McKinsey Digital

Artificial Intelligence for Industry

Norbert Biedrzycki

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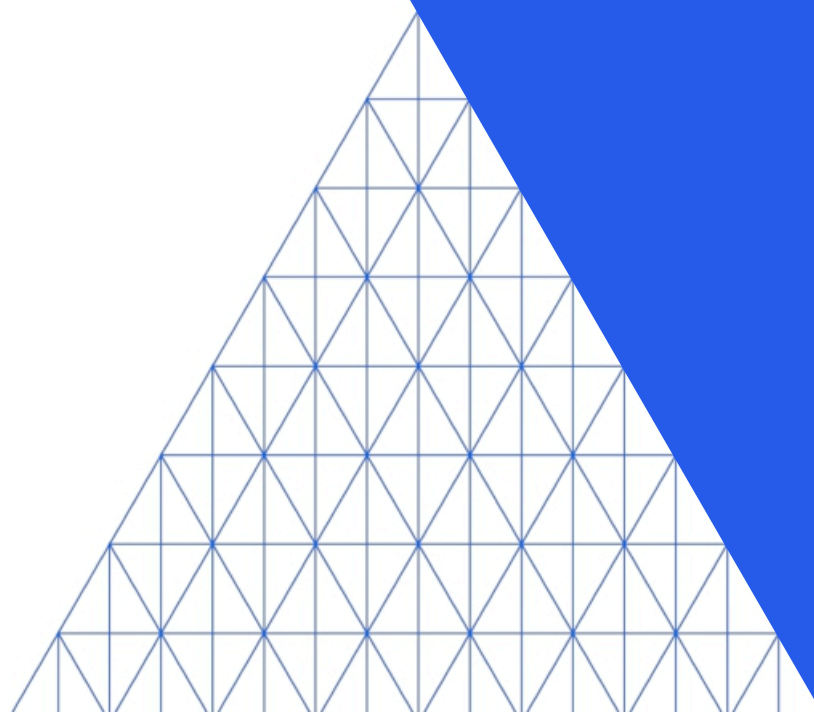


Artificial Intelligence is on the verge of disrupting businesses and society

13X
Equity investments in AI startups 2018E vs 2012

~4,500
Number of AI deals in 2018

250X
Processing power of a GPU over CPU for image classification

$15 trillion
Value of wages automatable

$37B
Equity funding in AI Startups in 2017 (3x 2016)

420+
AI US startups, exceeding $15bn in total capital raised

$300+ billion
Expected enterprise revenue from AI in 2025

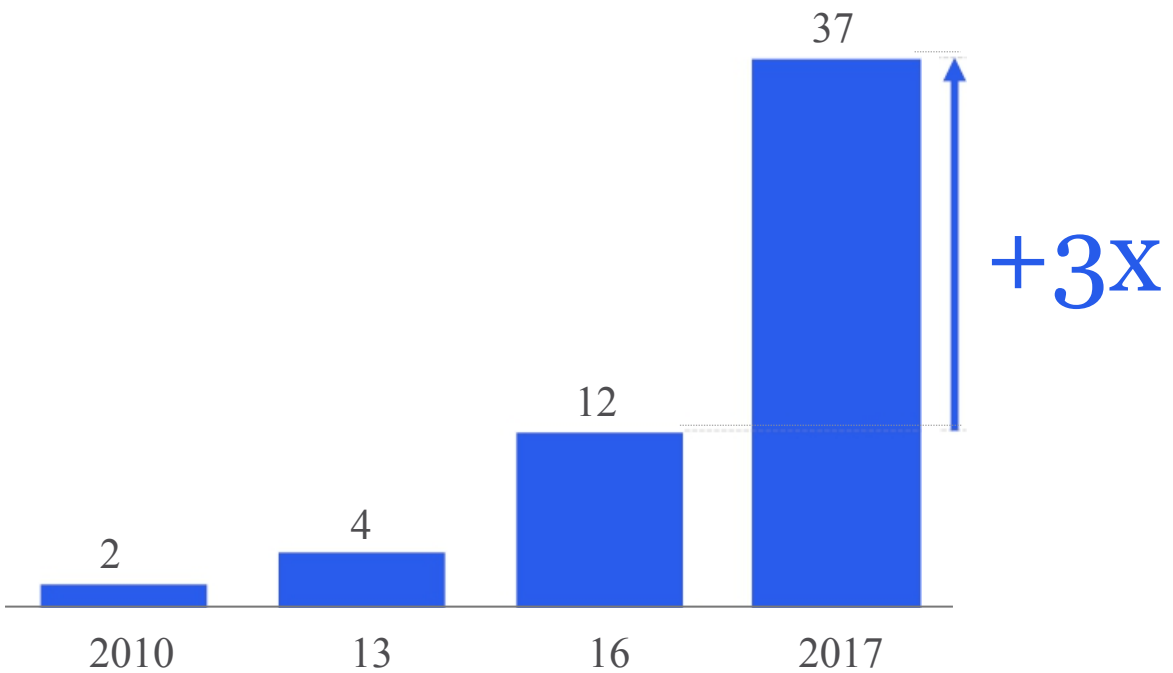
Year when computer power is estimated to surpass human brain power in terms of computations per second

SOURCE: MGI Artificial Intelligence – The next frontier June 2017

Investment in AI has continued to grow exponentially fueled by expectations of an emerging AI market that will be over $300 bn by 2025

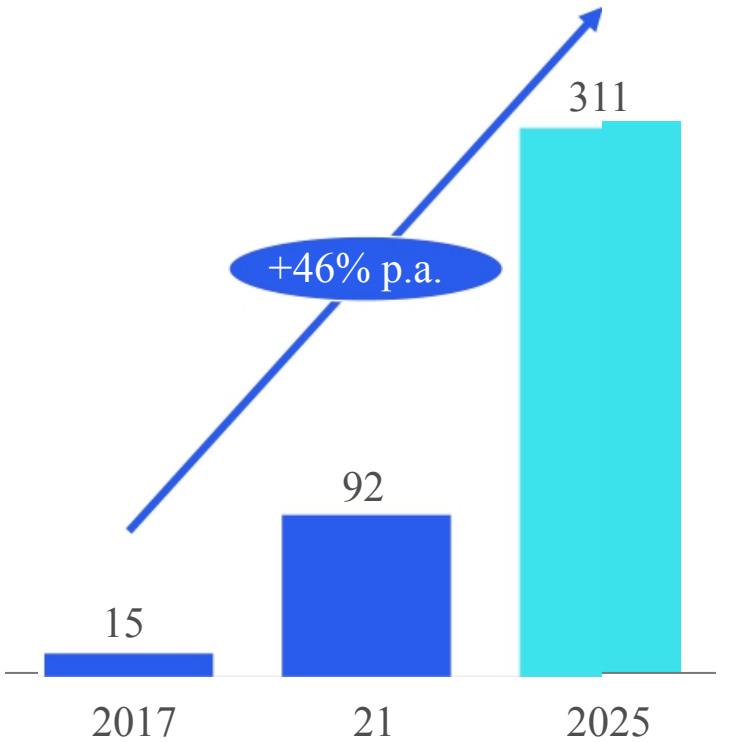
Global investment in AI companies has been tripling every 3 years[1]

USD bn



AI expected to be a +$300 bn market by 2025, growing at ~50% CAGR[2]

Enterprise AI revenue, USD bn



1 Estimates consist of annual VC investment in AI -focused companies, PE investment in AI -related companies, and M&A done by corp orations. Includes only disclosed data available in databases, and assumes that all registered deals were completed within the year the transactions were announced.
2 Enterprise AI Revenue including software, applications, hardware, services

SOURCE: Pitchbook, Tractica

Some business leaders and scientists foresee an AI revolution coming soon

Bill Gates
Founder of Microsoft

It will look at all the new information and present to you, knowing about your interests, what would be **most valuable**. What we're seeing is, for the first time, **computers can see as well as humans**. If you combine that with arm - like manipulation, then they could **make us far more productive**

Steve Wozniak
Founder of Apple

It is a new revolution in my mind, the **revolution of artificial intelligence, machines** that **will learn**, that will **be able to do things much better than we know how to tell them**

Andrew Ng
VP & Chief Scientist of Baidu

AI is the new electricity. Electricity had once transformed countless industries. **AI will now similarly transform transportation, manufacturing, healthcare, communications, and more**

Stephen Hawking
Professor,
U. of Cambridge

Success in creating **effective AI, could be the biggest event in the history of our civilization.** Or the worst. We just don't know. So we cannot know if we will be infinitely helped by AI, or ignored by it and side- lined, or conceivably destroyed by it. I fear that AI may replace humans altogether

Industry 4.0 is enabled by disruptive technologies that will change the manufacturing sector between today and 2025

Data, computational power and connectivity

- Sensors
- Internet of Things/ Machine- to machine
- Cloud technology

Analytics and artificial intelligence

- Automation of knowledge work
- Big data and advanced analytics

Industry 4.0

Human machine interaction

- Touch interfaces and next- level graphical user interfaces
- Virtual and augmented reality

Conversion to physical world

- Industrial automation (e.g., collaborative robots, AGVs)
- Additive manufacturing (i.e., 3D printing)

Industry in Poland needs to increase productivity to catch up with Europe it's full AI driven automation potential

- Productivity of industrial production in Poland is far behind the European average. The **gap to the average in the countries of Western Europe (EU - 15) is over 40%**
- On average **49% of working time is devoted to activities that could be fully automated** (potential of 3m jobs in Poland)
- Activities with the highest automation potential: predictable, repetitive activities such as **machine operation, production line work and simple maintenance duties**

Key AI Industry applications for further consideration by Polish Industrial sector

Failure avoidance based on prediction analysis

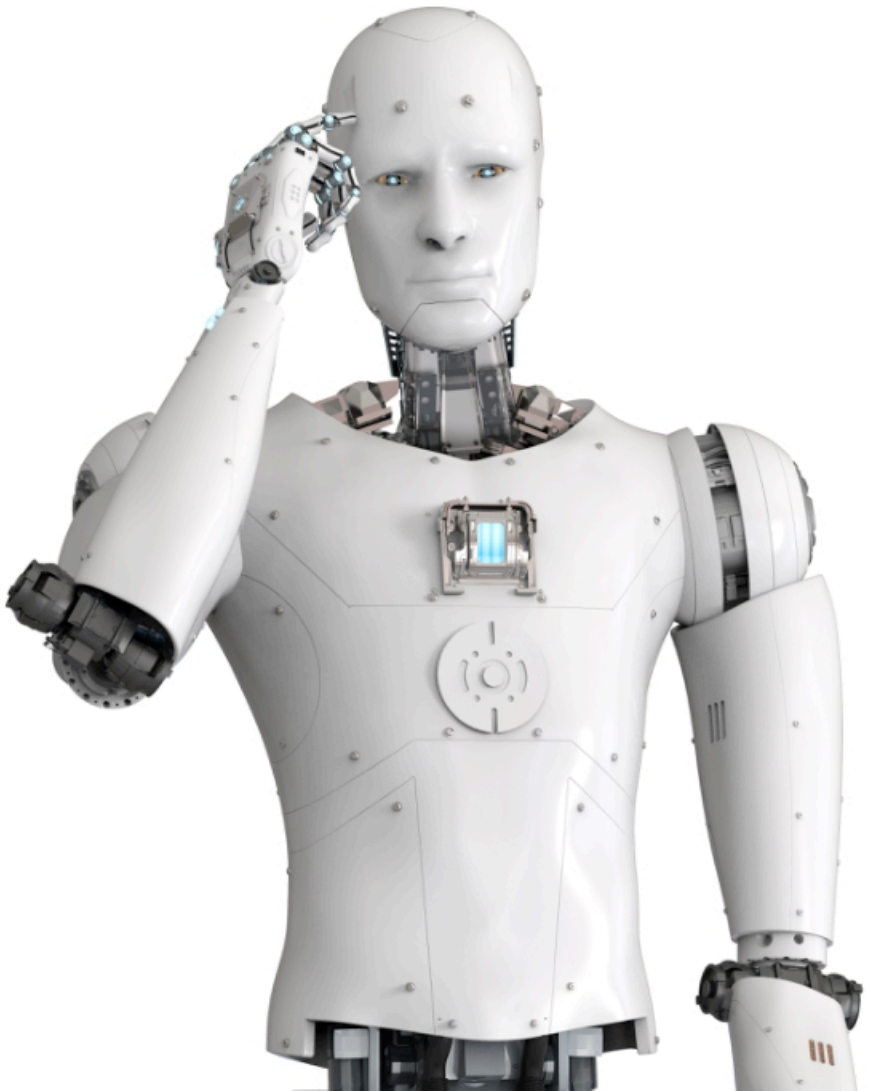
Computer vision enhancement

Postproduction and production inspection and **quality control**

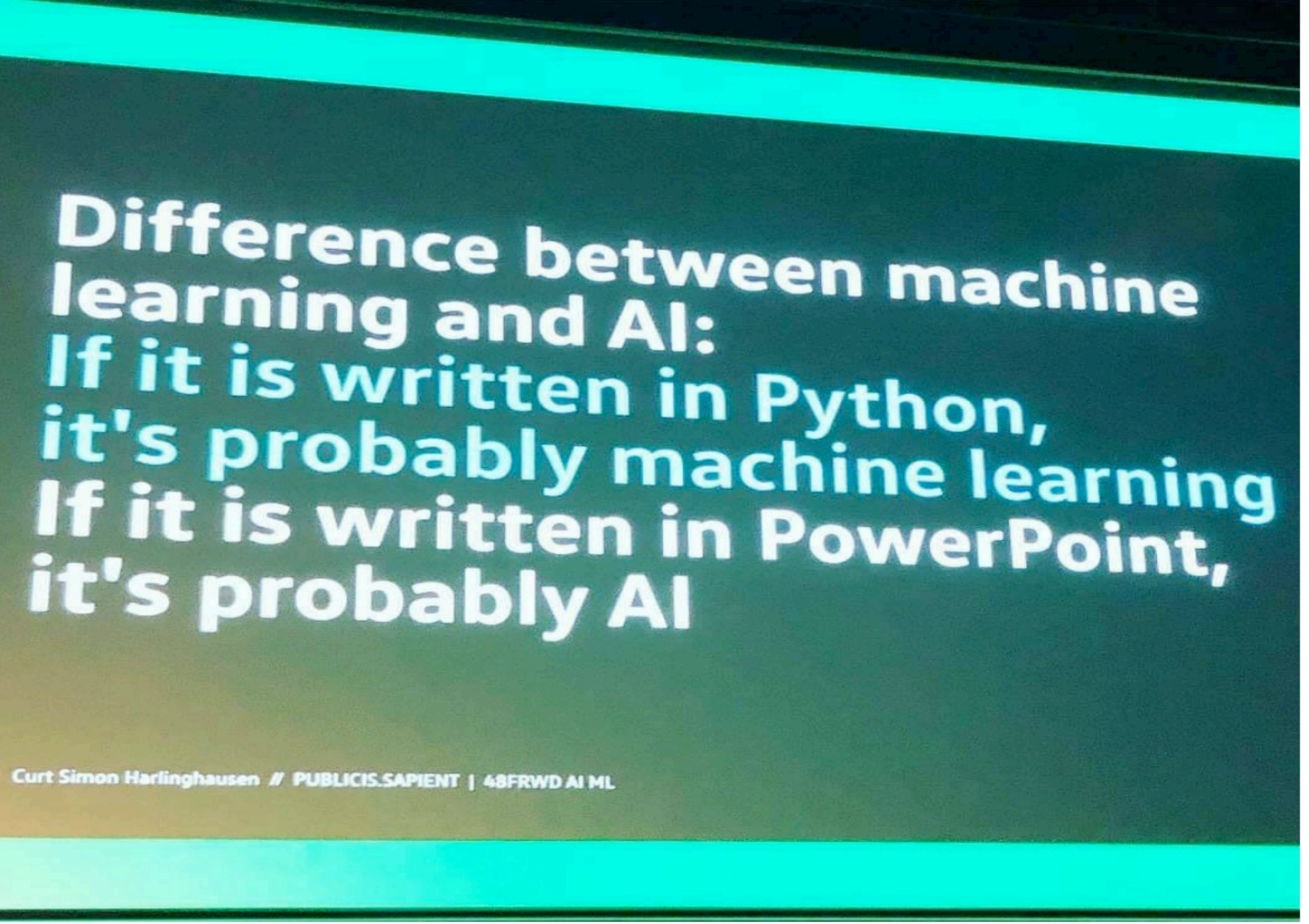
Demand prediction

Safety and early warnings

A definition of artificial intelligence

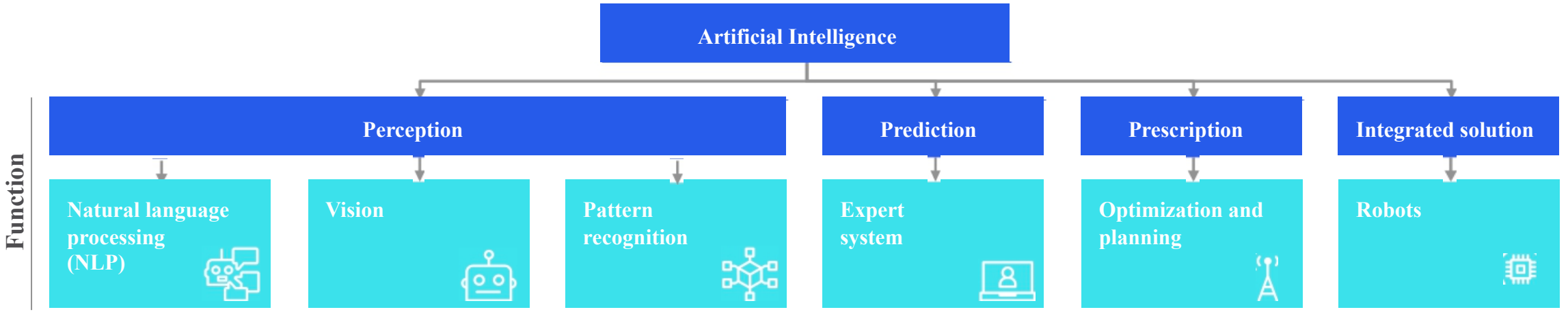


- **Intelligence exhibited by machines** that are used to perform **cognitive functions** we associate with human minds
- AI enables machines to deal with imperfect and new data, that they can process and learn from through algorithms and therefore can interpret new data and make decisions based on it
- **Human cognitive functions** performed by AI include **perceiving** (e.g. computer vision, language processing), **learning, identifying patterns, making predictions**
- **Machines learn through different AI techniques** . Depending on the technique used, AI can be limited to problems for which it was trained or adapt to new contexts i.e., situations it was not previously trained to deal with



True or not true?

Using the output from algorithms, machines can perform functions that imitate human cognition



Descriptions

Perception			Prediction	Prescription	Integrated solution
▪ Interpret, process, and respond to semantic and sentimental information of natural language	▪ Enable machine to gain visual input, extracting numerical, symbolic contextual information	▪ Enable computer to recognize patterns and regularities in data	▪ Simulate the judgment and behavior of a human expert	▪ Create data - driven solutions, improve operations integration	▪ Integrated system of AI hardware and software

Example solution/ usecase

Perception			Prediction	Prescription	Integrated solution
▪ Speech understanding ▪ Language translation ▪ Sentimental understanding	▪ Handwriting recognition ▪ Face detection ▪ Expression understanding ▪ Scene Analysis	▪ Financial risk stratification ▪ Data model building ▪ Music and Voice recognition	▪ Medical diagnosis ▪ Targeted advertising ▪ Recommendation engines	▪ Route planning ▪ Spend optimization ▪ Dynamic pricing	▪ Autonomous driving ▪ Robotic surgery ▪ Household robots

SOURCE: Literature search, team analysis

Machine/deep learning use cases yield tremendous value

The total value opportunity for all global Automotive OEMs together is about USD ~ 215 bn in 2025 – equaling a ~9 percentage point EBIT increase for an average OEM

In cooperation with: Google CES

Value potential from bottom - line effects
USD billions (as share of costs in corresponding part of the value chain)

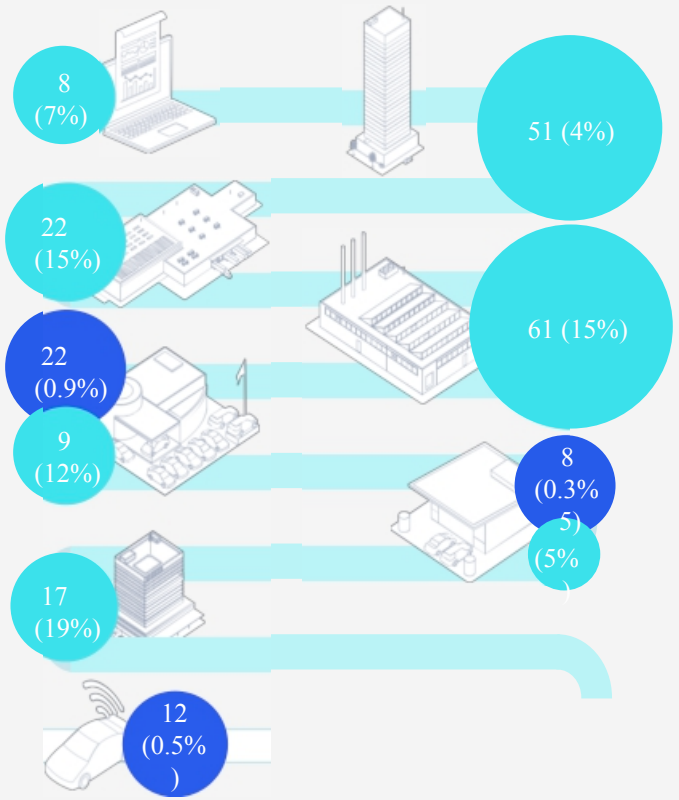
Value potential from top - line effects,
USD billions (as share of total revenue)

Research and development
Use of vehicle usage data for R&D optimization

Supply chain management
Autonomous guided vehicles

Sales and marketing
Reduction of discounts on vehicle
Next- product- to- buy prediction

Support functions
Automated processing of invoices with natural language processing



Driver/vehicle features
Autonomous obstacle avoidance and next- generation navigation

Procurement 1
Advanced spend intelligence

Manufacturing
In- line quality measurement by vision or sound

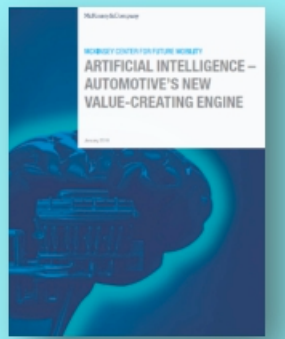
Aftersales and services
Pulling customers to licensed garage for service and spare parts
Assortment and storage level optimization for spare parts

+

Σ ~ USD 215 bn
≙ 9 EBIT percentage points or an average annual productivity increase of approximately 1.3%

Key insights

- **120 AI use cases** identified along the value chain
- AI- enabled **value opportunity of ~USD 215bn** derived
- **4 key success factors** for AI transformations: collecting/ synchronizing data, setting up partner ecosystem, establish AI operating system, build core AI capabilities/team
- OEMs need to start transformations now by **implementing pilots**



1 Includes direct and indirect spend

SOURCE: McKinsey

We identified AI enabled use cases along the entire value chain...

NOT EXHAUSTIVE

Most impactful

Industry example

AI capabilities	Value chain: R&D	Procurement	Supply chain management	Manufacturing	Marketing & Sales	Aftersales and services	Support functions
Insight generation from complex data	▪ AI - based suggestions for product design ▪ R&D prioritization and performance improvement (e.g. using outcome prediction for experiments) ▪ Concept quality increase (e.g. prediction of quality patterns at dev. process gates)	▪ Advanced clean sheet analytics for parts through on index- based parametrization ▪ ...	▪ AI - based demand forecasting for advanced planning ▪ Closed- loop planning (e.g. integrated pricing and inventory mgmt. across channels) ▪ ...	▪ Predictive maintenance through AutoML ▪ Automatic OEE optimization ▪ Overarching quality analysis to identify patterns of quality issues (e.g. for certain suppliers, dependencies between certain production steps, etc.) ▪ ...	▪ Sales forecast optimization ▪ Next product to buy ▪ Built - to- stock optimization ▪ ...	▪ Improved mapping of customers to service agents to increase customer satisfaction ▪ Predictive service recommendations, incl. pulling customers to own/ licensed garage ▪ Predictive churn prevention ▪ ...	▪ Financial forecasting (e.g. in combination with live analytics in "digital boardrooms") ▪ Credit risk optimization by prediction of customer risk score ▪ ML- based prediction of IT incidents minimizing downtime
Language processing, text and audio analytics	▪ ...	▪ Automated spend categori- zation through NLP text analysis (60 different clients) ▪ ...	▪ ...	▪ Sound analysis for engine quality assurance ▪ ...	▪ Automated root cause analysis of customer (dis-) satisfaction in social media ▪ ...	▪ ...	▪ Automated processing of invoices with natural language or image/text recognition processing ▪ Automated claims mgmt. ▪ Automated payment execution using text recognition (e.g., to identify the bank account number in non- standardized invoices)
Image recognition and video analytics	▪ ...	▪ Comparable document analysis through image- to-text ▪ ...	▪ Visual inspection of infrastructure (e.g. roads) ▪ ...	▪ In- line visual quality assessment (valve manufacturer) ▪ Improvement of parts mgmt. to reduce buffers/ inventory, e.g. using image recognition at supermarkets or constant learning to optimize order timing ▪ ...	▪ ...	▪ Visual inspection of used cars by image recognition ▪ ...	▪ ...
Virtual agents, bots, and avatar	▪ Wear & tear simulation ▪ ...	▪ AI - based supplier screening ▪ ...	▪ Autonomous guided vehicles (AGVs) in warehouses ▪ ...	▪ ...	▪ ...	▪ Customer service bots with the ability to adaptively guide customer journey	▪ Chat bot/Avatar as process "guardian" for employees in manual, indirect processes ▪ ...
Automated decision making	▪ Automated product design ▪ ...	▪ Automated supplier performance scorecard ▪ ...	▪ Improved utilization of transport capacity based on pattern recognition in real- time transport information ▪ Automatic order placement and management, esp. where algorithm can handle special situations based on constant learning	▪ Auto ML in for automated quality assurance decisions ▪ ...	▪ Customer base retargeting ▪ Digital advertising automatization based on customer profiles ▪ ...	▪ Automated order regis- tration, handling, and payment based on image/ text recognition ▪ ...	▪ ...

... of which we selected the top 11 use cases to kickstart an AI transformation

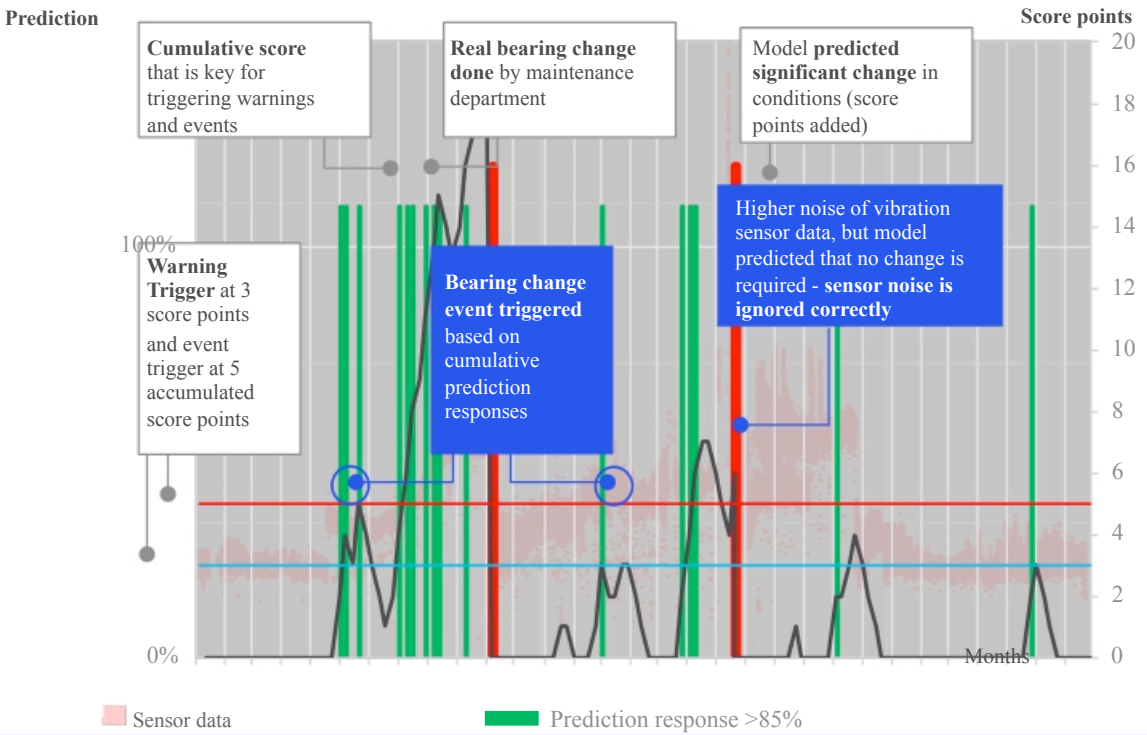
NOT EXHAUSTIVE

AI capabilities	Value chain: R&D	Procurement	Supply chain management	Manufacturing	Marketing & Sales	Aftersales and services	Support functions
Insight generation from complex data	1 AI-based suggestions for product design		3 AI-based demand forecasting for advanced planning	4 Predictive maintenance through AutoML (SPARKBEYOND)	6 Sales forecast optimization 7 Next product to buy	8 Predictive churn prevention	11 Financial forecasting
Language processing, text and audio analytics		2 Automated spend categorization through NLP text analysis					No deep dive available – confidentiality discussion pending
Image recognition and video analytics				5 In -line visual quality assessment		9 Visual inspection of used cars by image recognition (Google)	
Virtual agents, bots, and avatar					10 Customer service bots with the ability to adaptively guide customer journey		
Automated decision making							

Technology partner: SPARKBEYOND, Google, QUANTUMBLACK

4 Predictive maintenance through AutoML – AI - based bearing changes can reduce scrap in semiconductor production

Use case Improve OEE and reduce production downtimes through predicting production failures and optimize maintenance through identification of optimal replacement timing



Context

- Highly automated and connected semiconductor production environment
- Machine sensors were able to issue maintenance alert 24 hours ahead of downtime, simultaneous downtime of 2 machines would create production capacity constraint
- Bearing changes of semiconductor polishing arms require 8h of downtime

Methodology

- Analysis of 3 years of historical machine, maintenance, and quality data linked to malfunction (e.g., incident data, maintenance data, vibration sensors)
- Application of proprietary AutoML solution of technology partner Spark Beyond to automatically develop advanced algorithm for early prediction of required maintenance
- In total 100+ features (correlations, gradients, etc.) to be converted into score points, which indicate downtime likelihood
- Model was able to increase prediction times from 24 hours to 4 weeks with 90% accuracy

Advantage of Artificial Intelligence

AI can predict downtimes significantly earlier and more reliable

Learning algorithms can differentiate between irregularities with and without indication of future downtimes

Impact

1.5pp OEE optimization

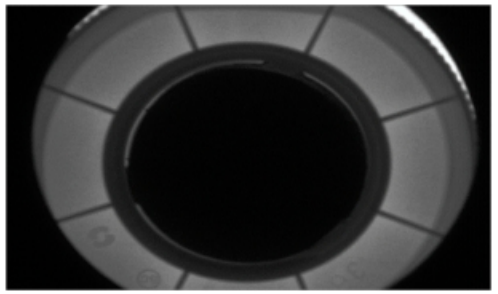
10% maintenance capacity freed up

90% Accuracy of predicting downtimes 4 weeks in advance

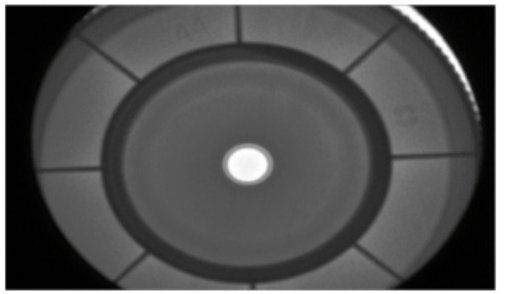
40% reduction of waste

5 In- line visual quality assessment – AI - based image recognition automates in- process quality inspection with perfect accuracy

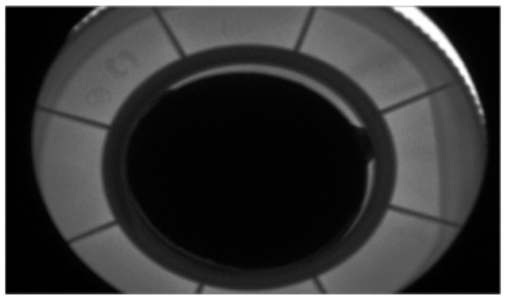
Use case Use AI - based image and video analytics to automate and improve current quality control processes, i.e., identify and reject defective parts/products



Non - defective valve



Valve with missing inner lining



Valve with shifted inner lining

Context

- Client is a large American manufacturer of pumps and valves
- Even the human eye has problems to identify product defects and is unable to deliver quality assessment for all products while upholding lead times
- Product defects in quality control are ever- changing and dynamic and require dynamic assessment procedures

Methodology

- Deep learning models outperformed all other methods and humans in several academic computer vision competitions (ImageNet)
- We built a Convolutional Neural Network (CNN), a deep learning architecture, that is specialized in processing images and automatically extracting patterns and features from images
- Self - learned features can be used to distinguish between defective and non-defective products – AI model can adapt to changing defects by online training without changing model architecture

Advantage of Artificial Intelligence

AI is faster, cheaper, and more accurate in basic image recognition tasks than a single human

All products can be quality controlled by AI within target lead times

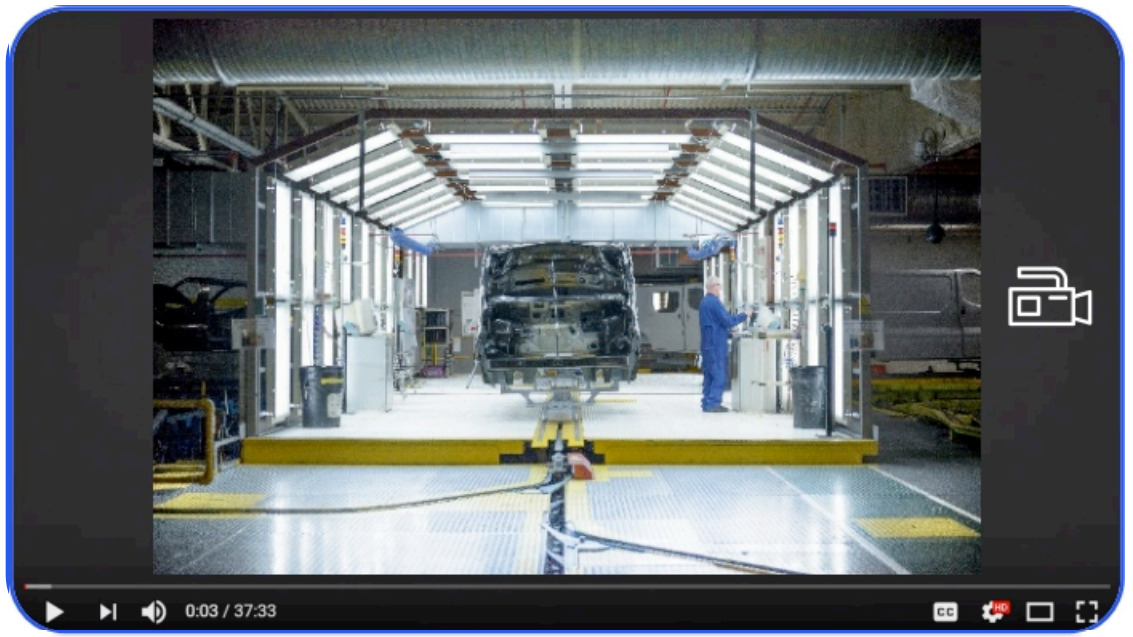
Impact

100% accuracy in detecting (non-) defective valves

32ms processing time for 1 image; enabling deployment in fast - paced manufacturing

9 Visual inspection of used cars by image recognition – Automated damage detection and residual value prediction

Use case Use AI - based image analytics to automate and improve accuracy of visual inspection and residual value estimation for used cars (e.g., for off - lease/employee vehicles)



Context

- Off - lease/employee vehicles require labor - intensive inspection and RV prediction before being sold in second price line
- OEMs can generate significant RV uplift by more accurate and granular RV setting

Methodology

- Image recognition requires deep learning model to cope with infinitely different and ever - changing image variations
- We used Google's cloud and machine learning capabilities to predict residual values by classifying physical damages to cars' exterior and interior
- AI model draws on image, vehicle, and meta data (e.g., age, mileage, configuration, recently realized residual values)

Advantage of Artificial Intelligence

AI is faster, cheaper, and more accurate in basic image recognition tasks than a single human

Image recognition requires learning algorithms

Impact

50 - 80%
fixed cost reduction through automation

Shorter
standing times until vehicle can be offered (10+ EUR higher CM per day)

Higher accuracy
in residual value prediction

9 Visual inspection of used cars by image recognition – Deep Dive 1/2

Data input and requirements

- Historic visual inspection data to train, optimize, and validate the AI solution (vehicle images incl. observed damages, residual value prediction, actual residual value, etc.)
- Vehicle meta data and external context data to enrich the predictive abilities of the model (e.g. vehicle age, mileage, configuration)

Applied AI technology

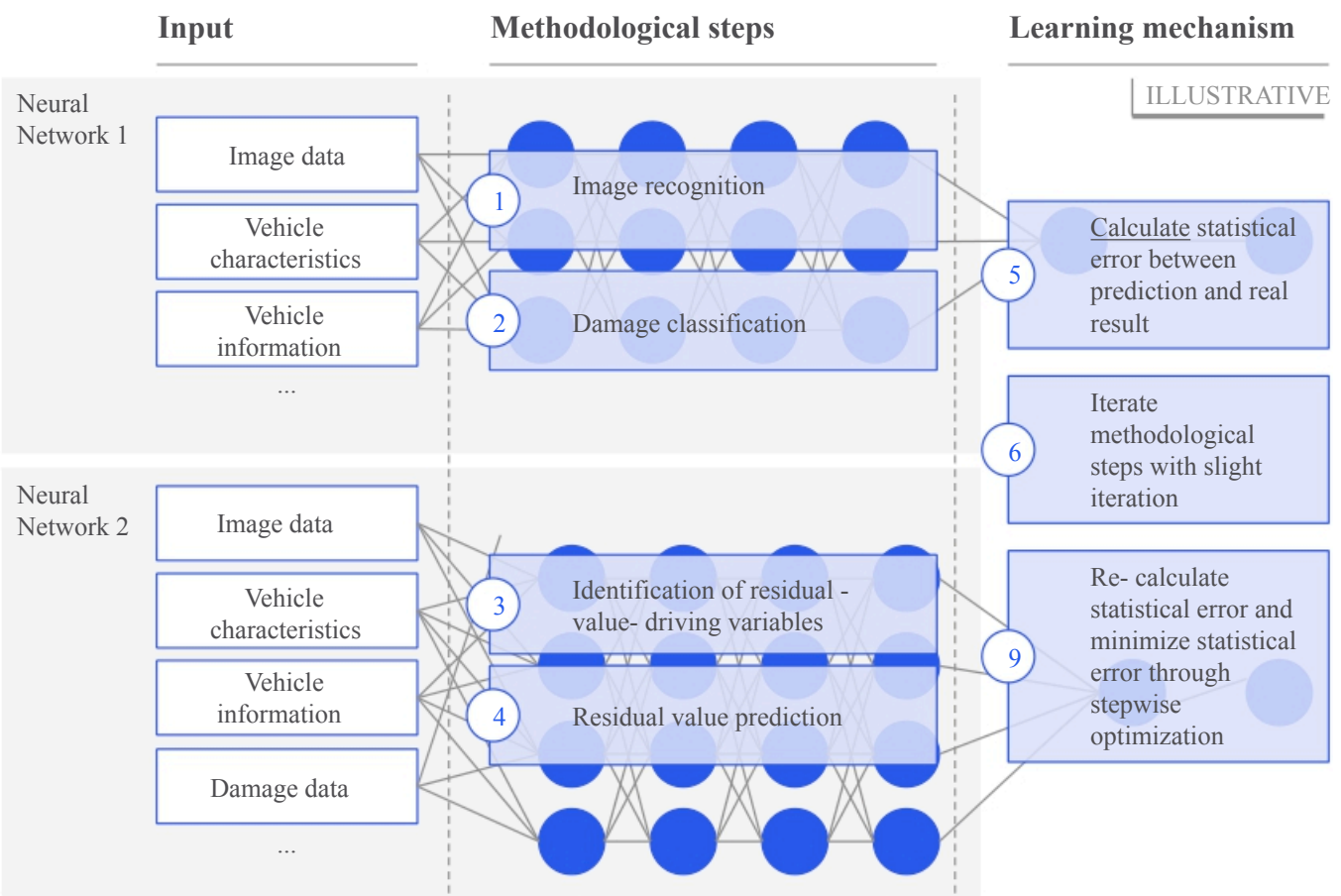
- Combination of 2 neural networks with 2 different objectives, which first detect relevant damages of the vehicle through image recognition and then predict the residual value
- Neural networks are able to mathematically dissect images through so- called layers, which layer by layer reduce the dissected information to the relevant elements
- The dissected mathematical information is used to sequentially predict properties of the picture (e.g., scratch vs. no scratch), calculate the statistical error of the prediction, learn from errors and minimize the prediction error

Results

- Identification of the respective vehicle (model, version, etc.)
- Detection of visible damages of the vehicle
- Prediction of the residual value

Modelling details

Combination of 2 neural networks with objective function to detect damages and predict the residual value



9 Visual inspection of used cars by image recognition – Deep Dive 2/2

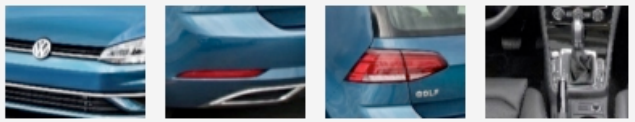
Exemplary prototype ILLUSTRATIVE

Vehicle information

Modell: Golf
Version: VII Highline
Engine: 1.4 TSI
Fuel type: Gasoline
Drive system: front drive

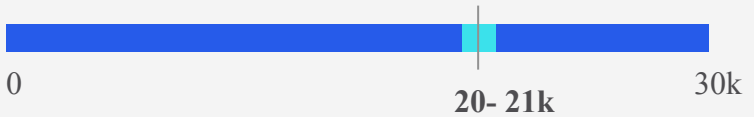
Confidence level: 93%

Visual data and detected damages



Identified damages
Scratch on right back car wing
Scratch marks on rims
Slight usage of interior leather seats

Residual value
Residual value range: 19.875 – 20.299 EUR



Range confidence level: 95%

Main output data points

Vehicle information
- Model displays entered vehicle information and characteristics
- Comparison of entered vehicle information with visual data

Confidence level of model and version match
- 100% matches are unlikely, confidence highly depends on data quality
- System improves with increased application

Display of associated visual data
- The model evaluates uploaded images per vehicle
- Matched visual data can also be displayed, if useful

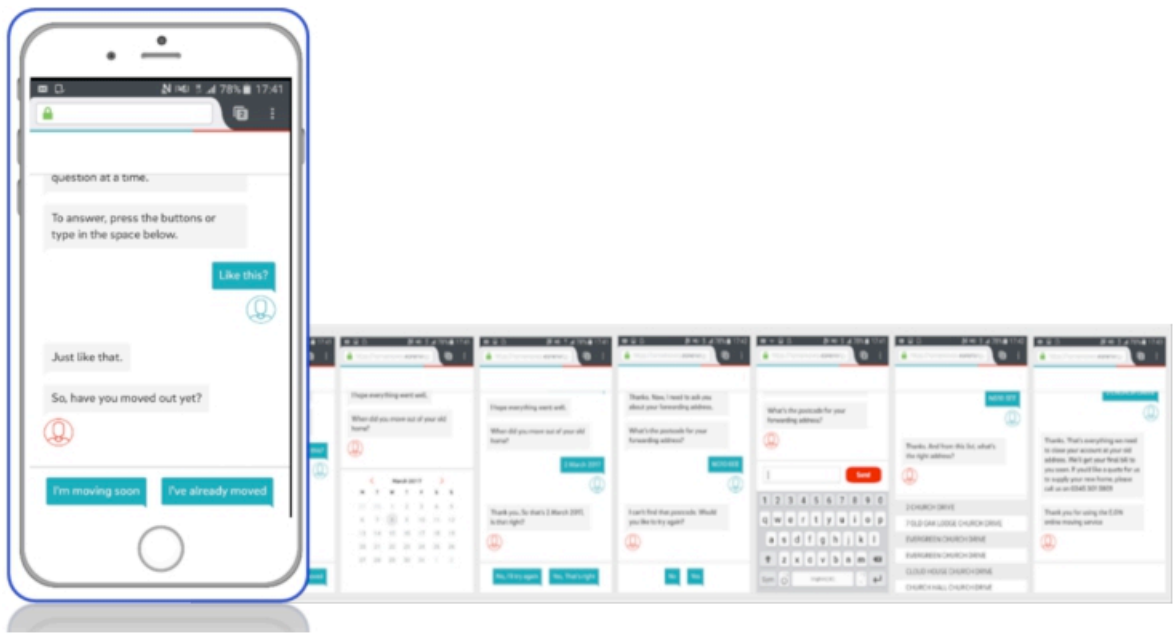
Detected damages
- Based on labelled historic data of manual visual inspections, the model can identify and list damages
- Damage detection improves over time through continuous learning of the model

Residual value prediction
- Residual values are predicted using historic residual values
- This feature is the key parameter for training, validating, and testing the model

Confidence level of residual value prediction
- Predictions are displayed as confidence intervals
- Precise value predictions will be highly unlikely

10 Customer service bots– chat bot automates and improves customer journey (e.g., scheduling appointments, change contract information)

Use case Reduce cost - to - serve while improving customer experience by automating customer service processes using bots and Natural Language Processing (NLP)



Context

- Utility provider client experienced high customer churn after customers had to update contract information when moving to a new home
- Customer journeys can be complex and costly, while not meeting customer requirements regarding simplicity and 24/7 availability
- Customer satisfaction and churn is significantly driven by how easy and smooth after sales customer journeys are designed

Methodology

- We developed a chat bot based on natural language processing, which significantly improved accuracy vs. purely rule - based chat bots
- AI - based image recognition allowed meter readings from customers' mobile phone pictures

Advantage of Artificial Intelligence

Natural Language Processing (NLP) allows bots to react dynamically to input by the user (customer, employee, etc.) Bots can learn large numbers or combinations of keywords and answers

Impact

>80% customerrecommendation rate

50% reductioncustomer churnof

20 - 30% reduction of cost-to-serve

80% reductionfrom >30 minof timeto <5ne

While AI based automation was only the beginning, we already see the benefits of ML and will move towards cognitive intelligence building new processes on its own

Task automation & robotic process automation (RPA)

- Rule based **process automation**
- **Structured** data sources
- **Static** performance level

Machine learning (ML)/ advanced analytics (AA)

- Algorithms **beyond human ability**
- Utilizes **unstructured** data
- Performance of models **improves over time**

Cognitive intelligence/ deep learning

- Neural networks and advanced ML algorithms **beyond 'statistical' learning**
- Natural language to **build neural network**
- Based on **largest unstructured data** sets and natural language
- **Execute new processes** based on observation

SOURCE: McKinsey, Company webpages

McKinsey Digital

and that's all folks!

Norbert Biedrzycki

http://norbertbiedrzycki.pl