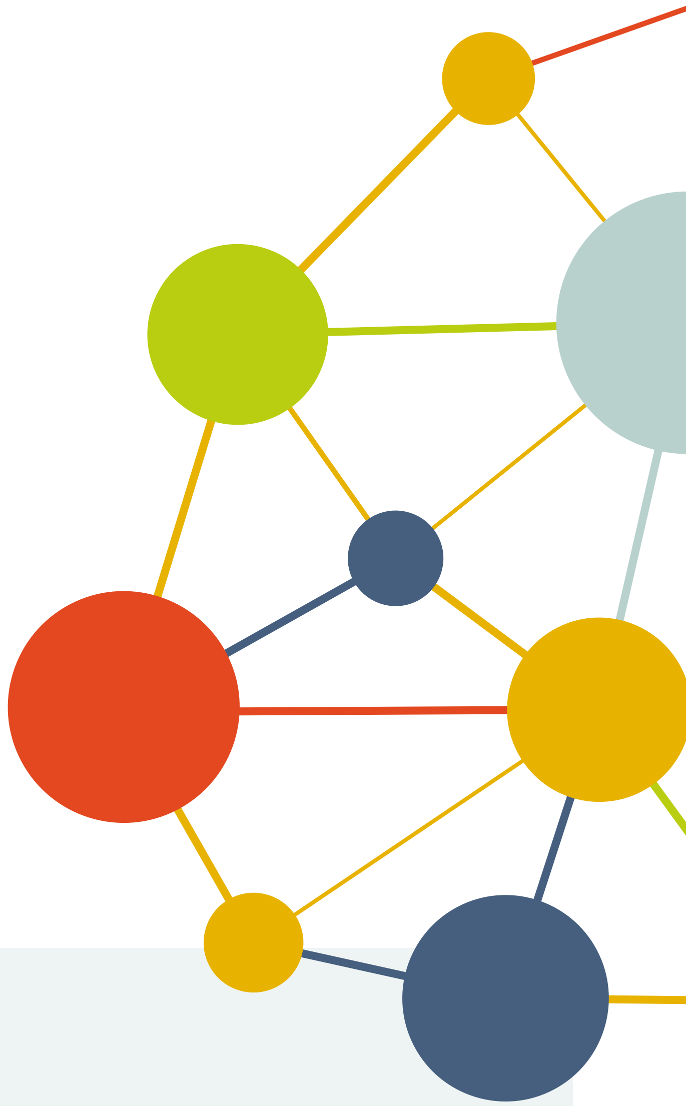
A number of respondents endorsed the establishment of open data ecosystems in order to leverage insights from multiple datasets, enabling the real power of AI to come into its own. For example, Transport for London provides a common API to access 80% of the UK's transport data. Thousands of developers (including the original Citymapper app) build on top of this open API platform. Similarly, Open Banking, recently introduced in the UK, will see the UK's nine biggest banks release data in a secure, standardised form, so that it can be shared more easily between authorised organisations so they can then use it to create more products and services to benefit citizens. The intention is to put citizens in control of their own banking data, providing an easier way for them to move, manage and make more of their money.

In order to unlock open innovation around data-driven health and social care services, any open data ecosystems must provide mechanisms for data to flow safely and securely across disparate health and care organisations, whilst ensuring informed consent and transparency. Enabling citizens to 'donate' their consumer data (e.g. from banking, retail, transport, telecommunications, utilities, etc) and data from sensors and IoT-enabled devices could also support citizens to stay healthy and in their own homes for longer[5].

Momentum is growing to establish open data ecosystems across health and care. This should accelerate over time as forthcoming Industrial Strategy Grand Challenge investments in initiatives such as Digital Innovation Hubs (connecting regional health and care data with biomedical data in secure environments) and the Healthy Ageing Challenge start to bear fruit.

NHS Digital and NHS England are also laying the groundwork for open innovation with a number of initiatives including:

- Apperta Foundation, which recently published 'Defining an Open Data Platform'
- Code4Health, which provides a home for the increasing number of open source projects providing software suitable for use in health and care
- International exemplars in the area of open innovation platforms in the health and care space include REshape Centre Radboud (Netherlands) and Boston Children's Hospital (United States)
- Closer to home, University Hospitals Plymouth NHS Trust and Great Ormond Street Hospital are exemplars in building open data ecosystems and fostering open innovation.



Case Study

Great Ormond Street Hospital DRiVE Unit (Digital Research, Informatics and Virtual Environments)

GOSH's DRiVE unit provides a good example of the type of open data ecosystem and infrastructure required for exploitation of AI's potential within health and care. The DRiVE unit provides both a concept and a physical space dedicated to accelerating research and evaluation of new AI-enabled technology and data analysis, with the aim of developing scalable solutions for child health. Working with partners including University College London (UCL)/ Alan Turing, major industry partners and NHS Digital, early areas of focus will include machine learning, assisted decision making and the use of medical chatbots.

GOSH's open data ecosystem captures and integrates data from multiple sources in a secure environment in the cloud that is compliant with ICO and GDPR guidance regarding the use of data for research. Clinicians, researchers and industry partners looking to address specific problems can come together in secure virtual 'workspaces' to run analyses and APIs. The data therefore does not leave GOSH's control and governance, providing full transparency. The GOSH team and regulators have full data provenance, including details of IP addresses accessing the code and whether changes have been made. During the development phase, the GOSH team are also working to generate synthetic datasets for innovators to test their early algorithms on, prior to validation on real data.

[5] *Woods, T.M. and Kihlstrom, E. (2018). Data and the Future of Health and Social Care. Report, Proceedings and Key Recommendations. Round Table, 17th November 2017. FutureHealth Collective. Available at: https://www.colliderhealth.com/future-health-collective.*

SUMMARY AND NEXT STEPS

The analysis of survey responses, together with the constellation of organisations in the AI map and illustrated by the case studies in this report, reveals that AI in health and care is still at a relatively early stage. At the same time, there are many promising early use cases for AI in this space, especially in diagnostics. The health and care AI ecosystem continues to grow at pace, with a range of promising interventions in the pipeline, currently gathering evidence that they are safe, effective and offer value prior to regulatory approval and widespread implementation.

Where are we now?

Whilst AI solutions are increasing in their complexity, most now delivering impact are on the low complexity end of the spectrum. Understanding the vast potential of AI – as well as its limitations - will be key moving forward. As one survey respondent commented, 'AI is still evolving… it won't solve all the problems healthcare faces as the moment' and we must avoid the trap of 'overhyping potential, unrealistic claims, and poorly thought out products'.

Top AI enablers include engagement with health professionals, as well as grounding the use of AI in real problems as expressed by citizens, carers and other health professionals. Providing mechanisms for improving data quality and the underlying data infrastructure will also be key, along with introducing a safe, evidenced and transparent approach to how algorithms and innovations are developed.

Currently in the NHS, we have a number of programmes such as the Local Health and Care Record Exemplars, NHS Test Beds and the forthcoming Digital Innovation Hubs that give us the opportunity to test and refine digital health innovations (DHIs) and algorithms with our partners. The NHS Apps Library and Digital Assessment Questions are examples of how the NHS is currently reviewing technical and clinical safety requirement and design standards before publishing onto the library.

Ultimately, the NHS must protect its reputation as an internationally trusted health and care system, ensuring patient safety and high quality care, and preserving the trust between citizens, clinicians and the wider health and care system. In order to do this we have collated a set of principles outlined in a Code of Conduct, which is in early stages of development.

The purpose of the Code is to provide a source of clear principles and guidance for the development of trusted digital health innovations and intelligent algorithms within the UK NHS health and care sector. This code can be used by innovators, industry, commissioners, academia and individuals, as a framework to support development and deployment of any DHI or intelligent algorithm (IA). Whilst this code will ensure that the DHI/IA being developed are in line with the principles and values of the UK health and care system, it is still a requirement that the relevant regulatory and/or approval processes are adhered to.

This code, if followed, can ensure that within the NHS and the wider UK health and care sector we collectively:

1. Build fairness and transparency in digital health innovations, algorithms and clinical decision support tools.
2. Help identify the requirements and standards that organisations and suppliers need to fulfil in order to show that products are safe, secure and maintain public trust.
3. Identify gaps within regulatory and approval processes that need to be addressed to accommodate developing technologies.

By working collaboratively with academia, industry, innovators, commissioners and AHSNs to iterate and continually update these principles, we can go some way to staying abreast of evolving technologies, helping to catalyse the scale and adoption of intelligent technologies. Addressing these requirements with the right solutions will spur collaboration across the NHS, social care and other partners in the ecosystem and build public trust. Strong cross government collaboration, including pooling resources and partnering on joint initiatives is also underway and is the key objective of the AHSN Network AI initiative.

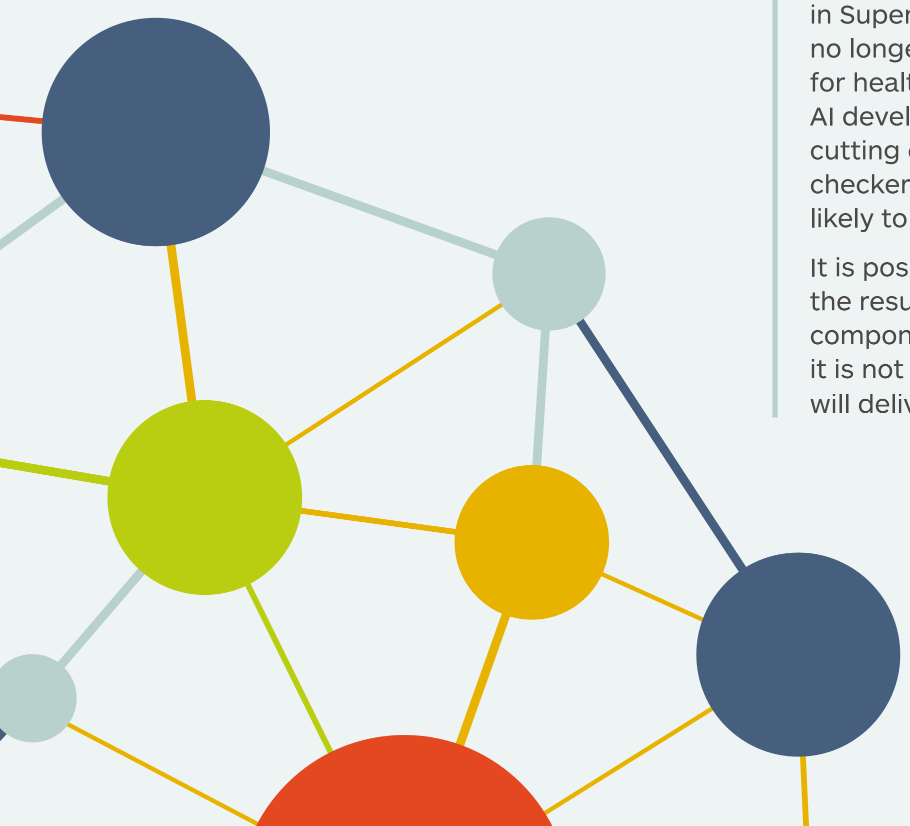
This is where we are, but where are we going?

This report highlights where Artificial Intelligence is currently having an impact on the health and care system. The survey results highlighted make it clear that innovations falling under the umbrella term of AI, are being used to transform every aspect of health and care delivery in the UK. It is incredibly exciting to witness this potential being unlocked, but it is only the beginning.

The development of AI has a long history, with the era of electronic computers beginning in the 1940s and the current enthusiasm for the use of AI dating from the publication of Norbert Wiener's Cybernetics: or Control and Communication in the Animal and the Machine in the 1960s. It, therefore, stands to reason that interest and investment in the development of AI techniques will remain high for a long time to come.

It is almost impossible to predict what health and care use cases these future developments will deliver because technology is cumulative. Technology adoption follows the normal distribution curve meaning that not everybody takes advantage of the latest developments at the same time, and the goal posts are always changing. As Garry Kasparov accurately points out in Deep Thinking it was once believed that if an AI chess game could play at grand master level, this would represent the unlocking of human level intelligence and yet this was achieved in the early noughties. Now nobody thinks twice about playing chess on their mobile phone because, as Nick Bostrom stresses in Superintelligence, once something works, it is no longer considered AI. This will be just as true for health and care AI interventions as it is for the AI developments of the past. Whilst it might seem cutting edge now to be able to use a symptom checker such as Ada, in the very near future this is likely to just be routine.

It is possible, however, to speculate about what the results of these AI developments will be for all components of the health and care system, even if it is not possible to say which exact developments will deliver these results.



For individuals

In the future AI will bring precision medicine into the realms of possibility for a far greater range of conditions and more nuanced interventions than it is now. As Neil Jacobstein, chair of the AI and Robotics track at Silicon Valley think tank Singularity University emphasises, truly personalised recommendations based on consideration of an individual's entire genomic profile will change the way we view medicine[6].

In addition, and perhaps more importantly, future AI tools will, enable a rapid shift towards preventive medicine. As the McKinsey Global Institute report, Artificial Intelligence the next digital frontier?, highlights, medical professionals will have enough information to provide genuinely personalised preventive recommendations to individuals based on both medical interventions and lifestyle and environmental factors such as nutrition and exercise. What's more, constant monitoring and associated feedback loops will enable clinicians to get over the hurdle articulated by Michie et al (2009) that whilst there have been many systematic reviews of behaviour change interventions that have demonstrated worthwhile benefits, it has not been clear which behaviour change processes were responsible for the observed results[7].

Thus, as a result of future AI developments, both quantitative medical and qualitative socio-cultural health interventions will become more accurate, targeted and effective.

For clinicians, care givers and researchers

The delivery of health and care is a fundamentally human endeavour. Even very far into the future it is impossible to imagine a world in which Artificial Intelligence – be it robotic or algorithmic – will replace the role of clinicians and carers completely. An artificial system is highly unlikely to be able to, for example, pick up on subtle shifts in things such as body language which can give clinicians vital clues into how a patient is feeling. However, future developments will be able to give clinicians and carers augmented intelligence, enabling them to process a greater amount of critically relevant information in a shorter amount of time and giving them the time to focus on such higher-level tasks by automating many mundane and routine actions.

Future developments in AI will also be game changing for epidemiological researchers who, since John Snow's study of the London cholera outbreak in 1854, have been trying to use mathematics to make the prediction of diseases less chaotic and more deterministic so that it can be more easily controlled. The ability to do this has always been hampered by the problems of modelling, data and computation. However, as AI programs become more computationally and technologically powerful and able to make connections between previously un-associated data points Dr Gunjan Bhardwaj , chief executive of Innoplexus AG, attests that they will deliver the ability to generate and test novel hypotheses for almost all healthcare scenarios.

These new statistical modelling capabilities will grant us the ability to forecast the spread of disease, anticipate which patients will be most likely to succumb[9] and deliver precision public health interventions with maximised effectiveness (Flahault et al 2017).

[6] *Ross, C. (2018). The Future of AI in Health Care. Psychology Today, 13 June 2018. Available at: https://www.psychologytoday.com/gb/blog/the-future-brain/201806/the-future-ai-in-health-care*

[7] *Michie, S., Fixsen, D., Grimshaw, J.M., Eccles, M.P., (2009). Specifying and reporting complex behavior change interventions: the need for a scientific method, Implementation Science, 4:40. Available at: https://doi.org/10.1186/1748-5908-4-40*

[8] *Forbes Technology Council (2018). How AI is transforming the future of healthcare. Available at: https://www.forbes.com/sites/forbestechnologycouncil/2018/01/30/how-ai-is-transforming-the-future-of-healthcare/ #4faf820d3e60*

[9] *McKinsey & Company (2017). Artificial Intelligence: the Next Digital Frontier? A discussion paper. Available at: http://bit.ly/2fRblkR.*

[10] *Flahault, A., Geissbuhler, A., Guessous, I., Guérin, P. J., Bolon, I., Salathé, M., & Escher, G. (2017). Precision global health in the digital age. Swiss Medical Weekly, 2017(1314), Article: w14423.*

For the system

Finally, on the largest scale, future developments in AI will deliver what Flahault et al 2017 describe as a 'learning healthcare system'. A system where all component parts are equipped with the relevant data and decision support devices that analyse results in real-time using machine learning techniques. These results are combined with systems thinking methods to deliver a healthcare system that constantly adjusts to ensure it is always following the principles of the currently best known evidence[11].

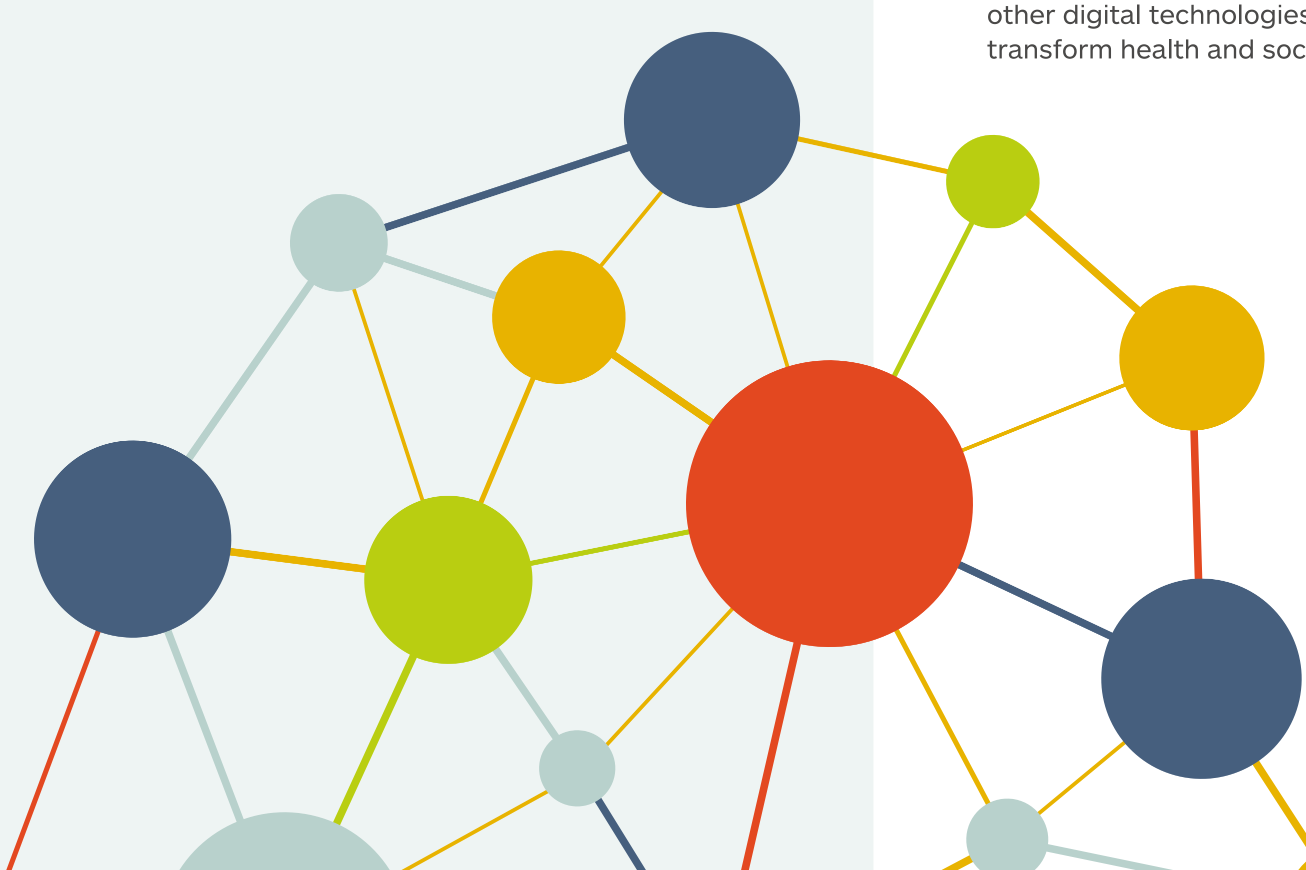
As such, in the future, we will be looked after by a health and care system that is using the most recent developments in mathematics, statistics, electrical engineering, neurophysiology, information theory, physics and epidemiology[12] to: (1) ensure that primary, secondary and community health and care services are running as efficiently as possible, and; (2) that the result of these hyper-efficient and effective services is delivery on the prime minister's mission to use data, artificial intelligence and innovation to transform the prevention, early diagnosis and treatment of chronic diseases to improve the overall quality of life of the nation's citizens.

Making this vision a reality

To achieve this vision, it will be paramount to ensure that only the best and most evidence-based AI innovations are allowed to spread throughout the system, but that all innovations have an equal chance of providing this evidence base. This is why the report not only focuses on the ways that AI is transforming health and care, but the steps that are being taken to create an open, transparent, clearly regulated, and competitive market for emerging health tech. Creation of this environment will mean that AI, and other digital health innovations, are given the opportunities necessary to deliver the best possible outcomes for all those receiving, delivering and managing health and care services.

[11] Ibid.

[12] Nag, N., Pandey, V., Hyungik, O., Jain, R. (2017). Cybernetic Health. ArXiv. Available at: https://arxiv.org/abs/1705.08514.



The AHSN Network AI Initiative: moving forward

This first AHSN Network AI Initiative survey sets a baseline against which progress can be monitored over time. The accompanying online interactive map that visualises the AI hotspots will also help inform the development of an ecosystem to promote collaboration and knowledge exchange. The map will be regularly updated, and a number of activities rolled out to develop the ecosystem, sustain momentum around solutions, and build awareness of the potential of AI across health and care.

Over time, the AHSN Network AI Initiative will develop and evolve as a mutually beneficial and self-sustaining ecosystem of leaders and innovators committed to using artificial intelligence and other digital technologies to transform health and social care.

Through it all, AHSNs look forward to continuing to play an important role in shaping and implementing the national digital and AI agenda, working directly with citizens and healthcare professionals to define clearly the problems that could be addressed by AI in the future.

Using our regional connections, convening power and expertise, AHSNs can also undertake commissioned work, for instance:

- expanding our innovation exchange role to support uptake of a wider range of evidence-based AI-enabled digital innovation working with the NHS in our regions, including with STPs and ACSs;
- supporting industry and entrepreneurs and brokering links;
- helping establish Digital Innovation Hubs and other open innovation ecosystems;
- supporting implementation of the Topol Review and other government policy recommendations; and
- helping partners including NHS England, NHS Improvement, the Office for Life Sciences and NHS Digital accelerate uptake and solve complex issues in the digital and AI space.

By catalysing this AI ecosystem, the AHSN Network AI initiative seeks to accelerate the development, validation and spread of AI in healthcare, which in turn has huge potential to improve care and cut costs within the NHS.

By building a collaborative framework and ecosystem within which we encourage the adoption of fair and transparent principles we will help to build a trusted and safe market for intelligent technology in health and care.

APPENDIX 1: CASE STUDIES

Unlocking value in data/analytics

myLevels

A recent start-up using AI to provide personalised diet recommendations based on people's unique sugar level responses. This stops sugar levels spiking and crashing – helping people lose weight and reducing their chance of getting diabetes.

Deontics

A clinical decision support and patient-facing aid software enabling quick collation of conventional knowledge including guideline, quality measures, clinical trial and research papers into a standard executable format that can be integrated with individual patient data to provide evidence-based treatment options.

Brainwear – wearables in brain tumour patients

Developed by the Imperial College London Computational and Academic Clinical Oncology team, Brainwear provides electronic activity monitors to adult patients with high-grade gliomas undergoing chemo-radiotherapy, providing the opportunity for continuous outpatient monitoring. The team at Imperial is currently evaluating results compared to conventional assessments of disease, and to demonstrate value to help Brainwear become part of the standard repertoire of Neuro-Oncology trial outcomes.

Ada Health

Ada is an AI-powered personalised health platform. Ada helps the NHS in two ways 1) empower patients to self-care for minor illnesses by providing access to high quality medical information within Ada's app, thereby reducing patient demand for GP and A&E services and 2) triage patients to ensure they get the right care at the right time in the right place, thereby releasing GP capacity and improving care outcomes.

Organisational processes

Space Finder

Space Finder is an artificial intelligence solution developed by Edge Health/ South Tees Hospitals to help operating lists run more efficiently. Using predictive analytics, Space Finder creates optimal operating lists tailored to the surgeon, the patient and the operation.

Blackford Platform

Developed by Blackford Analysis this platform is used to deploy multiple vendor AI solutions in to medical imaging workflows. A single platform unlocks multiple vendor solutions, with a single contract, support contact and deployment.

Leveraging skills and capacity

Virtual Lucy

Virtual Lucy enables patients to attend fracture clinics within the comfort of their own home, linking them with an end-to-end cloud-based service providing support from referral to rehab. Lucy's model, tested on 20,000 patients thus far, has been shown to reduce outpatient appointments by 50%, whilst also ensuring that 100% of patients have a consultant making decisions on diagnosis and rehabilitation.

Automated segmentation of head and neck tumour to aid radiotherapy planning

A partnership between DeepMind and University College London Hospitals NHS Foundation Trust (UCLH), applying machine learning to automated segmentation of head and neck tumour volumes and organs at risk on medical images including computed tomography (CT) and magnetic resonance imaging (MRI) scans captured for radiotherapy planning. Radiotherapy is one of the main ways head and neck cancers are treated; radiation is used to kill cancerous cells and prevent their recurrence. Through analysis of the images used in planning radiotherapy, the aim is to design a computer-based tool to automatically segment regions and improve efficiency in radiotherapy units.

Alder Hey Children's Hospital, Ask Oli Chatbot

This is a hospital artificial intelligence chatbot to answer common patient questions. The aim of this proposition is to reduce the number of low complexity questions asked to staff and to allow questions to be answered in a timely and engaging manner. The platform has also been designed for children. Analysis of the questions allows for real time quality improvement.

Medopad

Suite of mobile applications, remote monitoring devices and wearable technology, including Apple watches, to connect patients with health care professionals. It uses machine learning to analyse patient data to improve diagnosis, enhance treatment, predict deterioration and empower patients and carers.

Docobo (Doc@home free text symptom checker)

The doc@HOME Cloud EPR platform provides a free text symptom checker enabling both clinical users and patients the ability to key in symptoms and be taken down an automated triage to help determine the chief clinical complaint.

doc@HOME is currently deployed in the Innovate UK / NHS England Internet of Things test bed: Technology Improved Health Management research project (TIHM for Dementia).

Condition recognition

Astrodem

A predictive model developed by Brighton and Sussex Medical School which will help general practitioners (GPs) identify patients at high risk of dementia. 96,000 anonymised GP patient records from the Clinical Practice Research Datalink are being used to train the model.

Automated analysis of retinal imaging using machine learning techniques for computer vision

Working with Moorfields Eye Hospital NHS Foundation Trust, DeepMind have developed AI technology which could improve the way eye diseases are diagnosed and treated and could ultimately help the millions of people across the globe affected by preventable or curable sight loss. This includes exploring retinal pathology using deep learning tools on 3D volumetric optical coherence tomography and digital imaging of the fundus as well as the development of models to segment, diagnose and recommend treatment decisions from macular optical coherence tomography scans.

Detection, characterisation and risk stratification of breast lesions

Working with Cancer Research UK Imperial Centre this DeepMind project uses machine learning for the detection, characterisation and risk stratification of breast lesions. The project aims to demonstrate the feasibility of applying machine learning for potential future clinical benefit in mammography screening.

SkinVision

An awareness and tracking solution that supports individuals with the early recognition of melanoma, squamous cell carcinoma, basal cell carcinoma and precancerous actinic keratosis. It is the first global certified skin cancer application available for consumers.

Kheiron Medical

Technology focussed on helping radiologists detect breast cancer earlier using deep learning, to address two key problems: 1) ease the workload on overstretched screening units by serving as a second reader to support breast screening programmes and 2) increase the accuracy of screening by reducing the number of false positives and false negatives, and hence number of patients getting unnecessary biopsies.

APPENDIX 2: FURTHER READING

AI in the UK: ready, willing and able?

House of Lords Select Committee on Artificial Intelligence

Report produced by the House of Lords Select Committee on Artificial Intelligence to consider the economic, ethical and social implications of advances in AI. The report concludes that the UK is in a strong position to be among the world leaders in the development of artificial intelligence during the twenty first century. The Committee state that Artificial intelligence, handled carefully, could be a great opportunity for the British economy.

Artificial Intelligence: Real Public Engagement

Royal Society for the encouragement of Arts, Manufactures and Commerce (RSA)

This report is about getting citizens involved in the discussion around artificial intelligence. The RSA makes the case for engaging citizens in the ethics of AI and shares a snapshot of public attitudes towards AI and automated decision-making. They argue that the citizen voice must be embedded in ethical AI.

Code4Health

Code4Health is an initiative supported by NHS England and NHS Digital to enable the best use of digital tools and technology to deliver safe, high quality, efficient and compassionate care. Code4Health aims to educate and inform all participants in the health and care community: citizens, patients, carers, health, care and digital professionals about the possibilities digital technologies provide and equip them with the tools, knowledge and skills to collaborate to develop and implement high quality digital solutions.

Defining an Open Platform

Apperta Foundation

The Apperta Foundation believes that innovative technologies are the key to achieving positive transformation in health care. In its report the Apperta Foundation argues that open digital platforms based on an open platform can lower barriers to entry, stimulate innovation and enable successful start-ups to rapidly get to scale. The Apperta Foundation report is an attempt to propose a definition for an open platform, based on standards that have been proven to work worldwide including HL7 FHIR, SNOMED-CT, IHE_XDS and openEHR.

Ethical, social, and political challenges of artificial intelligence in health and care

Future Advocacy and Wellcome

This report looks at the current and potential use cases of AI in healthcare and explores the ethical, social, and political challenges that this would raise.

Industrial Strategy: building a Britain fit for the future

Department of Business, Energy and industrial Strategy

This white paper sets out a long-term plan to boost the productivity and earning power of people throughout the UK. The report sets out four areas where Britain can lead the global technological revolution: artificial intelligence and big data; clean growth; the future of mobility; and meeting the needs of an ageing society.

Life sciences: industrial strategy – A report to government from the life sciences sector

Office for Life Sciences

This report, written by Life Sciences' Champion Professor Sir John Bell, provides recommendations to government on the long-term success of the life sciences sector. It was written in collaboration with industry, academia, charity, and research organisations.

London: The AI Growth Capital of Europe

Mayor of London

CognitionX was commissioned by the Mayor of London to map AI innovation across London and identify the capital's unique strengths as a global hub of Artificial Intelligence. This report outlines their findings and will inform the actions that the Mayor will take to support the future growth of AI across different industries to drive innovation, productivity and growth.

Map of technology and data in health and care

The King's Fund

This map brings together case studies from across England, highlighting some of the places that are experimenting with and implementing new technologies to achieve better health outcomes or more efficient care.

Medical devices: the regulations and how we enforce them

Medicines & Healthcare products Regulatory Agency (MHRA)

MHRA is the designated competent authority that administers and enforces the law on medical devices in the UK. This online guide provides an overview of MHRA's investigatory and enforcement powers, which ensure the safety and quality of medical devices.

Policy Paper: AI Sector Deal

Department for Business, Energy & Industrial Strategy and Department for Digital, Culture, Media & Sport

The AI Sector Deal is the first commitment from government and industry to realise the potential of Artificial Intelligence and Big Data. It outlines a package of up to £0.95 billion of support for the sector, which includes government, industry and academic contributions up to £603 million in newly allocated funding, and up to £342 million from within existing budgets, alongside £250 million for Connected and Autonomous Vehicles.

Thinking on its own: AI in the NHS

Reform

This report illustrates the areas where Artificial Intelligence (AI) could help the NHS become more efficient and deliver better outcomes for patients. It also highlights the main barriers to the implementation of this technology and suggests some potential solutions.

The Topol Review: Preparing the healthcare workforce to deliver the digital future, Interim Report June 2018 – a call for evidence

Health Education England

A call for evidence from the Topol Review team. The review is looking at what training NHS staff would need to undertake to use Artificial Intelligence technologies and robotics.

APPENDIX 3: GLOSSARY

This glossary of selected items have been ordered in relation to the Complexity Scale for AI (described on page 10) developed by Jeremy Wyatt.

This glossary has been developed using Wikipedia except where specifically indicated and referenced. For further detail, a comprehensive glossary of AI terms can be found on Wikipedia at https://en.wikipedia.org/wiki/Glossary_of_artificial_intelligence.

High complexity – AI applications

Autonomous vehicle

An autonomous car (also known as a driverless car and a self-driving car) is a vehicle that can sense its environment and navigate without human input. Autonomous cars combine a variety of techniques to perceive their surroundings, including radar, laser light, GPS, odometry, and computer vision. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage.

Machine translation tool

Machine translation (MT) is a sub-field of computational linguistics that investigates the use of software to translate text or speech from one language to another. A deep learning-based approach to MT, neural machine translation has made rapid progress in recent years.

Care companion robot

Robot used to aid in caring for someone or to provide them with companionship. A robot is a machine—especially one programmable by a computer—capable of carrying out a complex series of actions automatically. Robots can be guided by an external control device or the control may be embedded within.

Chatbot

A chatbot (also known as a talkbots, chatterbot, Bot, IM bot, interactive agent, or Artificial Conversational Entity) is a computer program which conducts a conversation via auditory or textual methods. Such programs are often designed to convincingly simulate how a human would behave as a conversational partner, thus passing the 'Turing Test' (a test proposed by Alan Turing in 1950, of a machine's ability to exhibit intelligent behaviour equivalent to, or indistinguishable from, that of a human). Some chatbots use sophisticated natural language processing systems to parse the meaning of the user's input, but many simpler systems scan for keywords within the input, then pull a reply with the most matching keywords, or the most similar wording pattern, from a database.

Surgical or pharmacy robot

Robot used to support surgical or pharmacy tasks such as making the right shaped cavity in the femur for a hip replacement or selecting the right type and number of pills to fil a medicine bottle in a pharmacy. A robot is a machine—especially one programmable by a computer—capable of carrying out a complex series of actions automatically. Robots can be guided by an external control device or the control may be embedded within.

Mammogram interpretation system

A system using AI that assists doctors in the interpretation of medical images, specifically breast screening mammograms. Most systems highlight suspicious areas for human attention, though completely autonomous systems are being developed.

ECG interpreter

Systems using AI that assist doctors by generating a prose report describing the key findings in an electrocardiogram.

Diagnostic decision support system

The use of health information technology including algorithms and software to analyse complex patient data to assist healthcare professionals by suggesting a differential diagnosis.

Speech driven radiology report tool with SNOMED coded output

Use of speech recognition technology to create radiology report with SNOMED (Systematized Nomenclature Of Medicine) coded output for diagnoses etc. Speech recognition is the inter-disciplinary sub-field of computational linguistics that develops methodologies and technologies that enables the recognition and translation of spoken language into text by computers. It is also known as automatic speech recognition (ASR), computer speech recognition or speech to text (STT). It incorporates knowledge and research in the linguistics, computer science, and electrical engineering fields.

Middle complexity – AI modules or components

Natural language to SNOMED code processing module

Natural Language Processing (NLP) is a linguistic technique that enables a computer program to analyse and extract meaning from human language. Clinical NLP, using SNOMED CT's concepts, descriptions and relationships, may be applied to repositories of clinical information to search, index, selectively retrieve and analyse free text. These techniques can be used to extract SNOMED CT encoded data from free-text patient records and support the retrieval of clinical knowledge documents.

Image processing module

In computer science, digital image processing is the use of computer algorithms to perform image processing on digital images. As a subcategory or field of digital signal processing, digital image processing has many advantages over analogue image processing. It allows a much wider range of algorithms to be applied to the input data and can avoid problems such as the build-up of noise and signal distortion during processing. Since images are defined over two dimensions (perhaps more) digital image processing may be modelled in the form of multidimensional systems.

Text to speech module

A text-to-speech (TTS) system converts a digitised text string into an audio signal that sounds like spoken speech. A common example is the speech output from a satnav.

Knowledge based or expert system module

A knowledge-based system (KBS) is a computer program that reasons and uses a knowledge base to solve complex problems. The key feature of a knowledge-based system is that the knowledge is represented explicitly using a knowledge model based on the domain ontology. This allows them to generate plausible explanations of their advice. Other algorithmic or statistical advice generators lack this feature.

Signal processing & classification module

Signal processing concerns the analysis, synthesis, and modification of signals, which are broadly defined as functions conveying 'information about the behaviour or attributes of some phenomenon' such as sound, images, and biological measurements.

Recommender module

A tool to generate recommendations driven by algorithms applied to input data. Examples are the recommendations about films you might watch from Netflix or books you might like from Amazon.

Low complexity – AI reasoning methods

Deep learning module

Deep learning (also known as deep structured learning or hierarchical learning) is part of a broad family of machine learning methods based on learning data representations, as opposed to task-specific algorithms. Learning can be supervised, semi-supervised or unsupervised. Deep learning architectures such as deep neural networks, deep belief networks and recurrent neural networks have been applied to fields including computer vision, speech recognition, natural language processing, audio recognition, social network filtering, machine translation, bioinformatics and drug design, where they have produced results comparable (and in some cases superior) to human experts.

Ensemble methods (e.g. Random Forest Models)

Random forest models are an ensemble learning method for classification, regression and other tasks, that operate by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean prediction (regression) of the individual trees. Random decision forests help to correct for decision trees' habit of overfitting to their training set.

Neural networks

Artificial neural networks (ANNs) or connectionist systems are computing systems inspired by the biological neural networks that constitute animal brains. Such systems 'learn' to perform tasks by considering examples, generally without being programmed with any task-specific rules. For example, in image recognition, they might learn to identify images that contain cats by analysing example images that have been manually labelled as 'cat' or 'no cat' and using the results to identify cats in other images. They do this without any prior knowledge about cats (e.g., that they have fur, tails, whiskers and cat-like faces), such as would be necessary in a knowledge-based system. Instead, they automatically generate identifying characteristics from the learning material that they process using supervised learning.

Object segmentation algorithm

This is an algorithm used for delineating objects in digital images.

Signal processing algorithm / filter

Signal processing concerns the analysis, synthesis, and modification of signals, which are broadly defined as functions conveying "information about the behaviour or attributes of some phenomenon" such as sound, images, and biological measurements. A typical example of a signal processing algorithm / filter is analysing physiological signals to detect a QRS complex in an ECG signal.

Generative adversarial networks

Generative adversarial networks (GANs) are a class of artificial intelligence algorithms used in unsupervised machine learning, implemented by a system of two neural networks contesting with each other in a zero-sum game framework.

Time series analysis

A time series is a series of data points indexed (or listed or graphed) in time order. Most commonly, a time series is a sequence taken at successive equally spaced points in time. Time series analysis comprises methods for analysing time series data to extract meaningful statistics and other characteristics of the data, often to predict future results.

Graphical models

A graphical model or probabilistic graphical model (PGM) or structured probabilistic model is a probabilistic model for which a graph expresses the conditional dependence structure between random variables. They are commonly used in probability theory, statistics—particularly Bayesian statistics—and machine learning.

Decision trees, rule induction

Decision tree learning uses a decision tree (as a predictive model) to go from observations about an item (represented in the branches) to conclusions about the item's target value (represented in the leaves). It is one of the predictive modelling approaches used in statistics, data mining and machine learning. Tree models where the target variable can take a discrete set of values are called classification trees; in these tree structures, leaves represent class labels and branches represent conjunctions of features that lead to those class labels. Decision trees where the target variable can take continuous values (typically real numbers) are called regression trees. CART refers to Classification And Regression Trees.

Clustering algorithm

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters). It is a main task of exploratory data mining, and a common technique for statistical data analysis, used in many fields, including machine learning, pattern recognition, image analysis, information retrieval, bioinformatics, data compression, and computer graphics. Cluster analysis itself is not one specific algorithm, but the general task to be solved. An example of a clustering algorithm is a Kohonen feature net which is a self-organising map that is trained using unsupervised learning to produce a low-dimensional (typically two-dimensional), discretised representation of the input space of the training samples.

Classification algorithm

In machine learning and statistics, classification is the problem of identifying to which of a set of categories (sub-populations) a new observation belongs, based on a training set of data containing observations (or instances) whose category membership is known. Examples are the diagnosis for a given patient, based on observed characteristics of the patient (gender, blood pressure, presence or absence of certain symptoms, etc.). Classification is an example of pattern recognition. In the terminology of machine learning, classification is considered an instance of supervised learning, i.e. learning where a training set of correctly identified observations is available. The corresponding unsupervised procedure is known as clustering and involves grouping data into new categories based on some measure of inherent similarity or distance.

Regression – linear, multiple, logistic

In statistical modelling, regression analysis is a set of statistical processes for estimating the relationships among variables. It includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Regression analysis is widely used for prediction and forecasting, where it has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships.

Inference engine for rules or frames

An inference engine is a component of the system that applies logical rules to the knowledge base to deduce new information. The first inference engines were components of expert systems. The typical expert system consisted of a knowledge base and an inference engine. The knowledge base stored facts about the domain. The inference engine applies logical rules to the knowledge base using data eg. about a patient and deduced conclusions or advice, eg the diagnosis for the patient.

Argumentation, temporal or spatial reasoner

Spatial–temporal reasoning is an area of artificial intelligence which draws from the fields of computer science, cognitive science, and cognitive psychology. The theoretic goal—on the cognitive side—involves representing and reasoning spatial-temporal knowledge in mind. The applied goal—on the computing side—involves developing high-level control systems of robots for navigating and understanding time and space. An example is a Qualitative Simulation and Modelling (QSIM).

Text generator using Directive Clause Grammars (DCGs)

Natural language generation (NLG) is the process of generating reasonably natural sounding text from data, such as a patient data base or data entry form. A simple example is systems that generate form letters such as contracts in a lawyer's office. These usually do not typically involve grammar rules, but more complex NLG systems dynamically create text. As in other areas of natural language processing, this can be done using either explicit models of language (e.g., grammars) and the domain, or using statistical models derived by analysing human-written texts.

Case-based reasoning algorithm

Case-based reasoning (CBR), broadly construed, is the process of solving new problems based on the solutions of similar past problems. It has been argued that case-based reasoning is not only a powerful method for computer reasoning, but also a pervasive behaviour in everyday human problem solving; or, more radically, that all reasoning is based on past cases personally experienced. Case based decision support systems use a computerised similarity matching algorithm to offer the user cases from a 'case base' that somehow resemble the new case whose data is provided. This could allow, for example, an oncologist to locate several historical patients with a similar disease and stage as their new patient, and then use the response to different treatment options of these historic patients to help choose the therapy for their new patient.

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About The AHSN Network AI Initiative

Working to create better, safer and more sustainable healthcare

The Academic Health Science Network (AHSN) AI (Artificial Intelligence) Initiative, is working to improve the quality of people's lives and address urgent challenges faced by the health and care system. We believe in creating better, safer and more sustainable healthcare through innovation in technology.

Our diverse perspectives and expertise span clinical, technological, legal and ethical areas as well as practical on-the-ground experience from innovators in the NHS.

Kent Surrey Sussex AHSN, led by Managing Director Guy Boersma, hosts the AI Initiative on behalf of all 15 AHSNs across England.

Innovation through collaboration

We support the market development and spread of Internet of Things, Machine Learning and AI technology by strengthening collaboration between citizens, industry, academia and the health and care sector.

The programme looks to work with everyone who wants to bring the benefits of AI into health and social care and incorporates user-driven design into solution development and deployment. Over time, the programme will mature and evolve as a mutually beneficial and self-sustaining ecosystem of leaders and innovators committed to using artificial intelligence and other digital technologies to transform health and social care.

We aim to help the UK become the leader in what the Life Sciences: industrial strategy refers to as 'entire new markets', drawing on the assets of our world class universities, our market leading AI SMEs (c.50% of global AI SMEs are UK based) and our comprehensive NHS health dataset.

Connecting people through technology

The healthcare system must place less reliance on face-to-face interaction to be able to continue delivering the best care for patients. The programme aims to develop and drive innovation and adoption of AI technology throughout the NHS and social care. It aims to improve care at a lower cost to healthcare commissioners and providers and promote healthier lifestyles

We believe technology can be used to improve the quality of people's lives and address urgent challenges faced by the health and care system. This is why we are working to create an ecosystem which will enable citizens, innovators and health and social care staff to connect and create sustainable health and social care solutions.

Find out more at www.ahsnnetwork.com

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