AI has been used in healthcare for decades. However, the increasing capture of data electronically in clinical information systems, the increase in personal data captured through devices, sensors, imaging or genomics and the increase in computing power available – either through cloud-based computing platforms or on the phones in our pockets – is enabling a new generation of applications of AI throughout the healthcare system. AI in healthcare is now a growth market.

Using the Australian experience, SNOMED CT is positioned to support AI/ML in three of the domains:

- **Predictive Analytics and Data-Driven Intelligence**: Example, using SNOMED CT to help stratify the patient risk for re-hospitalization, thereby providing improved detection and management of patients at risk of readmission.

- **Knowledge Representation and Reasoning**: Examples, developing AI tools to support SNOMED CT terminology deployment (e.g. Snorocket reasoner); as well as using SNOMED CT for advanced analytics of genomic phenotype data using Pathling.

- **Human Language Understanding**: Examples, using NLP and SNOMED CT to enhance data quality in cancer registries; using NLP, SNOMED CT and AI solutions to check radiology reports for missed fractures; using NLP and SNOMED CT to review antibiotic prescriptions in discharge summaries and microbiology test results for antimicrobial resistance.

Looking forward, the full power of SNOMED CT comes from using its semantic network, which is perfectly positioned to support Symbolic AI opportunities in healthcare.

Further details on the AEHRC and CSIRO Case Study are included in Appendix 5 here.
Case Study #10
Artificial Intelligence: A Look into Now and a Peek into the Future
Artificial Intelligence in Healthcare Globally

- Artificial Intelligence (AI) is simply defined by Merriam-Webster online as “1: a branch of computer science dealing with the simulation of intelligent behavior in computers, 2: the capability of a machine to imitate intelligent human behavior”.

- Many nations and regions around the world (e.g. US, Europe, UK, China) have been actively looking at the future role of artificial intelligence generally, as well as its use in healthcare specifically[1,2,3,4,5,6,7].

- As part of these reviews the impact on society (see table on right), organizations and the nations’ workforce have also been considered.

Case Study #10
Artificial Intelligence: A Look into Now and a Peek into the Future

Artificial Intelligence in Healthcare Globally

- The use of AI in healthcare is not new – it has been used for decades. However, the increasing capture of data electronically in clinical information systems, the increase in personal data captured through devices, sensors, imaging or genomics and the increase in computing power available – either through cloud-based computing platforms or on the phones in our pockets – is enabling a new generation of applications of AI through-out the healthcare system.

- Medical imaging/radiology were recent early adopters of AI given the substantial amount of imaging data available and the fact that early algorithm and model development was focused on images in general (e.g. LUNIT in South Korea).

- IBM Watson Health was an early entrant that initially focused on oncology via massive amounts of medical literature data and through acquisition of Truven Health Analytics and its 100 million patient records.

- In 2016 AI solutions focused on the diagnosis of diabetic retinopathy from a database of 128,000 retinal images. In neurology, AI was used in man/machine interfaces for spinal injury prostheses. In dermatology, a use of current models included an analysis of 129,000 dermatological lesions to distinguish two different skin cancers from seborrheic keratosis.

- In 2016, Mayo Clinic and AliveCor conducted a study utilizing EHR records from 2.8 million 12-lead ECGs from over 20 years of patient records and EKG readings for insights on potassium levels and correlations with T waves in ECGs.
Artificial Intelligence in Healthcare Globally

• Arterys was one of the first companies to receive U.S. FDA clearance for a cardiology application, Cardio DL, which provides automated, editable ventricle segmentations from MRI images of the heart.

• Since then there has been over 40 FDA approvals for artificial intelligence-based algorithms in medicine (as of 07/2019). The majority of the approvals have been in radiology, cardiology, oncology, and endocrinology.

• Not surprisingly, the venture capital investment in AI solutions has exploded during the past 5 years with the locus of development activity being in the U.S. (e.g. Recursion Pharmaceuticals), China (e.g. Ping) and Israel (e.g. OrCam) and the UK (e.g. Babylon).

• China leads the world in the number of healthcare AI research studies (41), followed by the US and Europe (28 each).
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Artificial Intelligence: A Look into Now and a Peek into the Future

Australia – One Nation’s View Into Artificial Intelligence in Healthcare

• For most nations, the introduction of AI into healthcare is seen as providing a wide range of access, quality and productivity benefits during a time when healthcare costs continue to steadily increase. However, for many, the use of AI is also daunting, given the potential workforce impacts and the potential for negative unintended consequences.

• In July 2020 CSIRO and the Australian eHealth Research Centre published “Exemplars of Artificial Intelligence and Machine Learning in Healthcare”8. It provides, an overview of artificial intelligence (AI) and machine learning (ML), where SNOMED CT fits in the AI/ML space, and thirty-four case studies showcasing the use of AI/ML in healthcare in Australia.

• CSIRO divides the use of AL/ML in healthcare into four domains:
  1. **Predictive Analytics and Data-Driven Intelligence** is concerned with extracting insights from existing data (e.g. SNOMED-CT coded clinical data).
  2. **Knowledge Representation and Reasoning** is how we represent information about the world (e.g. as in SNOMED CT semantic network) so a computer system can utilize it to solve complex tasks and enabling us to infer(new) knowledge.
  3. **Imaging and Vision** involves analyzing images or videos to derive insight into the cause and impact of medical conditions.
  4. **Human Language Understanding** uses AI methods to understand natural language and make it machine-readable.

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Case Study #10
Artificial Intelligence: A Look into Now and a Peek into the Future

Australia – One Nation’s View Into Artificial Intelligence in Healthcare

- **Artificial Intelligence** depends on high quality data to either train AI models or for AI based analysis. This includes clinical data, genomics data, imaging, administrative data, as well as sensor and wearables data.

- In AI, there have traditionally been two schools with contrasting approaches – symbolic AI and statistical AI.
  - **Symbolic AI** methods make use of curated medical domain knowledge (i.e. facts or rules), such as SNOMED CT.
  - **Statistical AI** takes the opposite approach; rather than predefining the knowledge and rules, it ‘learns’ these from the data itself by extracting patterns and insights.

- While SNOMED CT encoded healthcare data can support both approaches, the full value of SNOMED CT (i.e. its semantic network capabilities) is realized when symbolic AI is used.

- **Machine Learning (ML)** gives computers the ability to learn without being explicitly programmed. There are two main ML tasks: classification and regression.
  - Classification uses a ML model to ‘classify’ data into categories; for example, classifying the type of cancer found in a pathology report into breast cancer, lung cancer and so on.
  - Regression, in contrast, uses a ML model to predict a value rather than a category. For example, predicting the length of stay for a patient given their condition. ML models learn from data, in either a supervised (i.e. answer choices are provided) or an unsupervised manner (i.e. answer choices are not provided).

- **Deep Learning** uses artificial neural networks for either classification or regression, both supervised and unsupervised.
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Artificial Intelligence: A Look into Now and a Peek into the Future

Australia – One Nation’s View Into Artificial Intelligence in Healthcare

Predictive Analytics and Data-Driven Intelligence Case Studies (12)

• **Data Driven Insights from Clinical Information Systems** – In Case Study 1 ML uses clinical data to predict the risk of patient hospitalization or readmission. Case Study 2 optimized elective surgery by modelling all the inter-connected departments requiring access to share surgery resources. Case Study 3 demonstrates how real time analytics is made possible through interoperable data efforts such as SNOMED CT and FHIR. Case Study 4 demonstrates how analytics can be used to predict future demand for services and patient flow. Case Study 5 showed how deteriorating patients can be identified and with an earlier intervention, prevent their condition worsening.

• **Insights from the Human Genome** – Case Study 6 uses random forest models to identify the underlying genetic causes of neurodegenerative diseases, thereby opening up new treatment avenues. Case Study 7 uses ML to help with the laborious curation task that pathologists must perform with genetic data. Case Study 8 uses ML to guide effective gene editing. Case Study 9 presents a cloud architecture with ML to visualize and track the genomic fingerprint of the COVID-19 virus.

• **Insights from Sensors** - Sensors have become ubiquitous in the home environment. Sensors in the home can aid elderly people to live independently in their homes for longer, which has health and economic benefits. Case Study 10 used passive (non-wearable and non-intrusive) sensors to accurately measure how someone is coping at home and identify when they might need assistance. Where multiple people live together, Case Study 11 used ML to identify the different individual people, from the elderly to infants. Case Study 12 used miniature wearable sensors for early identification of infants at risk of Cerebral Palsy.
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Predictive Analytics and Data-Driven Intelligence Case Studies

CASE STUDY 3 HIGHLIGHTED: RE-HOSPITALIZATION RISK STRATIFICATION

• New South Wales (NSW) Health uses the SNOMED CT-embedded Cerner clinical information system. The use of the HL7 FHIR data model and the SNOMED CT terminology has improved the interoperability of these systems, as well as for use by AI algorithms. Leveraging these standards has facilitated the deployment and scalability of real-time clinical analytics and decision support applications.

• A predictive risk stratification algorithm developed by CSIRO was added to vendor Alcidion’s Miya Platform. SNOMED CT data from the NSW Cerner system was sent as FHIR resources to the Alcidion Miya platform whenever certain trigger conditions were met, e.g. a new pathology report was received (see diagram on the right of this page).

• The CSIRO algorithm then calculated a risk score based on the SNOMED CT clinical data received and was displayed in the Miya platform on dashboards to support real-time decision making. This work demonstrates the potential for improved detection and management of patients at risk of readmission.
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Knowledge Representation and Reasoning Case Studies (6)

- **Knowledge Representation using Ontologies** - Case Study 13 describes the “Snorocket” reasoner, software that uses the Dresden algorithm, to rapidly draws inferences and create new knowledge using the SNOMED CT medical ontology.

- **Extending Medical Ontologies** - One key advantage of the formal logic of ontologies like SNOMED CT and reasoners like Snorocket is that it can be extended to support new domains (e.g. medications). Case Study 14, shows how the Australian Medicines Terminology (AMT) and reasoners can be extended to provide support for medications, including numeric values such as dosages. AMT is included in the Australian edition of SNOMED CT. Case Study 15 solves the problem of keeping medication ontologies up-to-date by analyzing medication lists and automatically generating the appropriate medications knowledge in the AMT medical ontology. Case Study 16, shows how new medical knowledge can be added through ‘post-coordination’, whereby new concepts can easily be defined using the existing formal logic of SNOMED CT.

- **How Knowledge Representation Supports Analytics** - Knowledge about how to use the SNOMED CT ontology, including its rules and properties, supports the use of the ontology in many applications – including data analytics, search engines and NLP. The representation of knowledge in this way is a core part of AI. Case Study 17 demonstrates Pathling, an advanced analytics service that exploits standardized SNOMED CT medical data to provide APIs that enable data visualization, dashboard analytics, patient cohort selection and data preparation services.

- **Integrating AI into Clinical Workflow** - Case Study 18 presents FORTE, a FHIR-based Workflow Platform for integrating AI into a Radiology Clinic. This provides a means of integrating automated methods into an existing clinical workflow.
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Australia – One Nation’s View Into Artificial Intelligence in Healthcare
Knowledge Representation and Reasoning Case Studies

CASE STUDY 17 HIGHLIGHTED: ADVANCED ANALYTICS OF GENOMIC PHENOTYPE DATA

• Increasingly more data is being collected using SNOMED CT and shared using FHIR. This provides an opportunity to use these two standards to build advanced analytics tools on top of this data. Pathling, is an advanced analytics service that exploits this standardized health data to provide APIs that enable data visualization, analytics dashboards, patient cohort selection and data preparation services.

• Pathling understands the FHIR data model and it can integrate with a FHIR terminology server to enable the use of the description logic underpinning SNOMED CT.

• Pathling was recently used to perform an advanced analysis of genomic phenotype data which was collected using FHIR and SNOMED CT. In this set of data, differential diagnoses were collected at stages through the patient journey using SNOMED CT. As more testing was undertaken (including whole genome sequencing) Pathling was able to use the SNOMED CT semantics to understand the change in diagnosis – from a general diagnosis to a more specific diagnosis, or potentially to a completely unrelated diagnosis (e.g. see the Sankey diagram generated from the data to the right).
Case Study #10

Artificial Intelligence: A Look into Now and a Peek into the Future

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Human Language Understanding Case Studies (6)

- **Natural Language Processing** - There are two main automated approaches to Natural Language Processing (NLP): rule-based and ML based. Case Study 19 is an example of how rule and deep learning approaches can be combined to extract valuable SNOMED CT-encoded information on cancer from a range of free text medical documents. Case Studies 20 and 21 show how machine-learning based NLP and SNOMED CT can be integrated into hospital workflow to detect missed limb fractures and to identify patients with antibiotic resistant infections. Case Study 23 shows how NLP can be used to automatically quantify the semantic similarity between sentences in medical literature for evidence-based medicine.

- **Information Retrieval** - Case Study 22 demonstrates how a range of machine-learning based information retrieval methods can be used to help produce better systematic reviews of the literature.

- **Conversational Agents** - With the rise of social and communication technologies, conversational agents, or chatbots, provide a means for users to become engaged in conversation, continuing and progressing the dialogue in the same way human-to-human interaction occurs. Some examples where chatbots have been implemented include monitoring speech degeneration in patients with Parkinson’s Disease, disease self-management, encouraging behaviour change, and provision of health education. Case Study 24 presents a project to develop a chatbot to assist patients in decision making for the provision of genomic information.
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Human Language Understanding Case Studies

CASE STUDY 19 HIGHLIGHTED – AUTOMATING CANCER REGISTRY TASKS TO ENHANCE CLINICAL DATA QUALITY

• Information about cancers are gathered from a variety of different modalities – including imaging and from biopsy and resections – and then typically written into a narrative report and sent to the treating clinician. CSIRO has worked with Cancer Alliance Queensland to extract information from pathology and radiology reports and death certificates, using AI technologies, for a variety of reporting purposes – including cancer notifications, cancer staging and synoptic reporting.

• The AEHRC Medtex technology uses a mix of symbolic and statistical AI methods to process the clinical reports. A natural language processing (NLP) engine is used to break the discourse of the text into statements and then features are extracted from each statement. The meaning of these features is then inferred through using ML models, which are trained from ground truth (human judgements) data using deep neural networks. For some features a formal logic rule-based approach using the relationships encoded in SNOMED CT is utilized.

• The software now supports the extraction of over 20 different clinical features from the text of the histopathology reports covering a range of cancers. Studies have shown that the accuracy of the AI algorithms is very high. The algorithms have a 96% recall and precision for classifying notifiable cancers. Detailed extraction and coding of specific cancer notification items include basis of diagnosis, histological type and grade, primary site and laterality. Visual explanations and feedback from AI decisions are supporting clinical coders in their cancer abstraction task.
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Human Language Understanding Case Studies

CASE STUDY 20 HIGHLIGHTED: CHECKING RADIOLOGY REPORTS TO PREVENT MISSED FRACTURES

• Patients admitted to a hospital emergency department (ED) with a suspected fracture are X-rayed, treated and then discharged. However, when the X-ray report is later finalized by a radiologist, ED specialists have to manually match the report from the radiologist with the patient’s discharge diagnosis to ensure that subtle fractures were not missed. The manual checking process is an essential but laborious task.

• The Medtex system (See Case Study 19) was used to perform this check automatically and then flag any potential inconsistencies. The solution uses NLP to extract features from the reports. ML models including support vector machines and deep neural networks are then used to find associations between features in the radiology report. SNOMED CT clinical terminology concepts are used as features to reliably identify limb fractures and other abnormalities documented in radiology reports (see diagram to right of this page).

• Medtex automatically matches fractures identified in the radiology reports with patients' ED discharge diagnosis to provide decision support for the current manual checking process. Studies have shown that this checking can be done with high precision and recall across three different hospital ED settings. By fast-tracking diagnoses and streamlining test result reviews, emergency departments can save time and deliver improved patient outcomes.
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Human Language Understanding Case Studies

CASE STUDY 21 HIGHLIGHTED: TACKLING ANTIMICROBIAL RESISTANCE WITH TEST RESULT REVIEW

• Antibiotic overuse contributes to antimicrobial resistance, which could cost the global economy US$100 trillion by 2050 and cause up to 10 million deaths per year. Patients with suspected infections are tested for the presence of bacterial organisms with antibiotic resistance. These test results are then manually reviewed to ensure patient’s infections are not resistant to the antibiotics they are taking. This project aims to automate this process in two parts: 1) streamline Emergency Department microbiology test result review to identify bacterial organisms and their antibiotic sensitivities; and 2) match these with antibiotic prescriptions extracted from Emergency Department discharge letters.

• Our NLP methods extract antibiotic prescriptions detailed in discharge letters. Then we parse microbiology reports for bacterial organisms and antibiotic sensitivities. Given these two sources, we exploit the semantics in SNOMED CT to match antibiotic prescriptions (e.g. generic and trade names) with the bacteria’s sensitivities for a given antibiotic class. This provides clinical decision support to identify patients that have been prescribed an antibiotic for which the bacterial organisms are resistant. The patient can then be contacted for follow-up treatment, such as a change of antibiotic treatment.

• An example scenario is when the discharge letter notes that a patient was prescribed with “ampicillin”. When the microbiology test result returns, it notes the bacteria present was “Escherichia-coli” (E. coli): a bacterium known to be resistant to ampicillin. The system would pick this up immediately and alert the clinician, enabling the patient to be contacted and provided with a more appropriate antibiotic.
Case Study #10
Artificial Intelligence: A Look into Now and a Peek into the Future

Imaging and Vision (10)

- **Medical Image Analysis** - Medical image analysis employs a range of supervised and unsupervised AI and ML techniques to extract clinically relevant information or knowledge from medical images.

- **Using Imaging for Early Detection of Abnormal Development** - Case Study 25 is a cloud-based ‘Developing Brains’ toolbox using ML to analyze MRI scans of very preterm-born infants to identify biomarkers that predict later motor, neurological and neurobehavioral problems. Case Study 26 describes AssessCP, a clinical support tool for pediatric brain injury.

- **Image Guided Treatment and Disease Monitoring** - Case Study 27 shows how software that integrates with MRI machines can be used to quantify the changes in cartilage indicating osteoarthritis – this guides surgery such as joint replacements. Case Study 28 uses MRI images to help guide the delivery of radiotherapy for prostate cancer. Case Study 29 uses PET imaging to generate quantified measures for risk of Alzheimer’s Disease. In Case Study 30, deep learning methods are used on ocular images for automated detection of macular degeneration that can cause blindness. Case Study 31 uses image processing for segmentation of flecks in the eyes to track Stargardt disease progression.

- **AI-Based Telehealth** - Case Study 32 presents a tele-oral care system that provides AI-driven oral mucosal disease classification and specialist-based clinical decision support. Case Study 33 provides face detection and automated classification of patient emotion from video for tele-health.

- **Robotics** - Case Study 34 shows how socially-assistive robots are used to supplement traditional therapy and education for children with autism.
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Australia – One Nation’s View Into Artificial Intelligence in Healthcare

IN SUMMARY

• Artificial Intelligence, including Machine Learning and Deep Learning is rapidly being adopted in healthcare systems around the world, as a way to achieve access, quality and productivity gains.

• **SNOMED CT** is uniquely positioned to support the expansion of AI in:
  1. Predictive Analytics and Data-Driven Intelligence (i.e. data driven insights from clinical information systems)
  2. Knowledge Representation and Reasoning (i.e. knowledge representation to support analytics and research)
  3. Human Language Understanding (i.e. natural language processing).

• Looking forward, the full power of **SNOMED CT** comes from using its semantic network, which is perfectly positioned to support symbolic artificial intelligence opportunities in healthcare.
Experience the value of SNOMED CT

Read the full report and visit the value platform at:

snomed.org/value