Prof. Dr. Frank J. Furrer:

AUTONOMIC COMPUTING

Ringvorlesung

«Softwareentwicklung in der industriellen Praxis»

Montag, 30.01.2017 / 16:40 (6. Doppelstunde)
Fakultät Informatik, Raum APB/E006

CONTENT:

1. Motivation
2. Definition
3. Architecture
4. Applications
5. Risks
6. Outlook

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AUTONOMIC COMPUTING

Algorithmic Computing

Why? **How?**

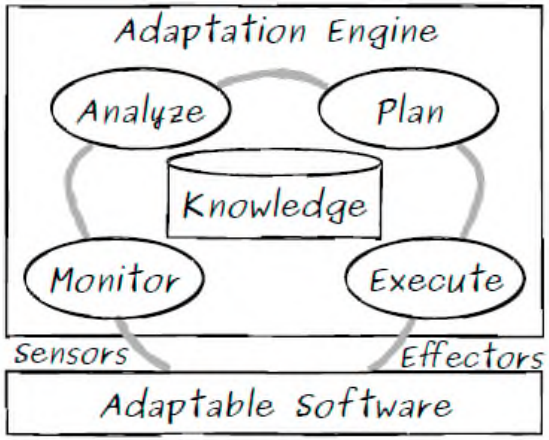
Autonomic Computing

Promises **Risks**

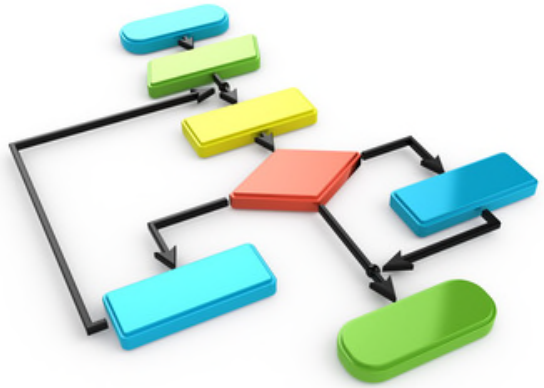
Applications

```
<h1>Computer Code</h1>
<img src="../image/story/2013/08-computercode.jpg" width="700" height="394" id="vplayer">
<script type="text/javascript" src="jquery-1.7.1.min.js"></script>
<script type="text/javascript" src="videoplayer.js"></script>
<script type="text/javascript">
     var publishedDate = "20130326"; //reverse date format
     var origtitle = "Did you know kids are learning about computer coding?";
     var origurl = publishedDate+"_computercode_hi.mp4";
     videoplayer.smooth = true;
     videoplayer.wmode = "opaque";
     videoplayer.embedPlayer('vplayer',origurl,null,null,origtitle,false);

     //to handle the title overlay.
     videoplayer.onStateChange = function(vplayer,state){
     if (state=="PLAY_STATE") {
          $("#kiosk h1").fadeOut();
     } else if (state=="STOPPED_STATE" || state=="PAUSE_STATE") {
          $("#kiosk h1").fadeIn();
     }
}
</script>
```



Algorithmic Computing



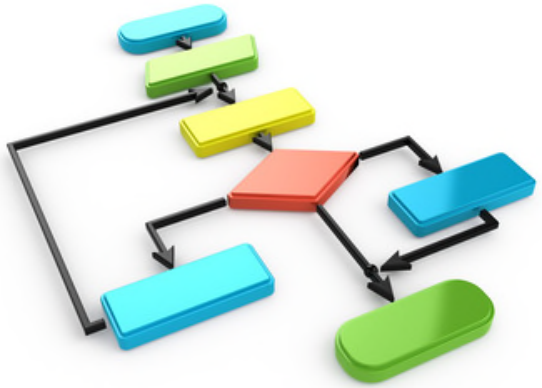
http://www.bobology.com

You use **code** to tell a computer what to do ⇐ "Program"

Before you write code you need an **algorithm**

An algorithm is a **list of rules** to follow in order to solve a problem

Algorithmic Computing



http://www.bobology.com

An algorithm is a **list of rules** to follow in order to solve a problem

http://kingofwallpapers.com

The «programmer» must think of all *possible* cases and decisions *beforehand*

Example: Algorithmic Computing (1/4)

http://static3.businessinsider.com

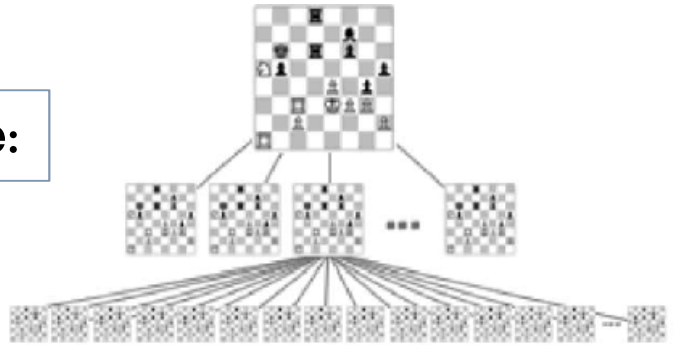
Deep Blue versus **Garry Kasparov** was a pair of six-game chess matches between world chess champion Garry Kasparov and an IBM supercomputer called Deep Blue.

The match was played in New York City in 1997 and won by **Deep Blue**.

The 1997 match was the first defeat of a reigning world chess champion to a computer under tournament conditions

Example: Algorithmic Computing (2/4)

Algorithm Structure:

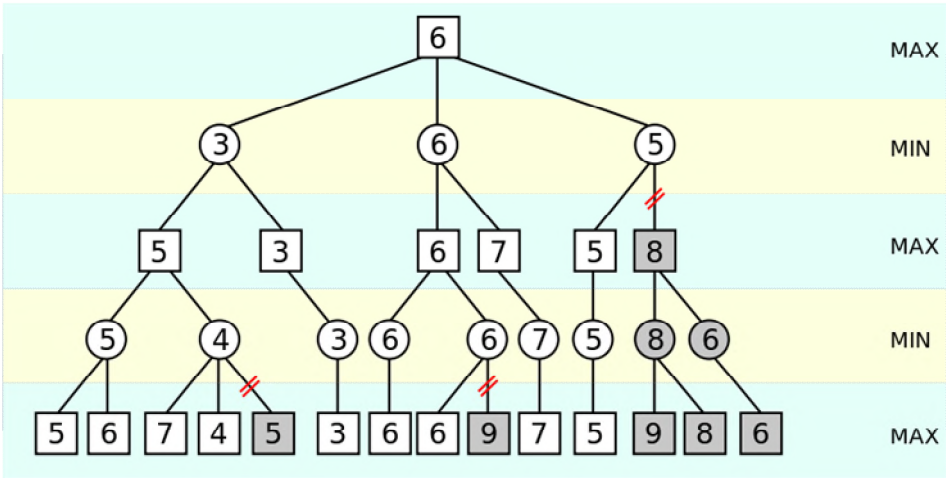


1. Model Chess as a tree structure

Deep Blue would typically search to a depth of between six and eight moves based on 11.38 GFLOPS power

2. Define an Evaluation Function

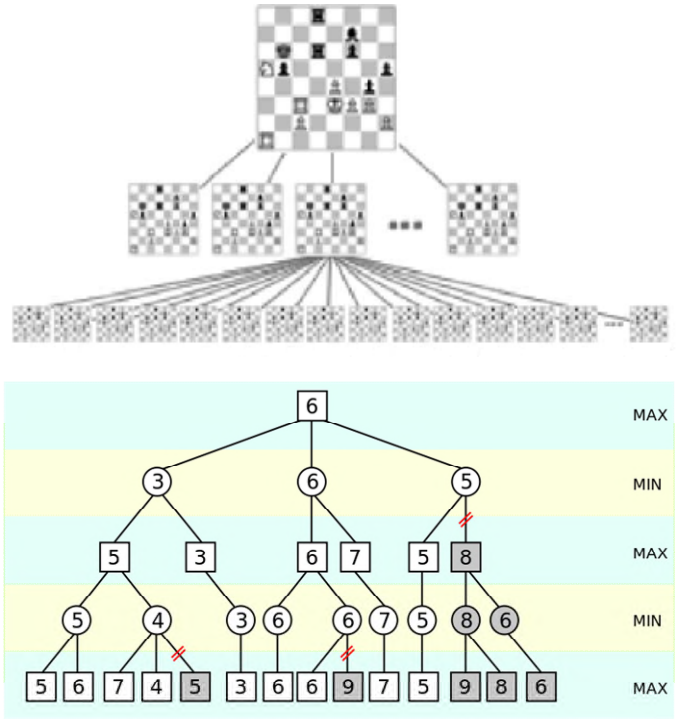
3. Use Minimax Algorithm



4. Heuristics/Optimizations

Example: Algorithmic Computing (3/4)

https://images.chesscomfiles.com



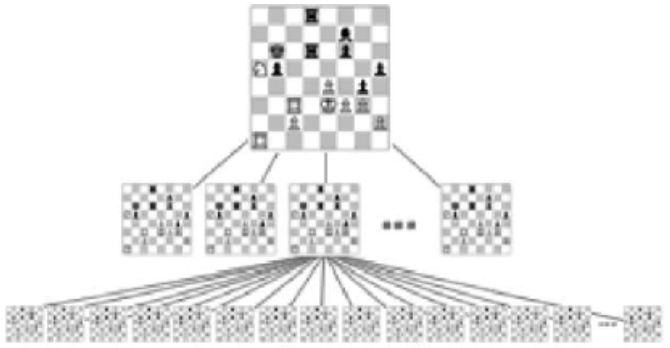
http://www.randalolson.com

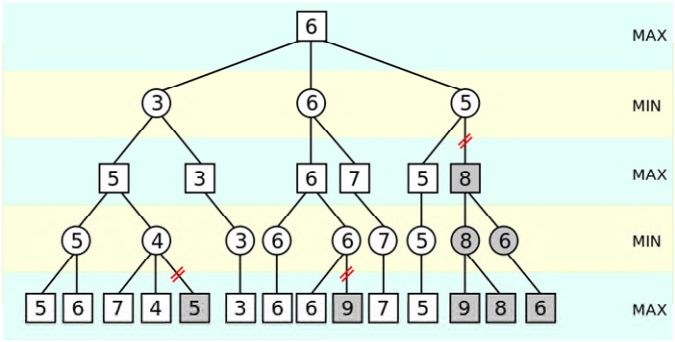
1) The problem (game) is completely ***determinstic***

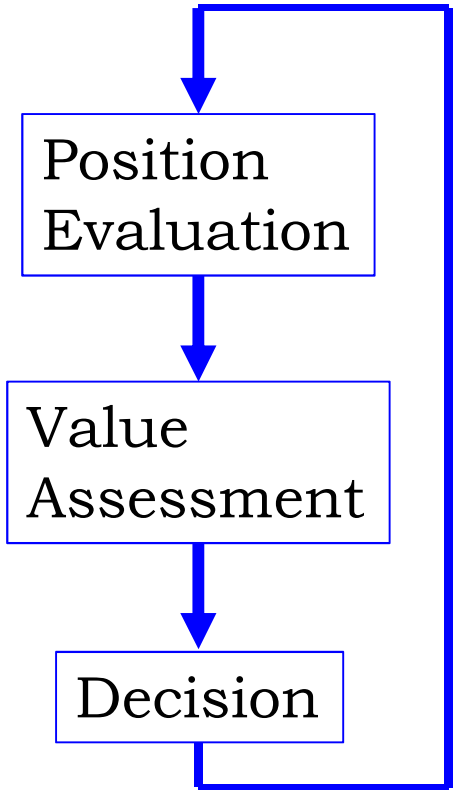
2) The context is completely ***known*** and ***stable***

3) All stakeholders have ***full*** information (real-time)

Example: Algorithmic Computing (4/4)







Evaluation:
How many moves?

http://blog.pdus2go.com

Algorithm
+
Computing Power

http://cbttherapyuk.com

But what if the problem

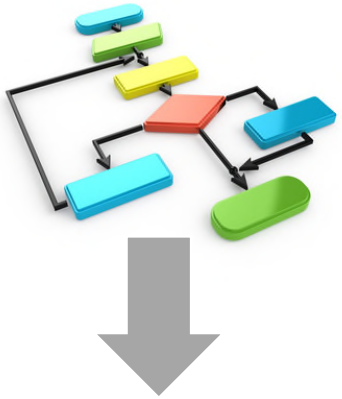
- **is not fully defined**
- **or the environment is uncertain?**

But what if situations

- **are too complex to be predicted**
- **or the environment is changing dynamically?**

https://s3.amazonaws.com

http://www.bobology.com



The algorithmic approach **fails**!

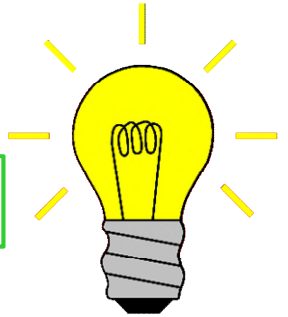
http://thumbs.carbonated.tv

Why?

1) ***Incomplete*** information
2) Dynamically ***changing*** environment (context)
3) ***Unforeseen*** cases / Unmanageable ***complexity***
4) ***Emerging*** behaviour

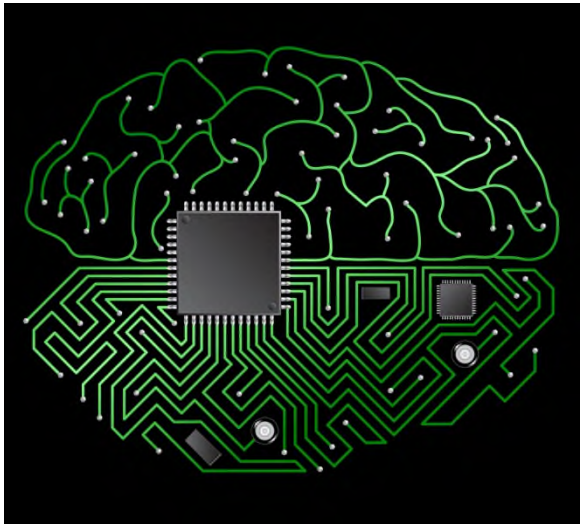
The algorithmic approach **fails**!

Is there a solution to the problem?



http://images.clipartpanda.com

YES: … we need a higher level of software technology



http://news.mit.edu

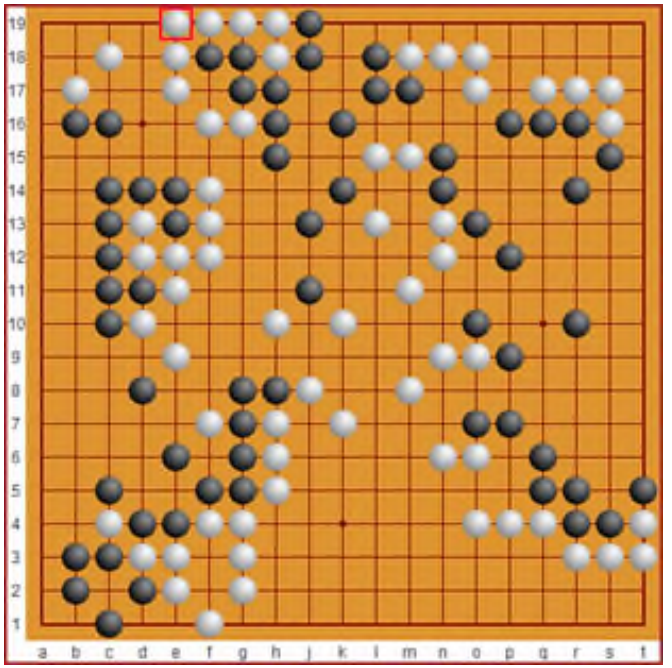
… making use of ***artifical intelligence***

Example: Non-algorithmic computing (1/5)

«**GO**» is a strategy board-game which was invented 2`500 years ago in China.

https://fr.wikipedia.org

Board: 19 x 19 lines, unlimited number of black and white stones



http://www.brettspielnetz.de

Goal: Occupy as much territory as possible

Example: Non-algorithmic computing (2/5)

1. The board is empty at the onset of the game (unless players agree to place a handicap).
2. Black makes the first move, after which White and Black alternate.
3. A move consists of placing one stone of one's own color on an empty intersection on the board.
4. A player may pass their turn at any time.
5. A stone or solidly connected group of stones of one color is captured and removed from the board when all the intersections directly adjacent to it are occupied by the enemy. (Capture of the enemy takes precedence over self-capture.)
6. No stone may be played so as to recreate a former board position.
7. Two consecutive passes end the game. However, since black begins, white must end the game.
8. A player's territory consists of all the points the player has either occupied or surrounded.
9. The player with more territory wins.

https://en.wikipedia.org/wiki/Rules_of_go

Example: Non-algorithmic computing (3/5)

https://static01.nyt.com

Number of different positions on the GO-board: ~ **4,63 x 10^{170}**

Chess: ~**10^{43}**

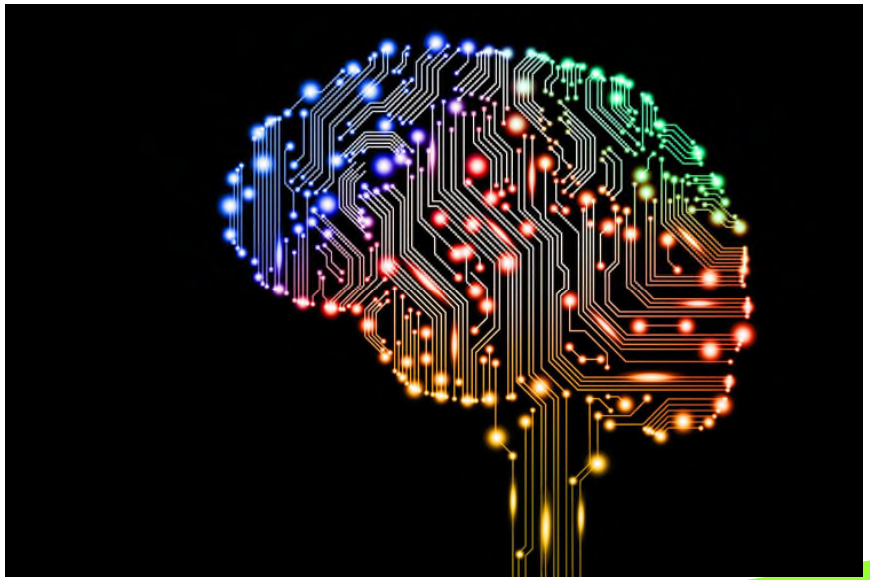
# of atoms in the universe: ~**10^{80}**

Example: Non-algorithmic computing (4/5)

http://www.watson.ch

March 2016: The AI-program «AlphaGO» wins a tournament against the GO World champion Lee Sedol 4:1

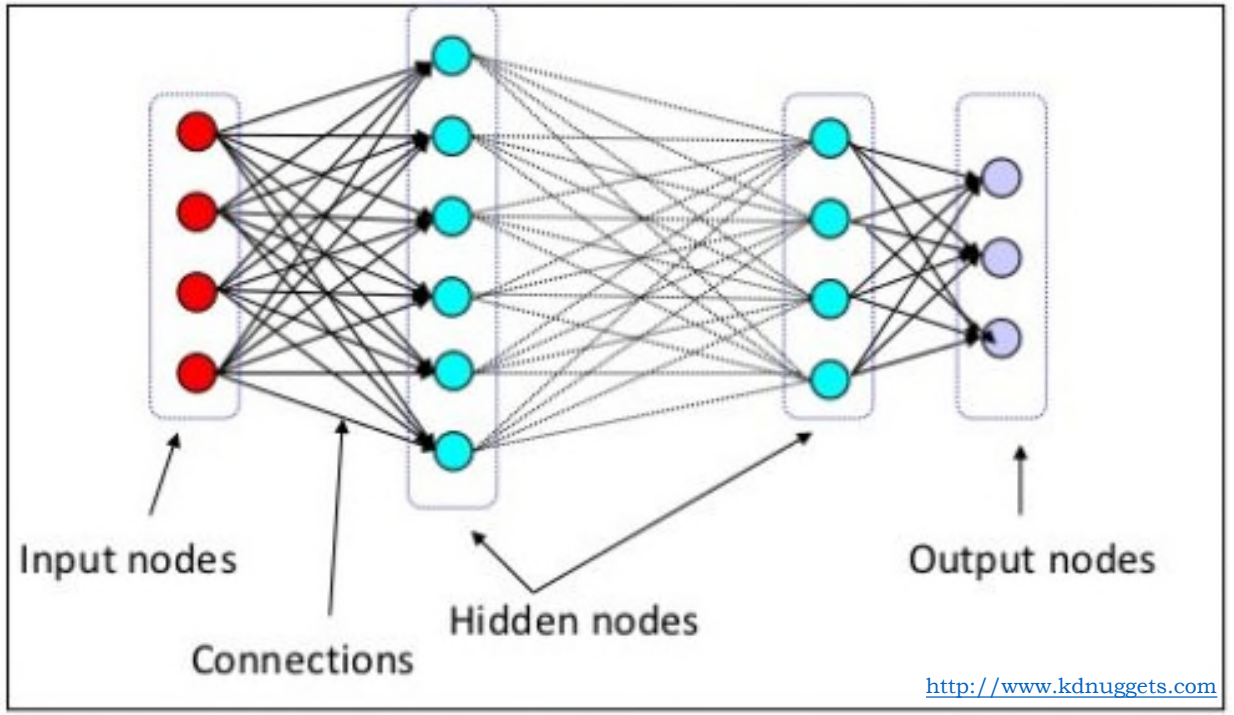
Impressive/Worrying:
«AlphaGO» is **NOT** an algorithm, but a self-learning software [Deep Learning]

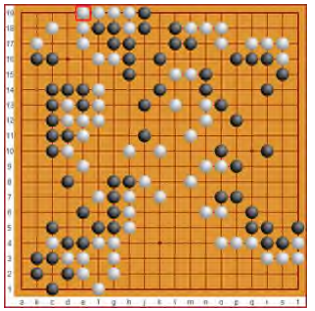


http://www.digitaltrends.com

Example: Non-algorithmic computing (5/5)

«AlphaGO» is **NOT** an algorithm, but a *self-learning* software
[Deep Learning in Neural Networks]





... we know the full configuration of the neural network:
But we have NO chance to ever understand its inner workings!

But what if the problem:

- **is not fully defined?**
- **or the environment is uncertain?**

But what if situations:

- **are too complex to be predicted?**
- **or the environment is changing dynamically?**

Is there anything we can do?

What can we do?

Is there anything we can do?

What can we do?

… we need some help from artificially ***intelligent software***

New paradigm: Autonomic Computing

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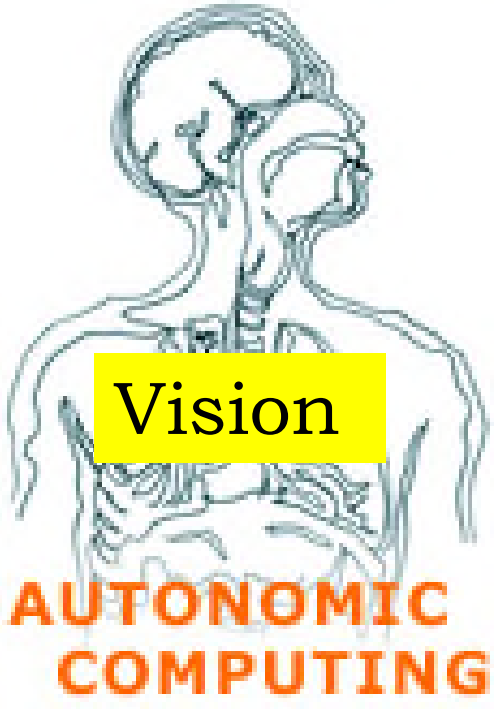
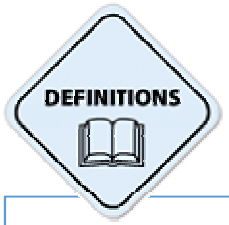
AUTONOMIC COMPUTING



= Specific approach to the engineering of software systems

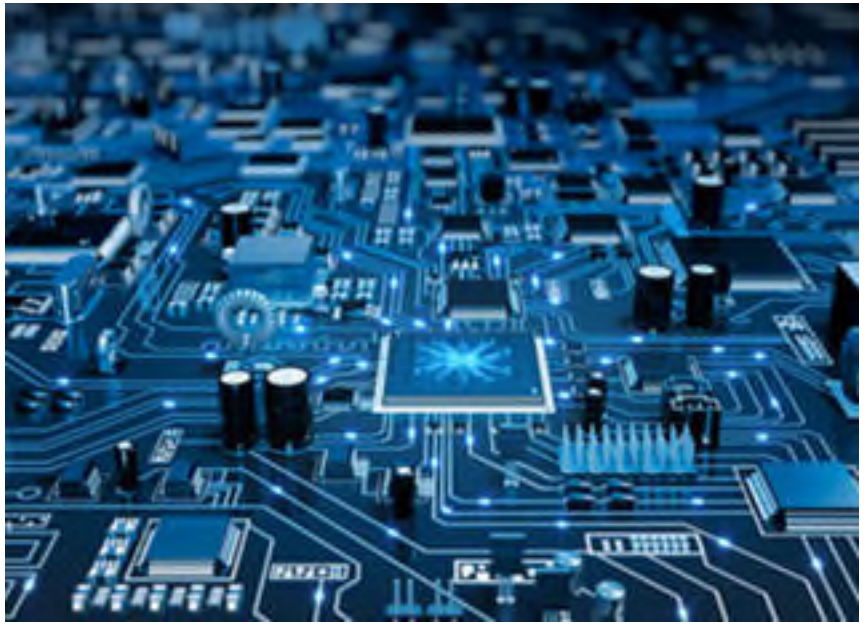


A type of ***computing model*** in which the system is *self-healing*, *self-configured*, *self-protected* and *self-managed*

⇒ self-* properties

Some history (1/4):

1980 … 2000



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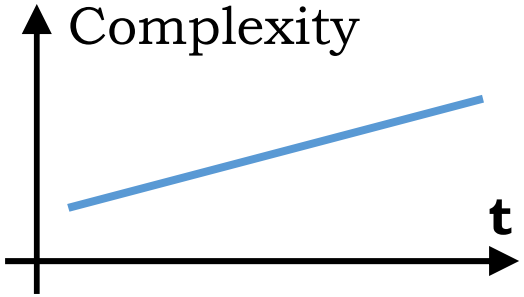
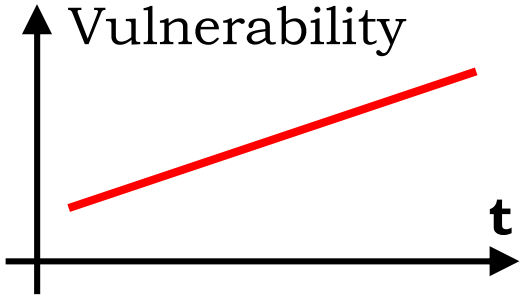
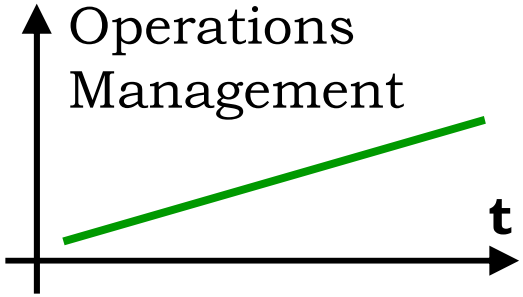
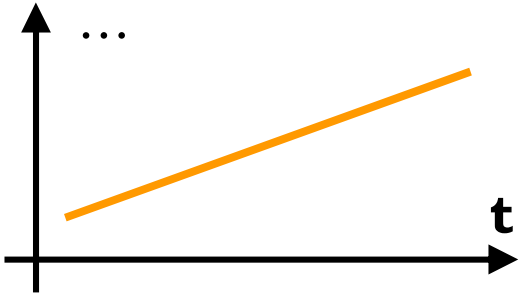


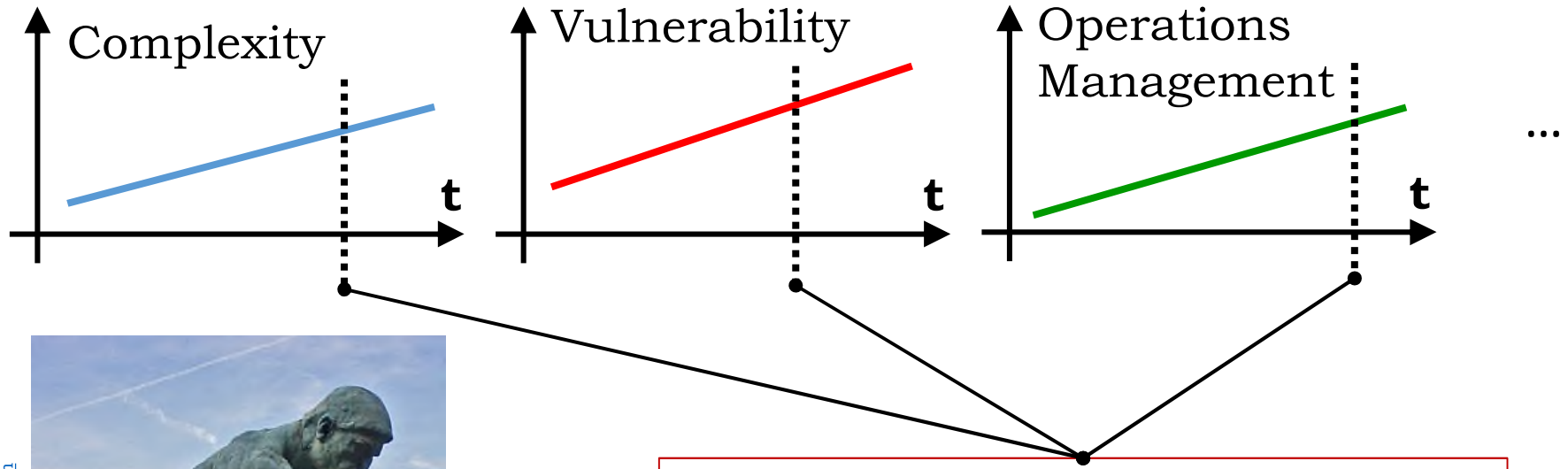


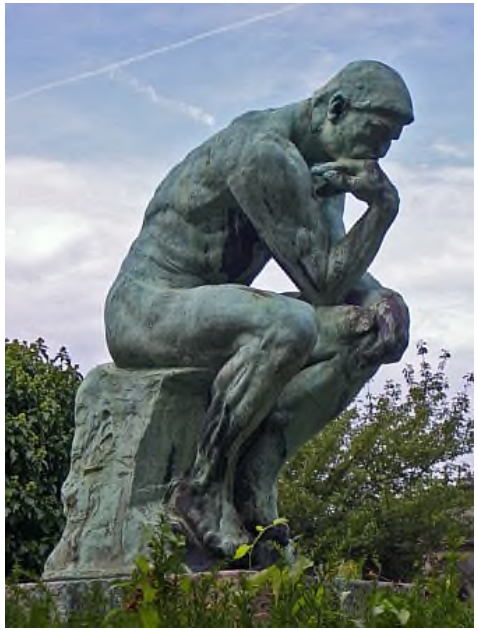




Some history (2/4):

2001

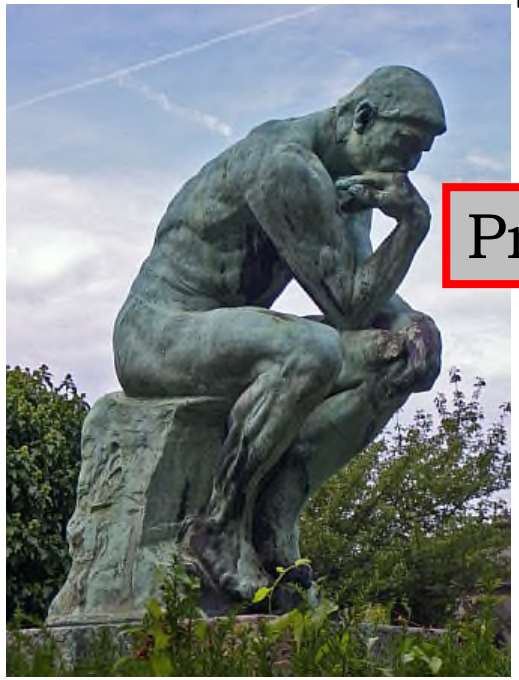




http://www.aseymour.com

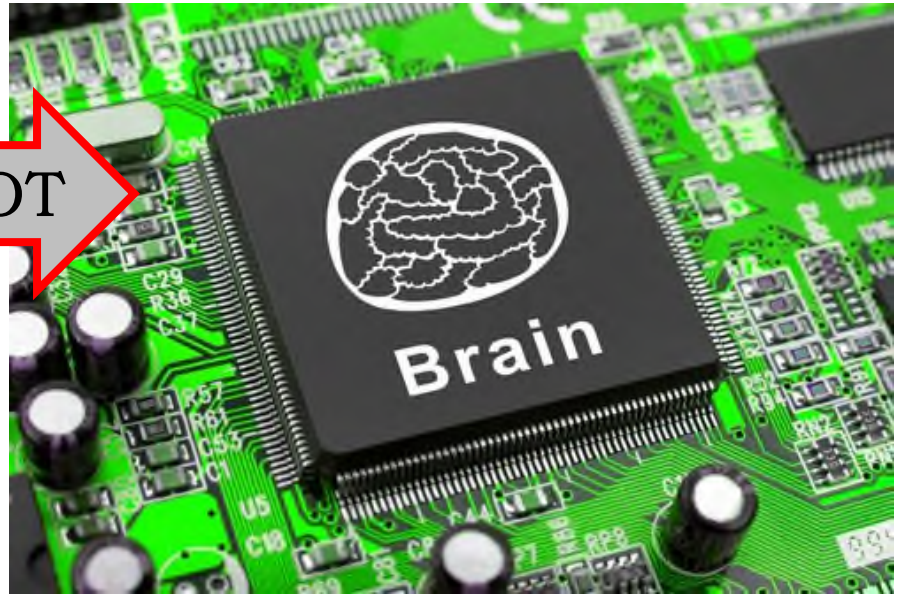
Can we humans successfully cope with these trends ?

Some history (3/4):



http://www.aseymour.com

Probably NOT



http://mcvcbca.blogspot.ch/2012

Can we humans successfully cope with the trends of:

- increasing complexity
- raising vulnerability
- operational risks

?

… we will need the support of intelligent machines

⇒ of the software itself !

Some history (4/4):

2001

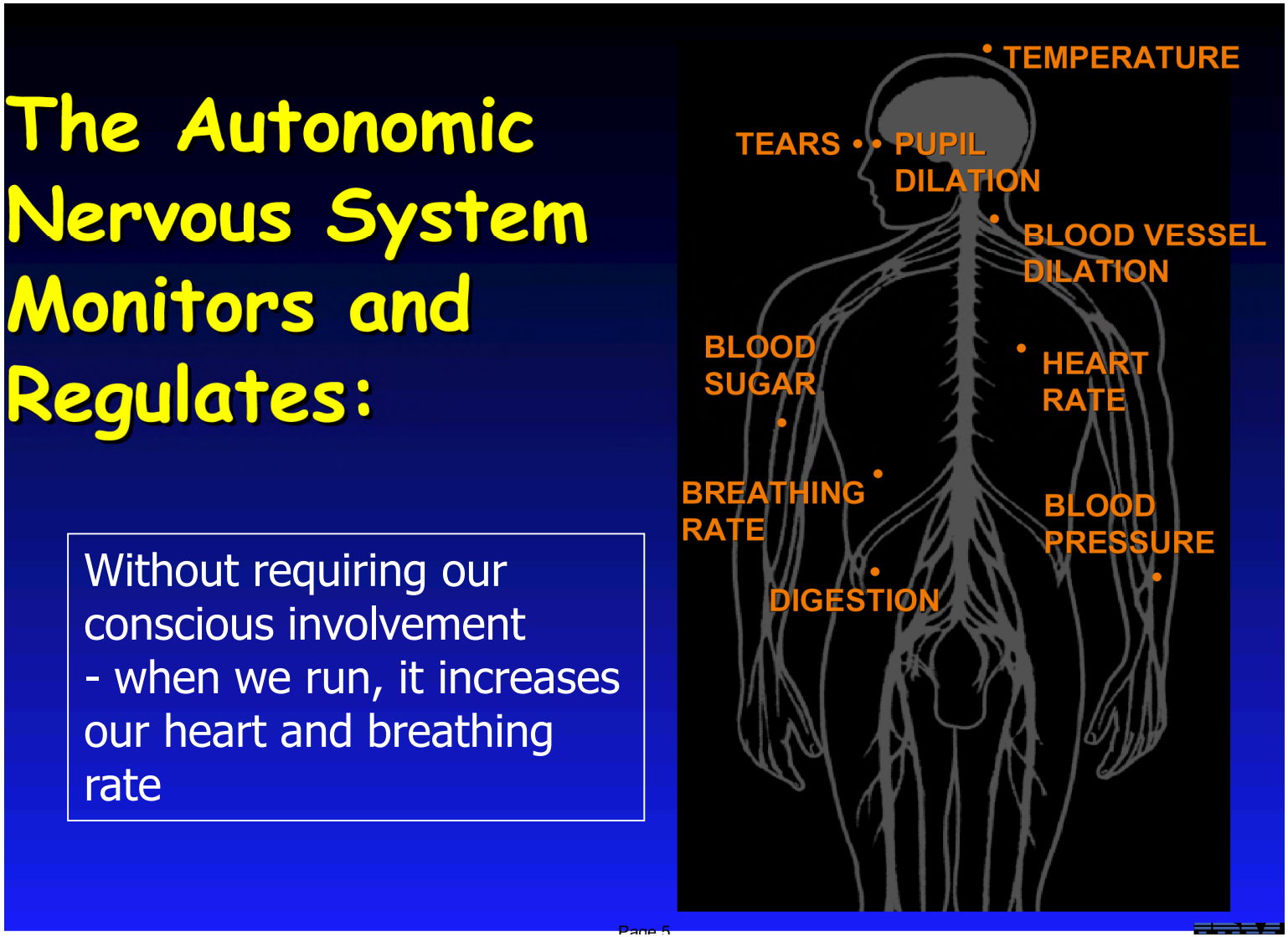
http://elpais.com

Paul Horn, IBM

[National Academy of Engineers at Harvard University in a March 2001 keynote]:

"**Autonomic Computing**": The system makes decisions on its own, using high-level policies; it will constantly check and optimize its status and automatically adapt itself to changing conditions

Autonomic Computing: Convergence of Information Technology and Biology



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«Autonomic Computing»

http://flylib.com

Definition:

A type of ***computing model*** in which the system is self-healing, self-configured, self-protected and self-managed (self-* properties).

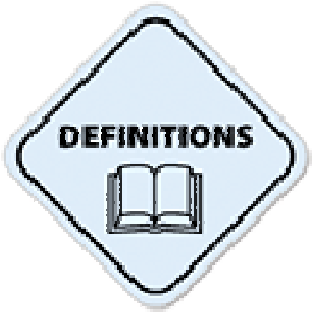
An autonomic computing system functions with a high level of ***artificial intelligence*** while remaining invisible to the users.

The autonomic computing system ***operates autonomically*** in response to the inputs it collects and processes.

http://www.webopedia.com/TERM/A/autonomic_computing.html

Self-Configuring

http://flylib.com



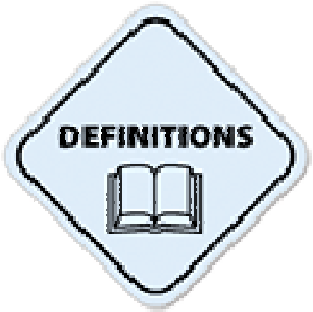
Definition:

An autonomic system configures and reconfigures itself in order to ***adapt*** to various, possibly unpredictable conditions, so as to continuously meet a set of ***business objectives***

Examples: Integration of new autonomic elements or reconfiguration of the run-time system (number of elements and topology)

Self-Healing

http://flylib.com



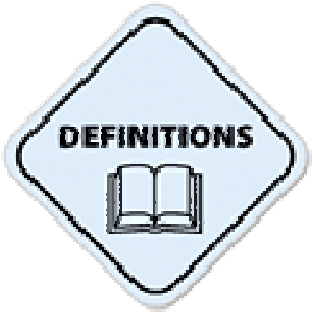
Definition:

An autonomic system detects, diagnoses and recovers from routine or extraordinary ***problems*** while trying to minimize service ***disruption***

Examples: Identify and enable alternate resources, download software updates, restart failed elements, request human assistance, eliminate faulty elements

Self-Protecting

http://flylib.com



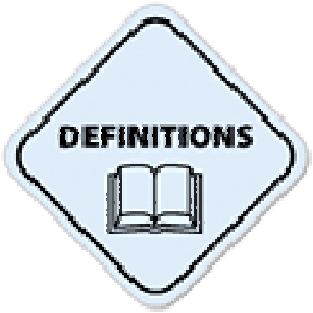
Definition:

An autonomic system anticipates, detects, identifies and protects itself from internal and external ***threats***, in order to maintain ***quality attributes***, such as security, integrity, availability, safety, …

Examples: Identify and enable alternate resources, download software updates, restart failed elements, request human assistance, eliminate faulty elements, neutralize malicious activities

Self-Optimizing

http://flylib.com

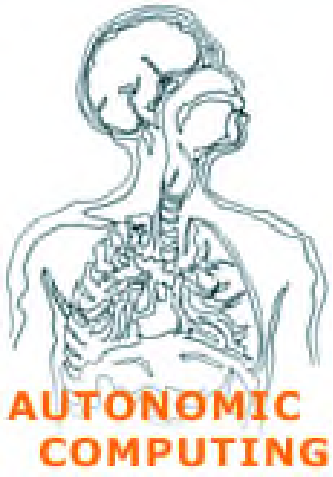


Definition:

An autonomic system continuously seeks ways and sizes opportunities to ***improve its operation*** with respect to multiple, possibly conflicting, ***criteria***

Examples: Improve and maximise quality of service, performance, power consumption, resilience, etc.

AUTONOMIC COMPUTING



Original Autonomic System

http://flylib.com

More self-* properties

Autonomous systems

Cognitive systems

Intelligent cyber-physical systems

...

http://ce-publications.et.tudelft.nl/publications/610_a_survey_of_autonomic_computing_systems.pdf

1. **Self-regulation**: A system that operates to maintain some parameter, e.g., Quality of service, within a reset range without external control;
2. **Self-learning**: Systems use machine learning techniques such as unsupervised learning which does not require external control;
3. **Self-awareness**: System must know itself. It must know the extent of its own resources and the resources it links to. A system must be aware of its internal components and external links in order to control and manage them;
4. **Self-organization**: System structure driven by physics-type models without explicit pressure or involvement from outside the system;
5. **Self-creation**: System driven by ecological and social type models without explicit pressure or involvement from outside the system. A system's members are self-motivated and self-driven, generating complexity and order in a creative response to a continuously changing strategic demand;
6. **Self-management** (also called self-governance): A system that manages itself without external intervention. What is being managed can vary dependent on the system and application. Self -management also refers to a set of self-star processes such as autonomic computing rather than a single self-star process;
7. **Self-description** (also called self-explanation or Self-representation): A system explains itself. It is capable of being understood (by humans) without further explanation

AUTONOMIC COMPUTING

But what if the problem

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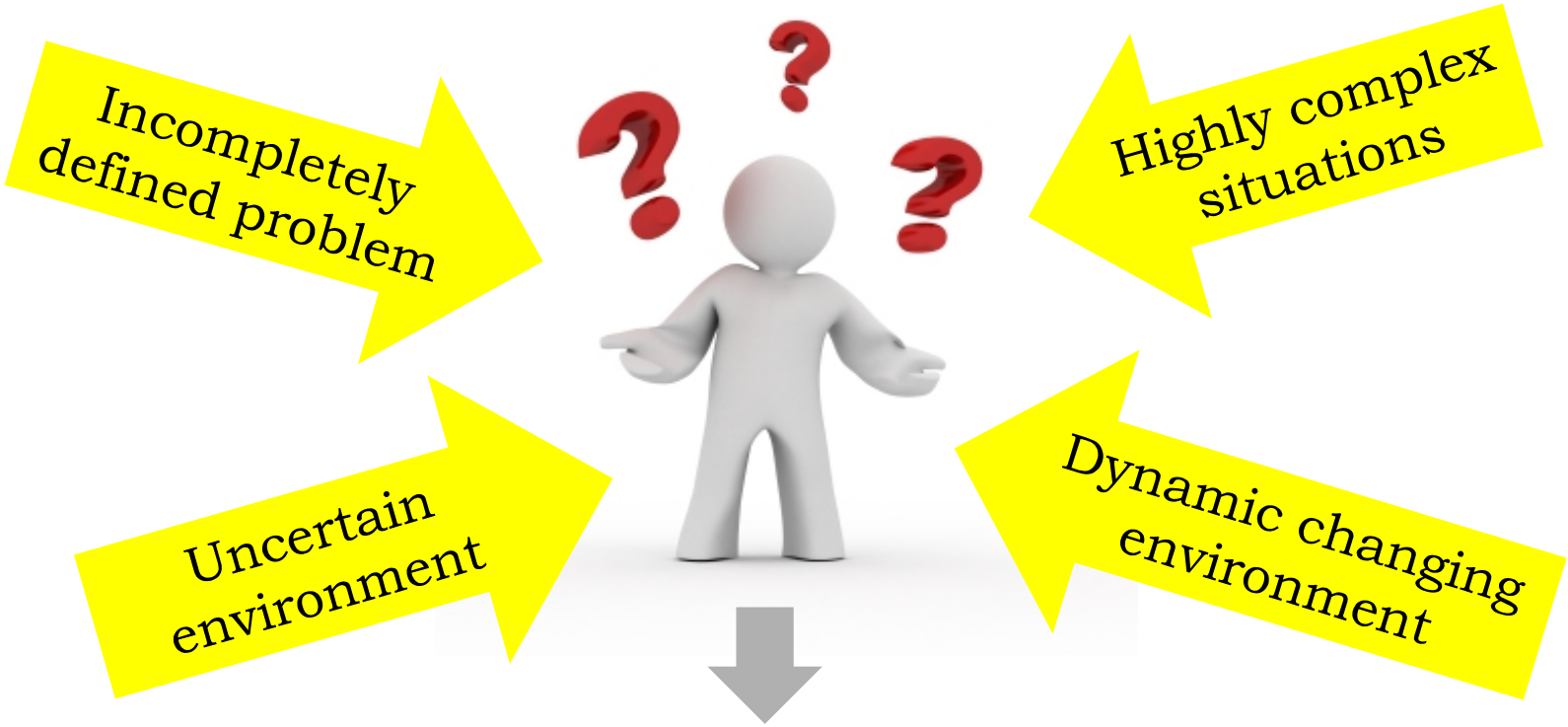
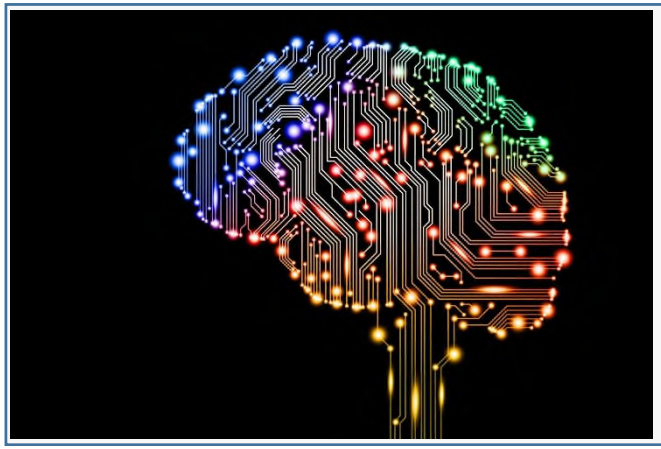
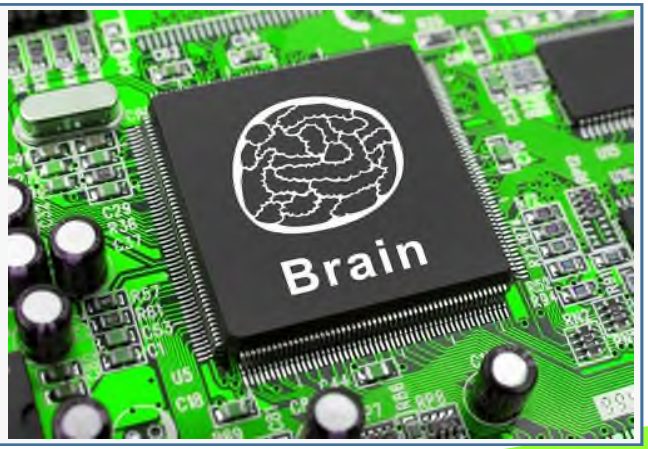




«We need some help from **Artificial Intelligence»**



How do we construct Autonomic Systems?

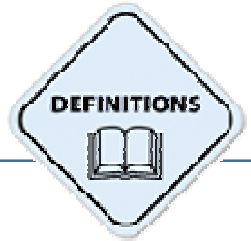
http://freedesignfile.com

We need expertise from many fields:

- Software engineering
- Systems engineering
- Control theory
- Artificial intelligence
- Machine-learning
- Multi-agent systems
- …

Foundation
=
Architecture !

Foundation = Architecture

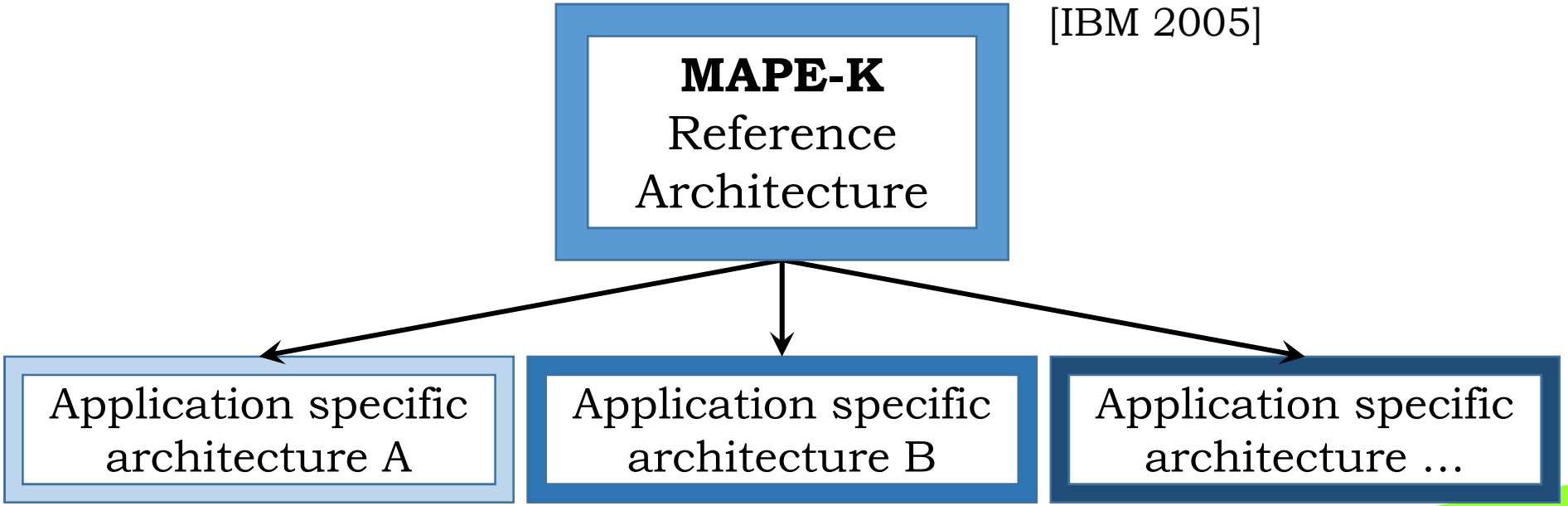


IT Architecture Definition:

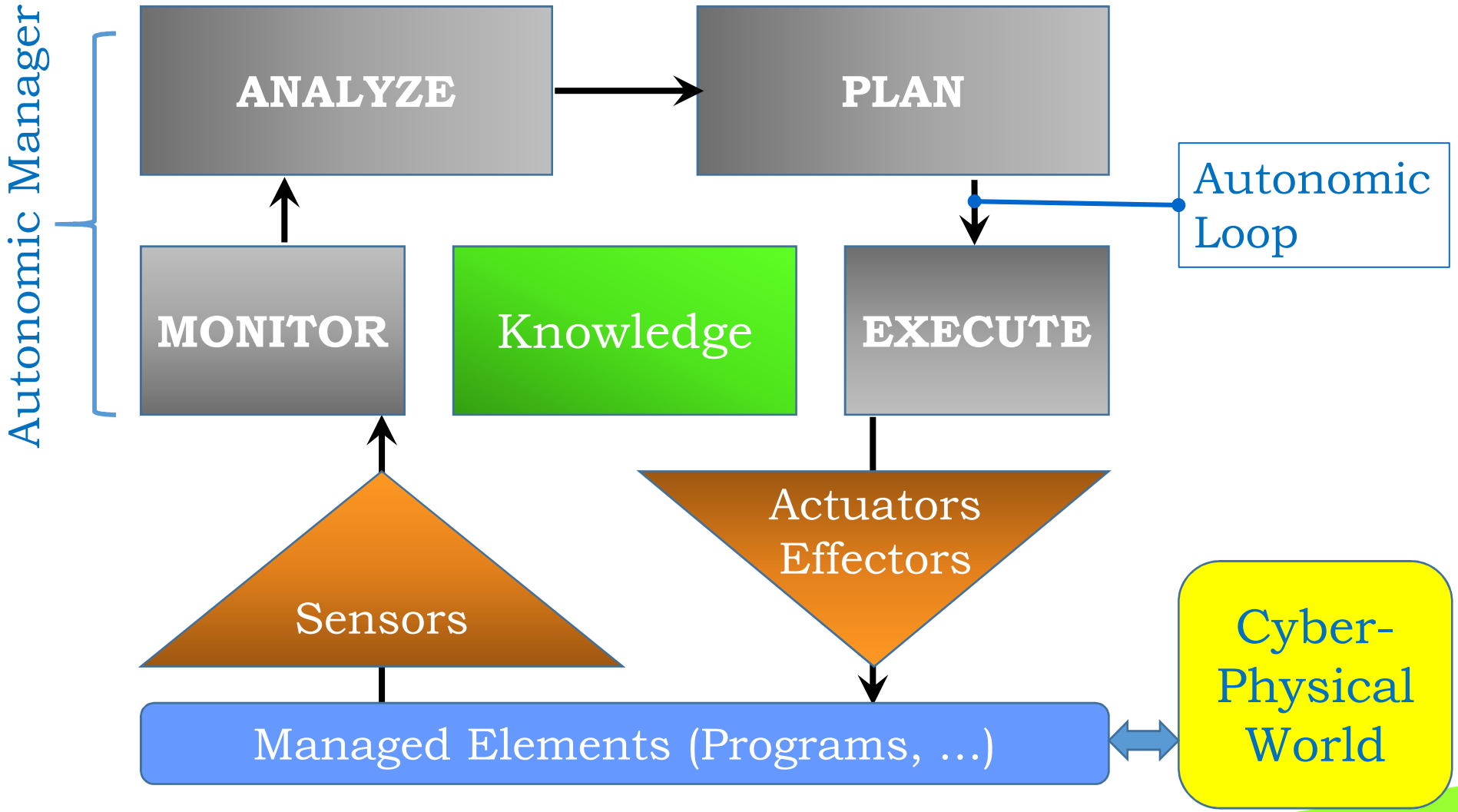
"The fundamental *organization* of a system embodied in its *parts*, their *relationships* to each other and to the environment, and the *principles* guiding its design and evolution"

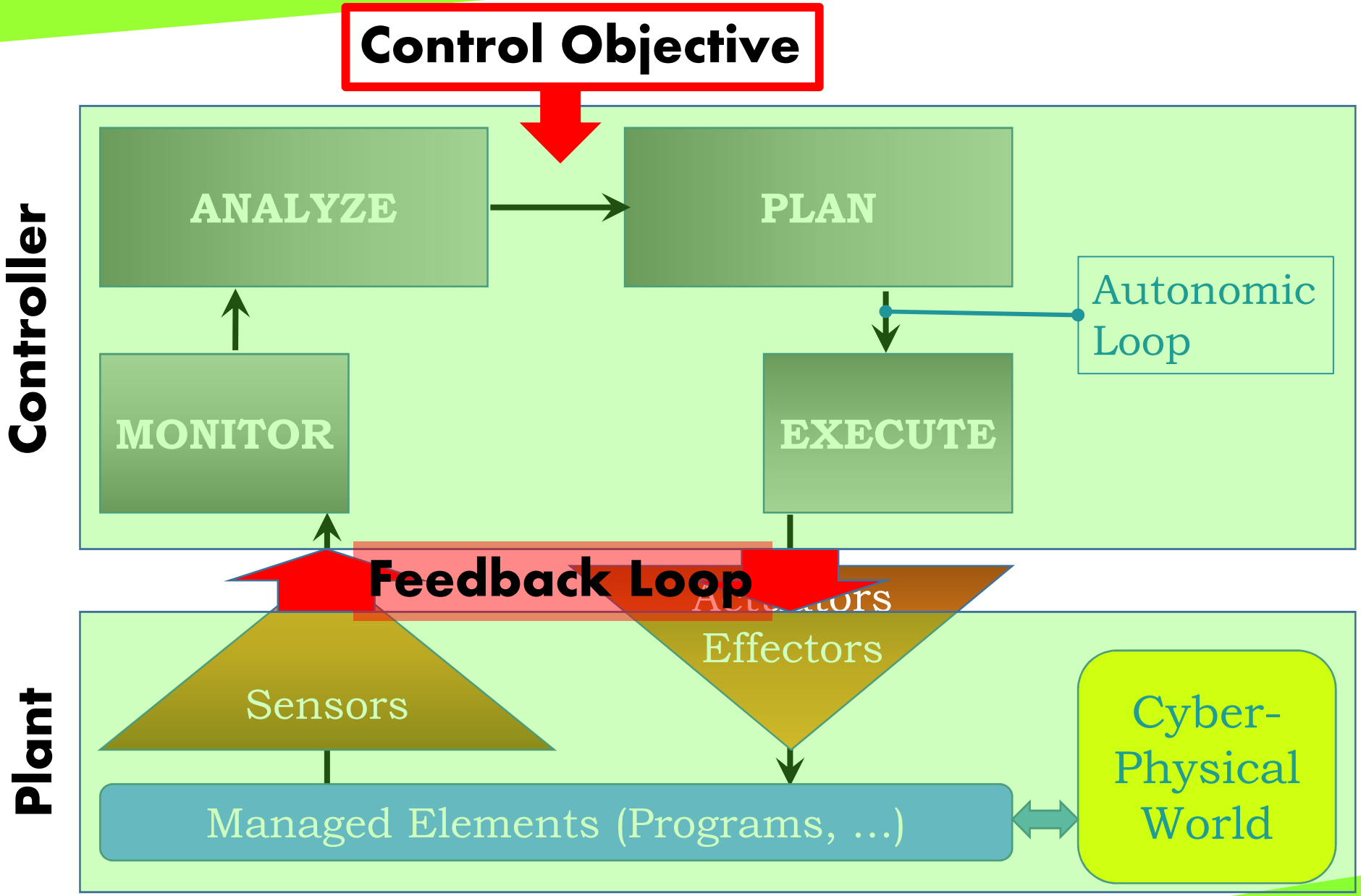
[IEEE]

[IBM 2005]



Autonomic System **Reference Architecture**

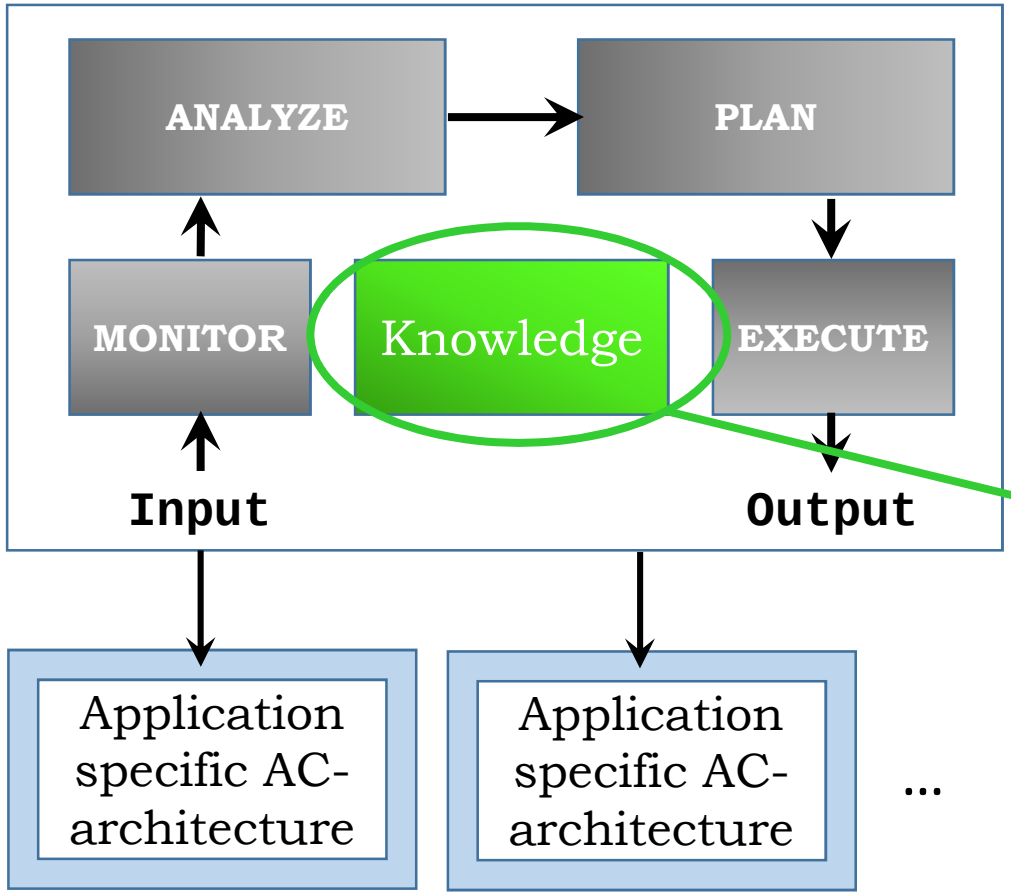



Control Objective
Controller
ANALYZE
PLAN
Autonomic Loop
MONITOR
EXECUTE
Feedback Loop
Effectors
Sensors
Plant
Managed Elements (Programs, …)
Cyber-Physical World

MAPE-K: IBM Reference Architecture

Knowledge

Monitor – **A**nalyze – **P**lan - **E**xecute



Artificial Intelligence Technologies:

- Modeling
- Reasoning
- Data Analysis
- Machine Learning
- Agent systems
- Inference
- Control theory
- …

The ***Origins*** of Autonomic Computing: ***Large Computing Infrastructure Management***

2004:

«It's time to design and build computing systems

capable of *running themselves*,

adjusting to varying circumstances,

and preparing their resources to handle *most efficiently*

the workloads we put upon them»

Richard Murch

AUTONOMIC COMPUTING

∅ -50%/+400%

Business Load

> 1'000 changes/day

Intended Changes

~ 10 disruptions/h

Disruptions

60'000 Servers

2'000 Routers

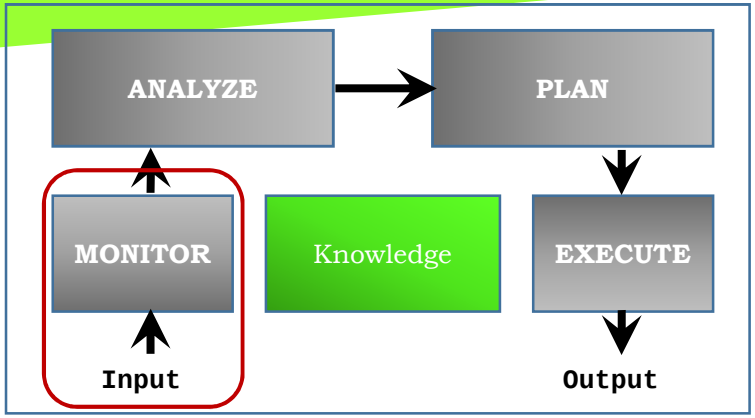
10'000 Business Databases

12'000 Business Applications

90'000 Workstations

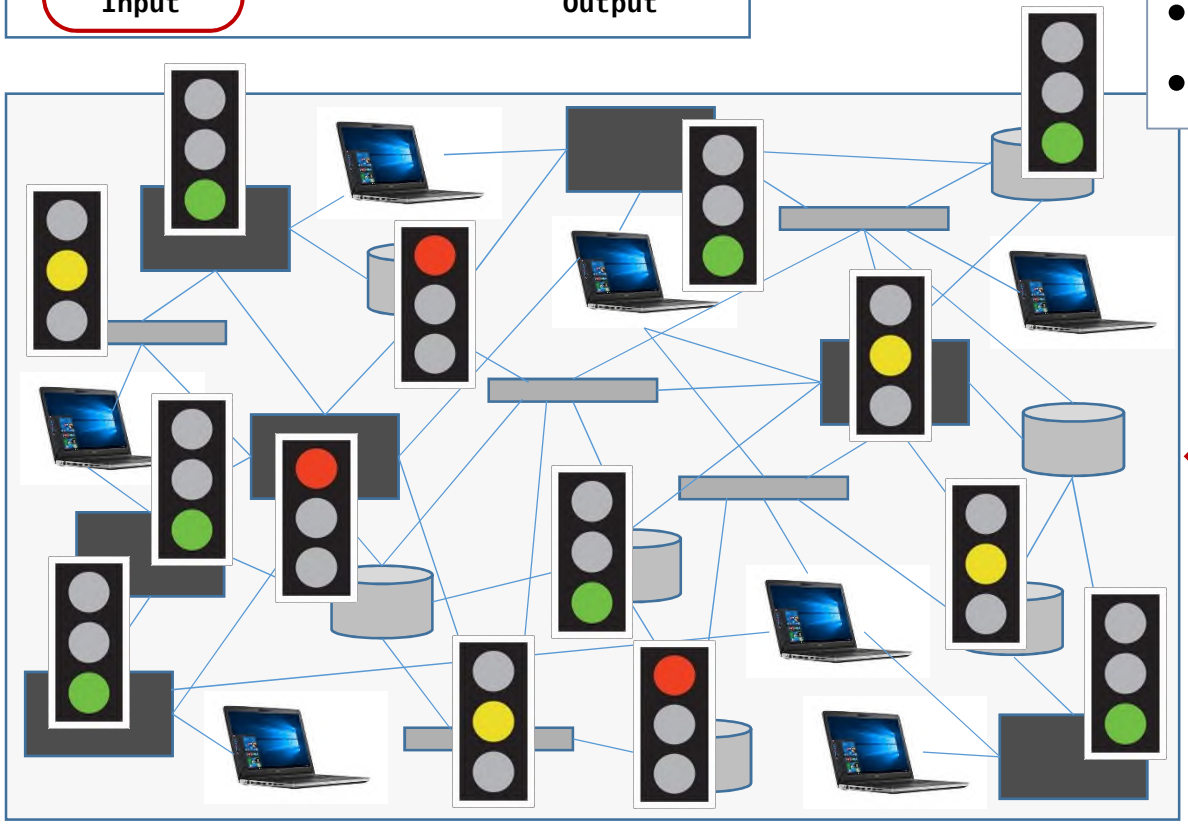
Large Computing Infrastructure

AUTONOMIC COMPUTING

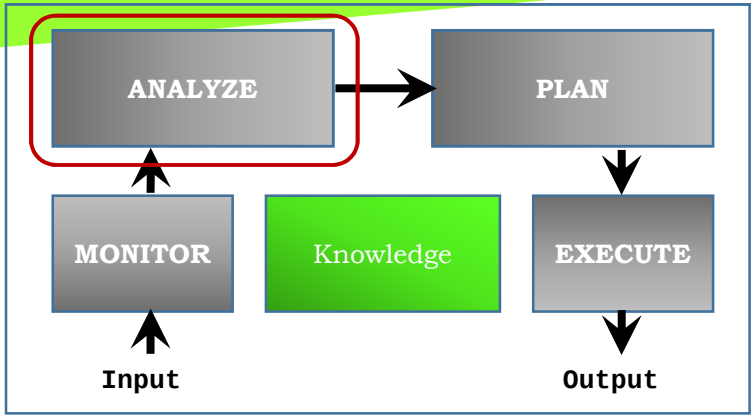


Autonomic Manager for large computing infrastructure

Real-time
- System model
- System health state

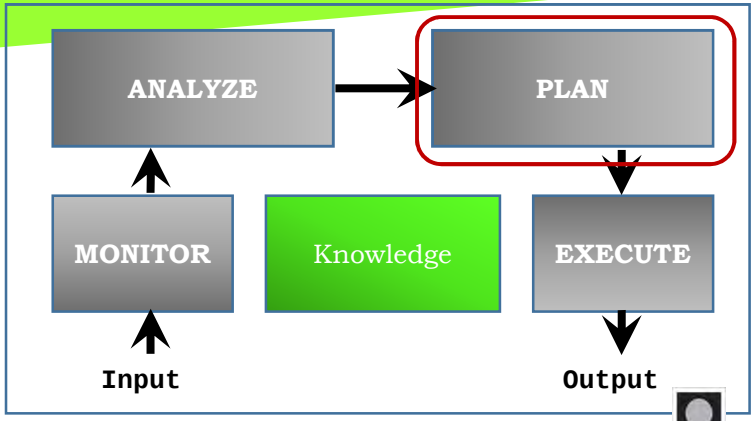


AUTONOMIC COMPUTING

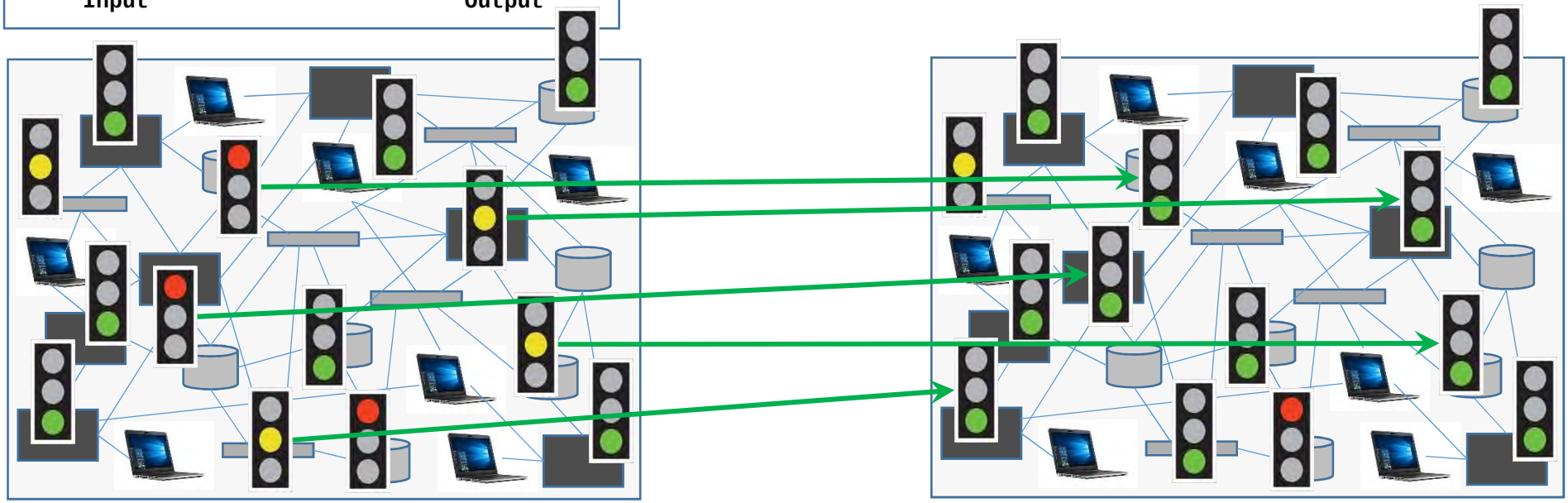


Autonomic Manager for large computing infrastructure

AUTONOMIC COMPUTING

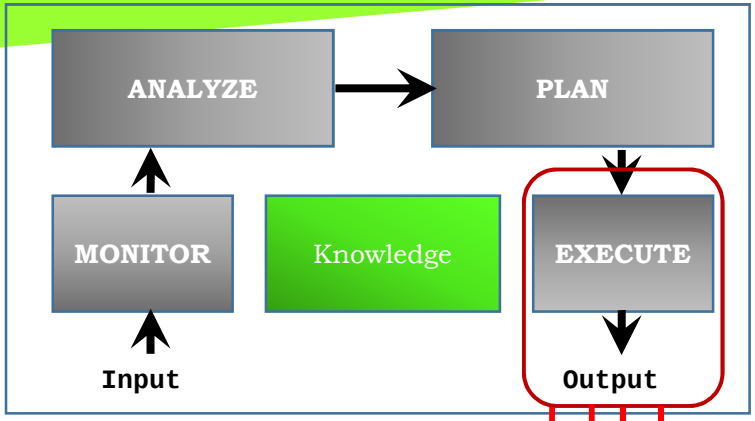


Autonomic Manager for large computing infrastructure

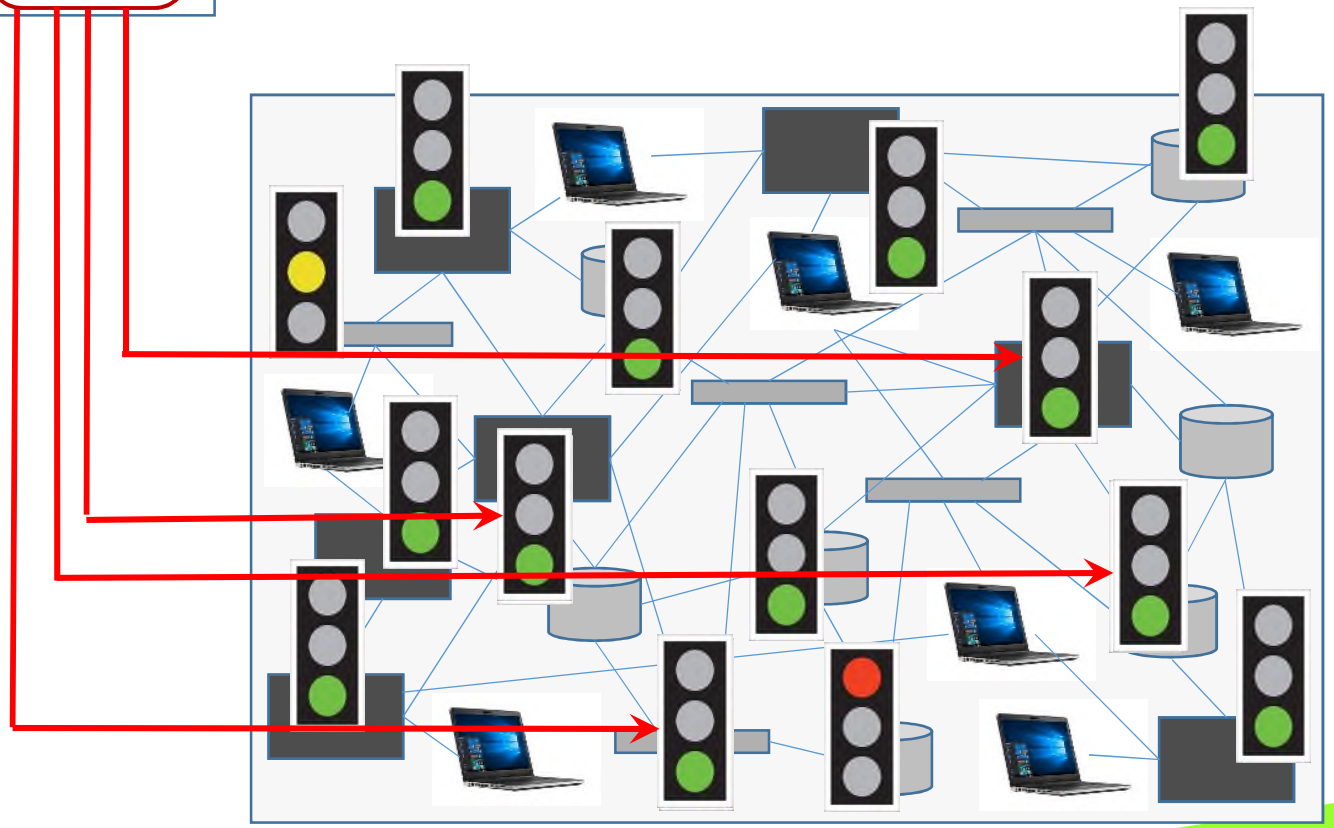


Redundancy, switchover, fault-tolerance, load-balancing, rerouting, back-up activation, human intervention, …

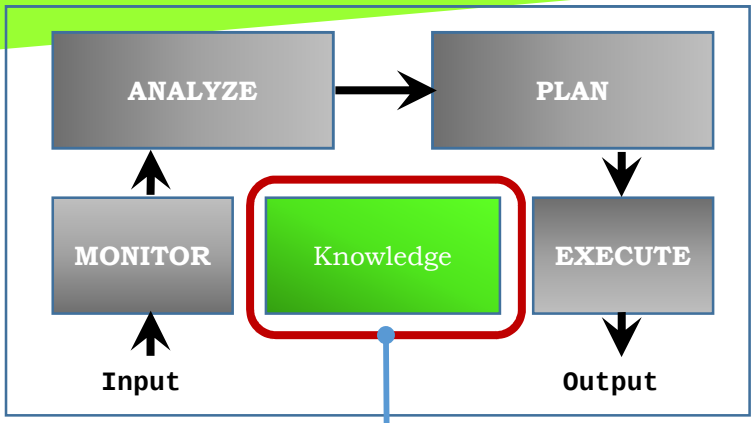
AUTONOMIC COMPUTING



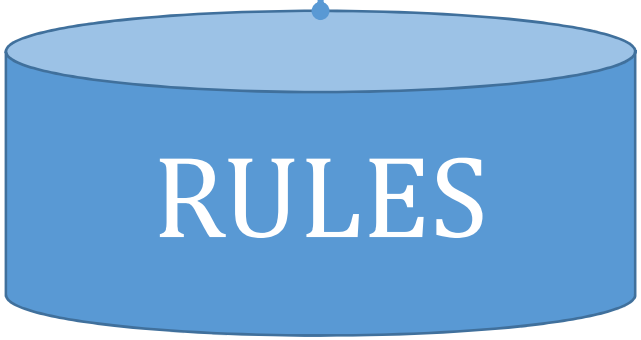
Autonomic Manager for large computing infrastructure



AUTONOMIC COMPUTING



Autonomic Manager for large computing infrastructure



- Device parameters & semantics
- Device error states
- Device constraints
- Back-up/switchover configurations
- Cold standby devices
- Router reconfigurations
- Human intervention points
- …

MAPE-K:
Autonomic
Infrastructure Management

2010+:

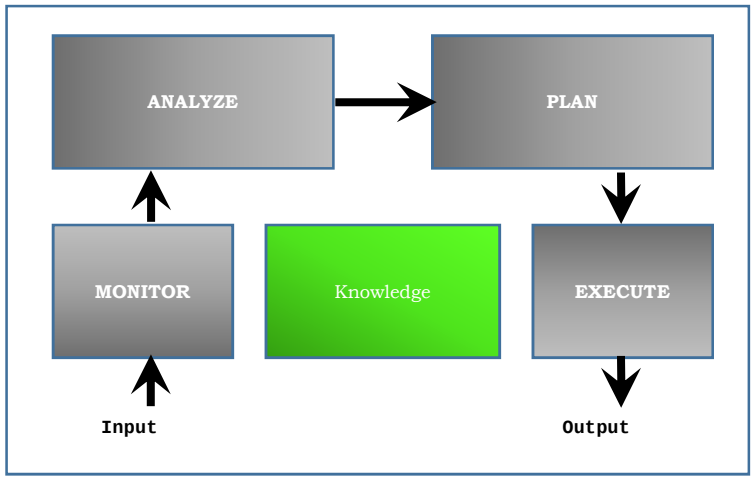
Important Extension

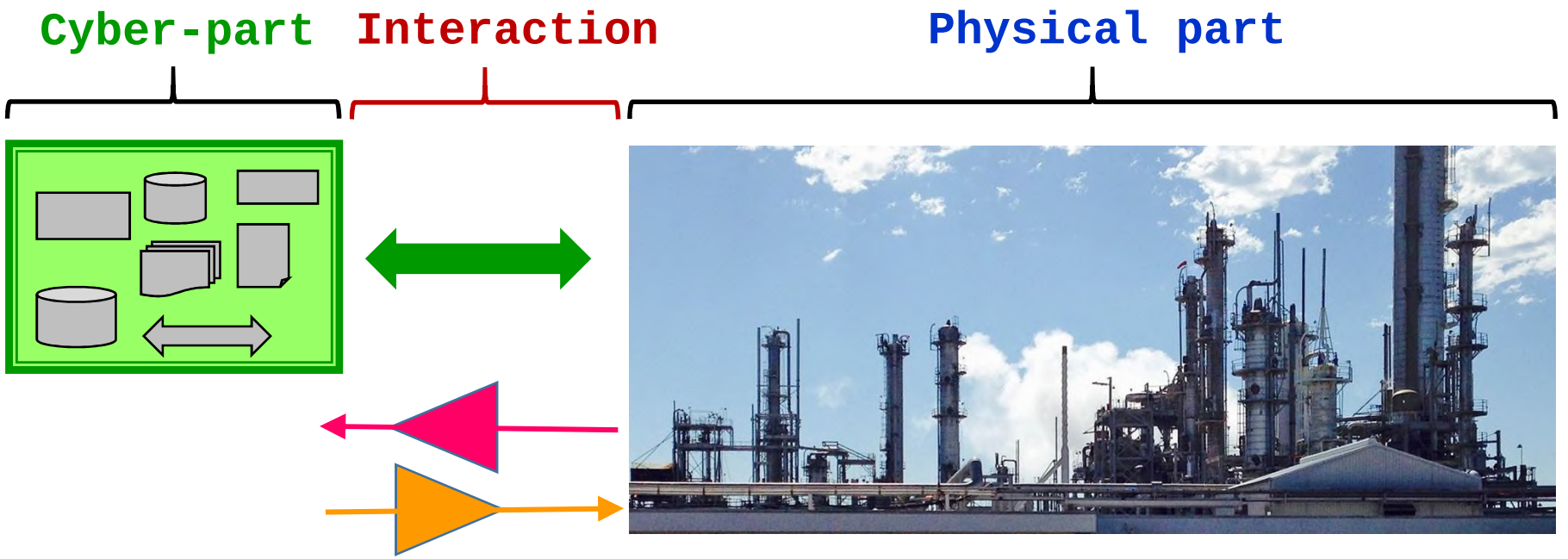
MAPE-K:
Autonomic/autonomous
Cyber-Physical Systems

http://photojournal.jpl.nasa.gov/catalog/PIA19920

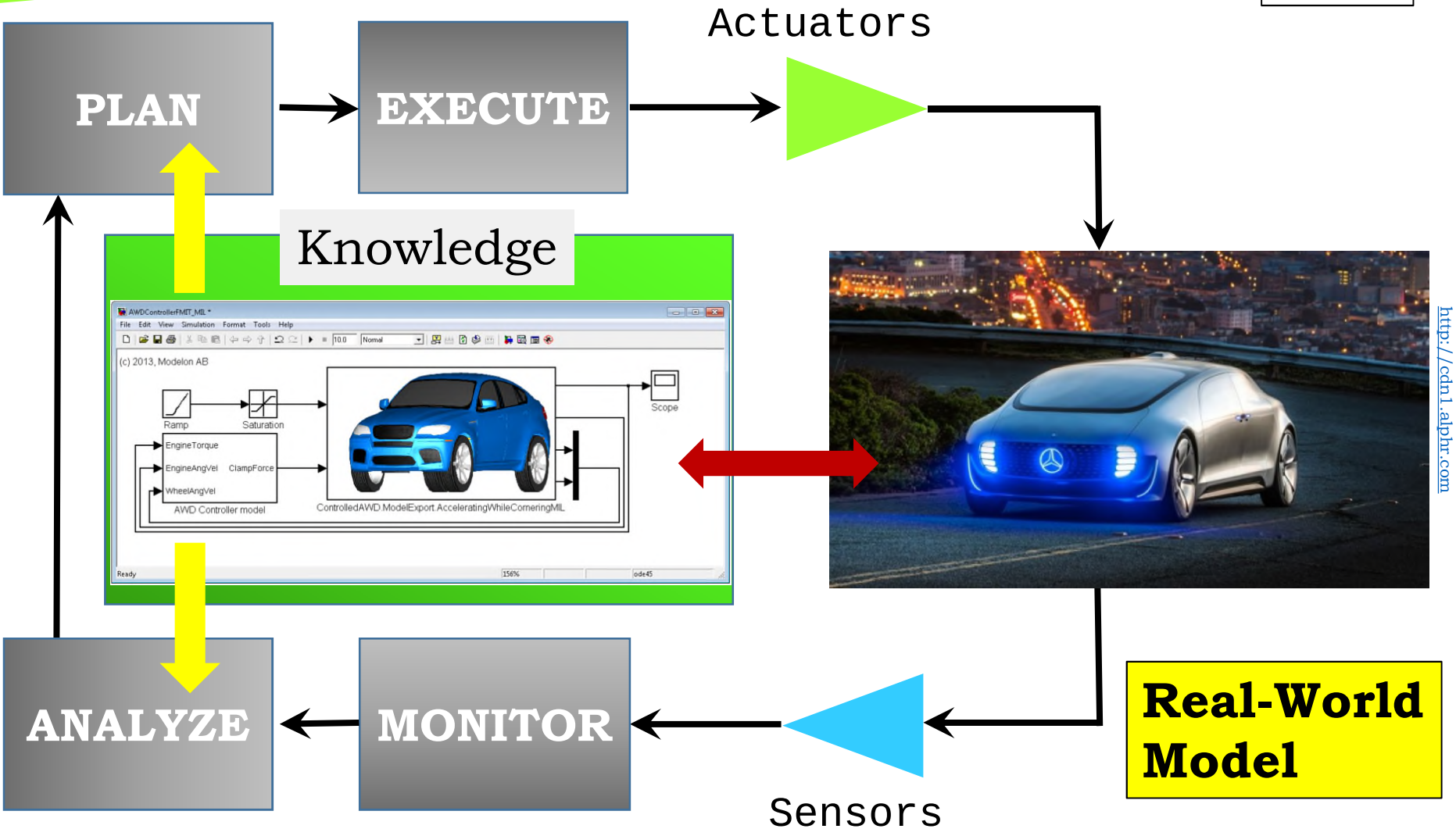
"A ***cyber-physical system*** (CPS) consists of a collection of ***computing devices*** communicating with one another and ***interacting*** with the physical world in a ***feedback loop***"

R. Alur: Principles of Cyber-Physical Systems, 2015

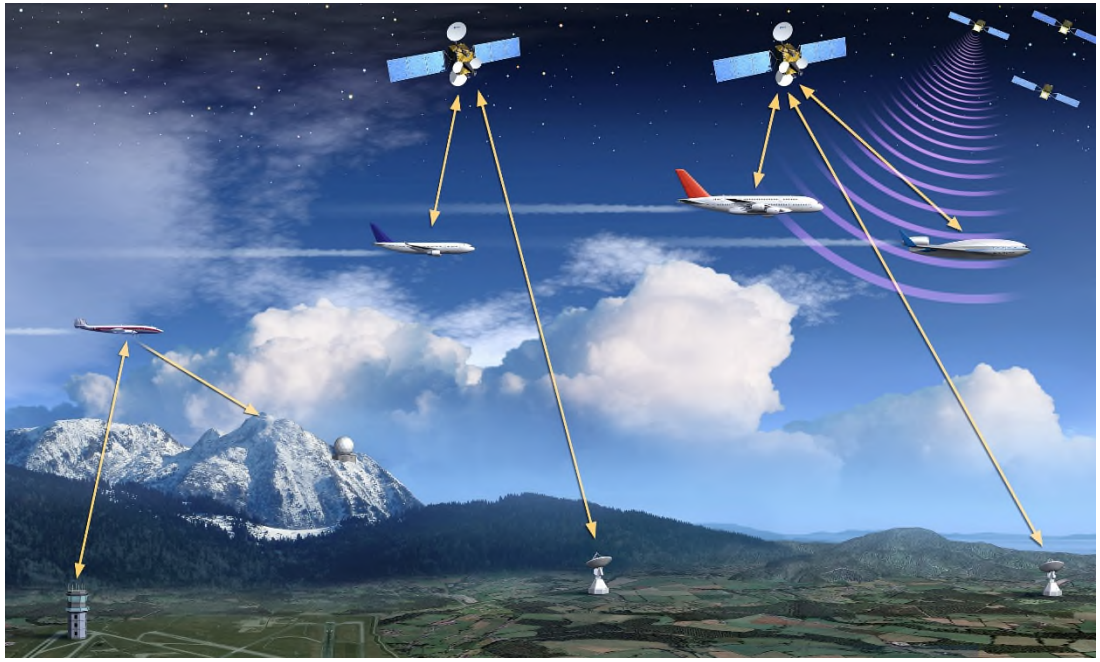



Cyber-part
Interaction
Physical part
http://www.etemaaddaily.com
Sensors: Input Signals
Actors: Output Signals
Cyber-physical system

CPS



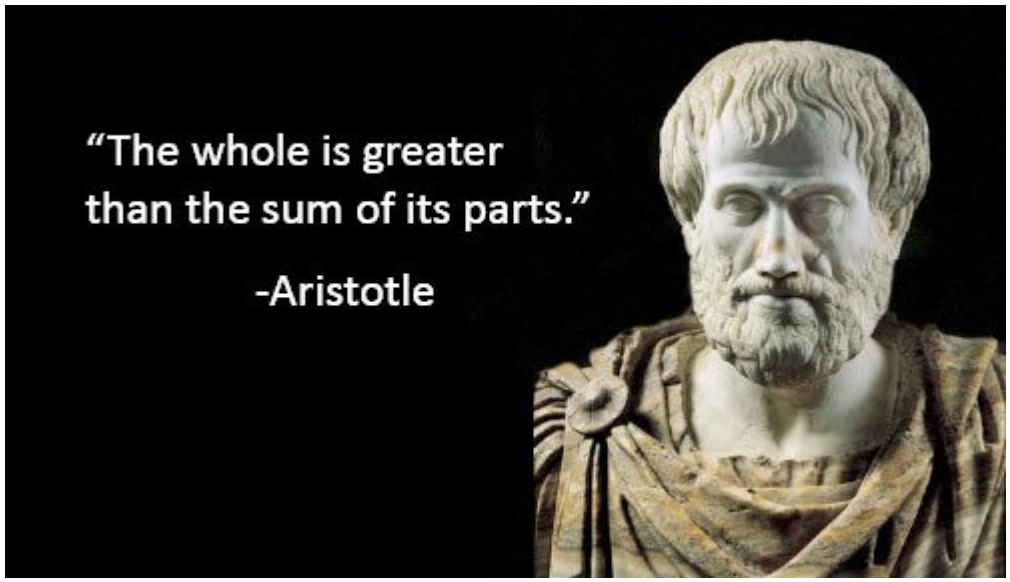
Cyber-Physical Systems-of-Systems (CPSoS)



http://www.aero.sbg.ac.at

CPSoS

"A ***cyber-physical system-of-systems (CPSoS)***
is a ***collaboration*** of dedicated systems
that pool their resources and capabilities
to create a new, ***more complex system***
which offers ***more functionality***
than the sum of the constituent systems"



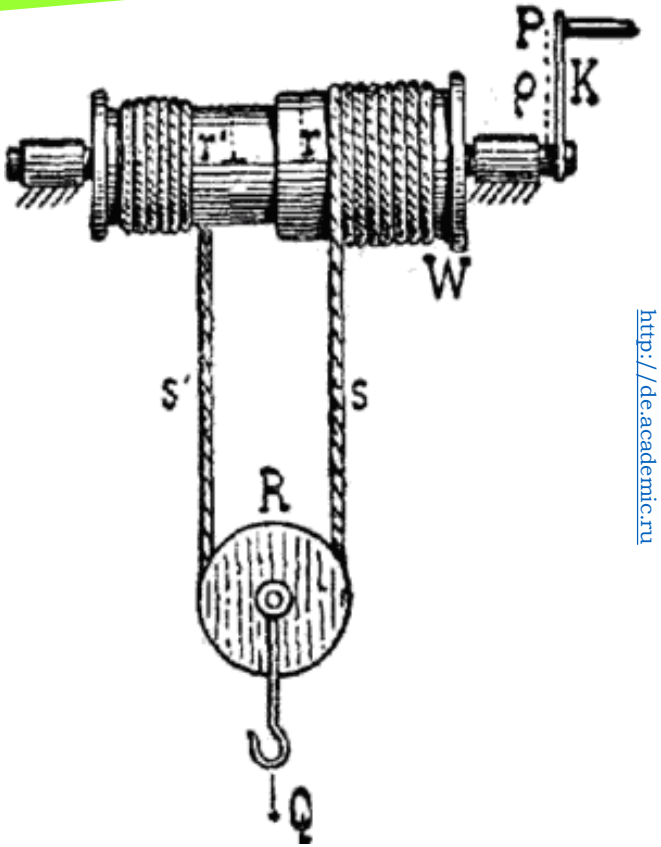
https://media.licdn.com

CPSoS:

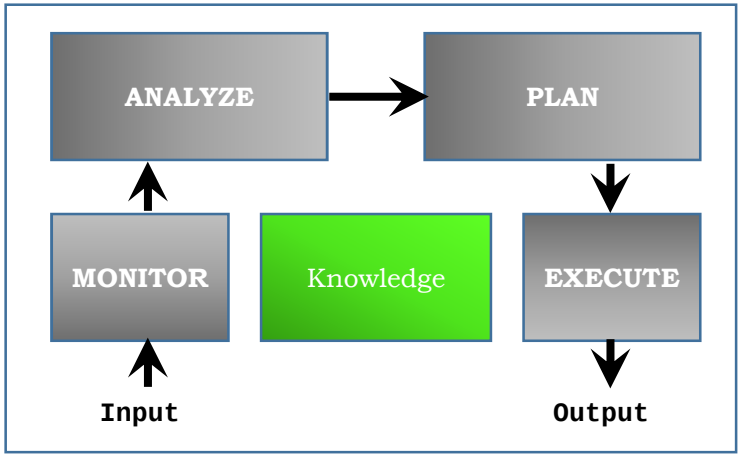
Emergent Properties

CPSoS:

Most of today's (and all of tomorrow's?) interesting applications are Cyber-Physical Systems-of-Systems



http://de.academic.ru

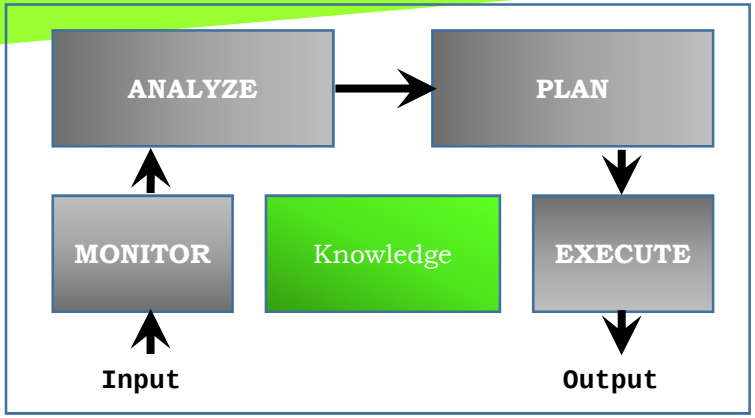


*… and use **Artificial Intelligence**:*

- Real-time models
- Machine learning
- Reasoning/Inference
- Intelligent agents
- Knowledge representation

CONTENT:

1. Motivation
2. Definition
3. Architecture
4. Applications
5. Risks
6. Outlook

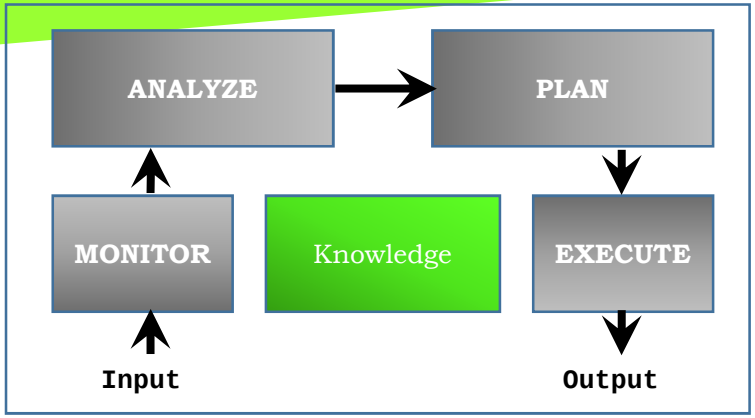


Future Applications (Examples)

Unmanned Ships

http://dsg.files.app.content.prod.s3.amazonaws.com

The large cargo ships will sail unmanned from port to port, including port leave and port entry

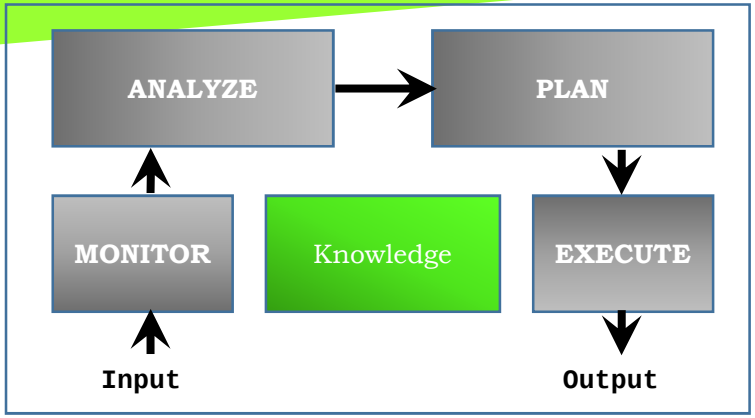


Future Applications (Examples)

Truck Platooning

http://www.itsinternational.com

Trucks combine to «platoons» and drive in close convoy

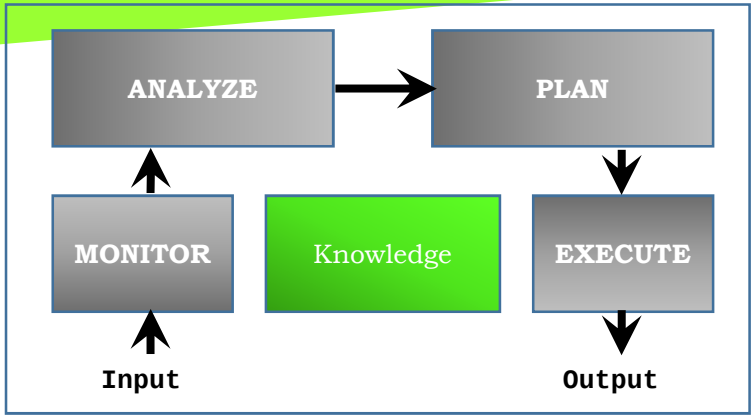


Future Applications (Examples)

Car Platooning

http://www.techadvisor.co.uk

Autonomous cars combine to a «platoon» and optimize space requirements and travel time

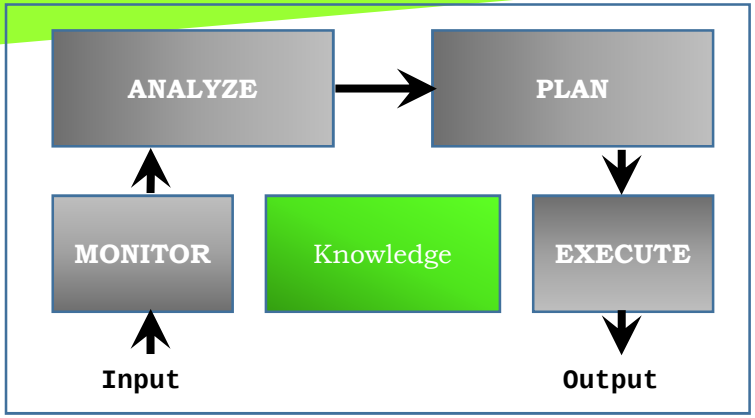


Future Applications (Examples)

Drone delivery service

http://www.futuretimeline.net

Autonomous drones may deliver goods to your doorstep



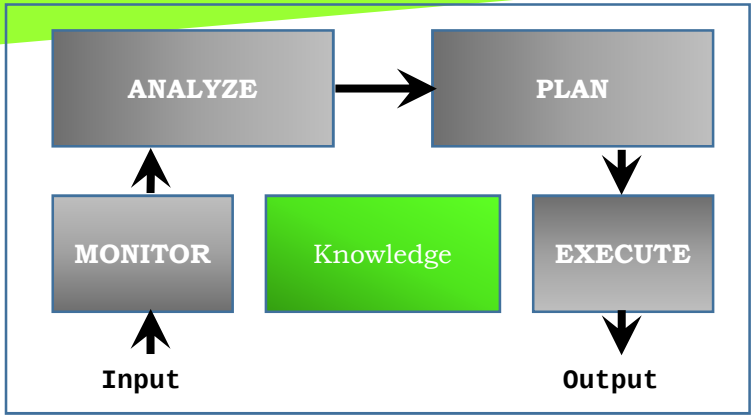
Future Applications (Examples)

Medial diagnostic systems

https://ehealthfordummies.files.wordpress.com

Autonomous medical expert systems may diagnose your health problems

[see IBM Watson]

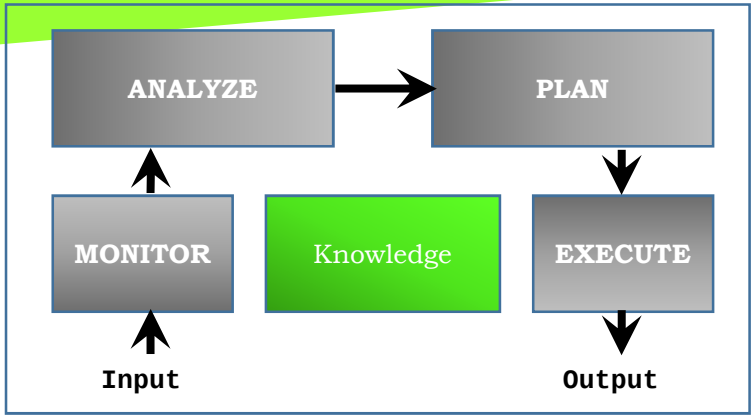


Future Applications (Examples)

Catastrophe relieve robots

http://english.sia.cas.cn

Autonomous robots support rescue operations after catastrophes

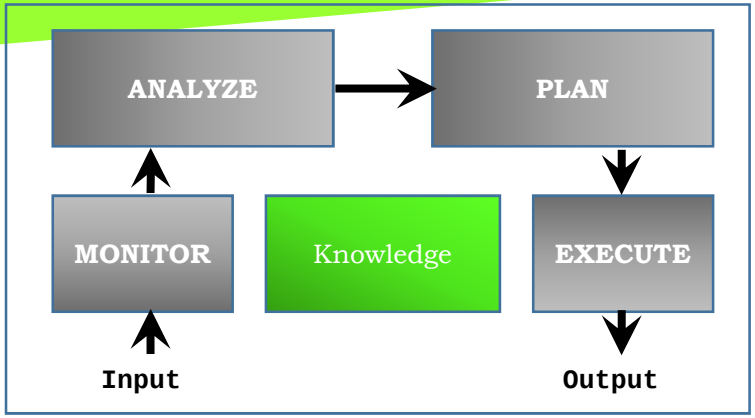


Future Applications (Examples)

Cyber-attack defense

Autonomous, AI-based, preventive cyber-attack detection and defense

http://www.bibliotecapleyades.net



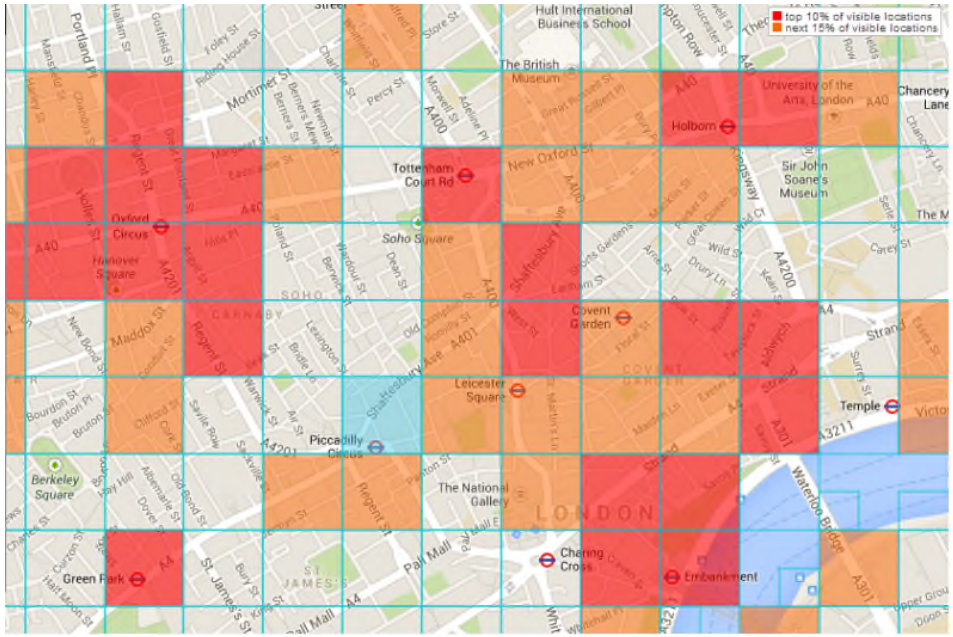
Criminal profiling

http://psychcare.us

Future Applications (Examples)

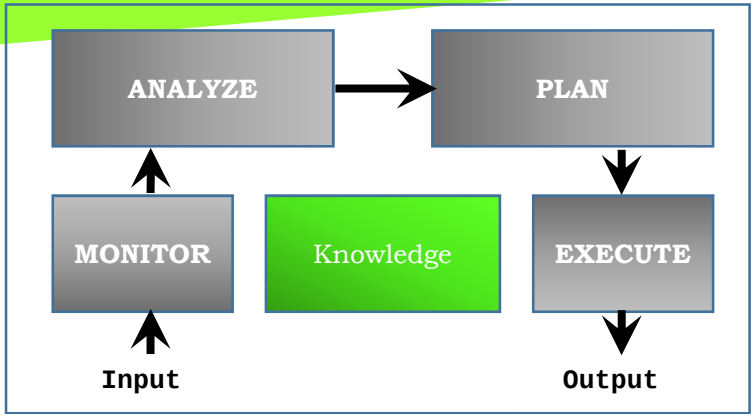
Crime location prediction

Crime location prediction helps police to deploy forces most effectively



https://cdn-images-1.medium.com

Criminal profiling may not lead to the exact individual but it often helps police narrow the focus of their investigation

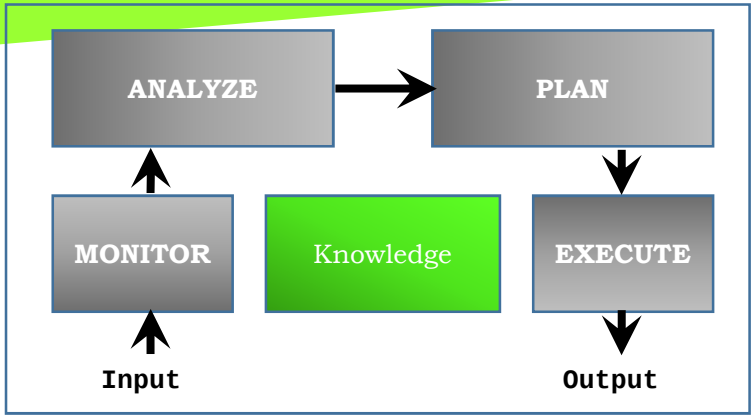


Future Applications (Examples)

Financial fraud prevention

https://media.licdn.com

Powerful, efficient, adaptive machine learning for Credit Card fraud detection and prevention are more and more in use



Future Applications (Examples)

Early cancer detection [Medical image processing]

http://herb.co

Deep learning adapted to automatically detect ***lung cancer nodules*** in chest CT images …

… was 50 percent more accurate than an expert panel of thoracic radiologists

15.9.2016: https://www.cbinsights.com/blog/ai-startups-fighting-cancer

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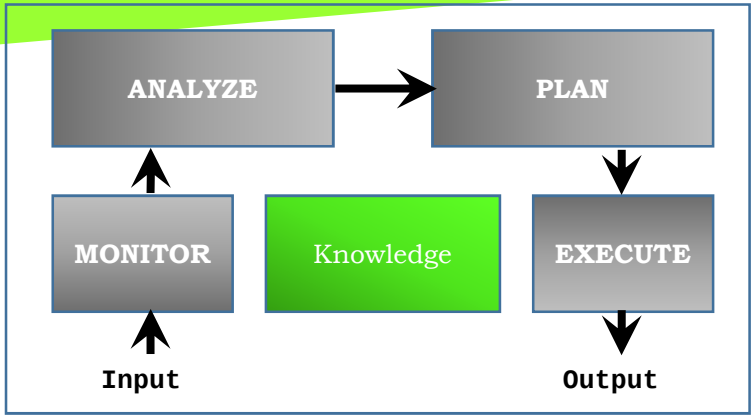


Risks of Artificial Intelligence

https://www.wired.com

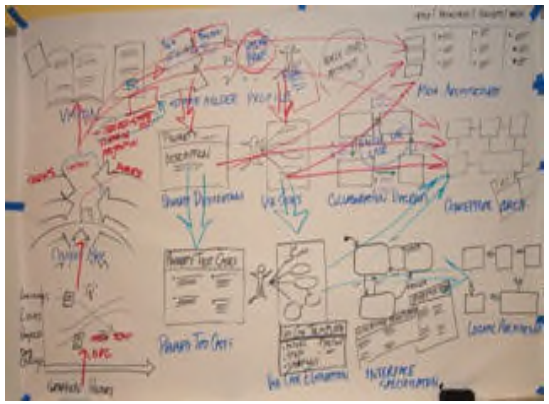
«The development of full artificial intelligence … could spell the end of the human race»

Stephen Hawking

Risks

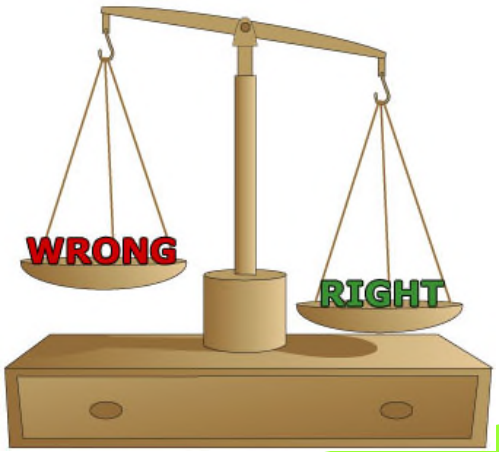
http://emergingtech.tbr.edu

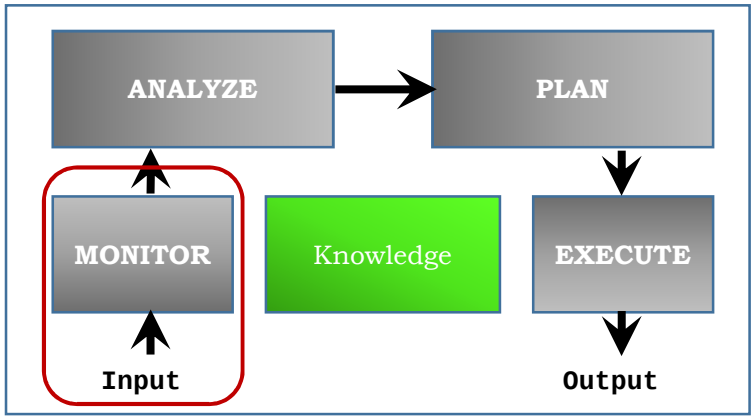
Complexity: Architecture challenge



Self-learning: Loss of understanding

Autonomous decisions: Legal & ethical questions





May 7, 2016:
TESLA Autopilot accident

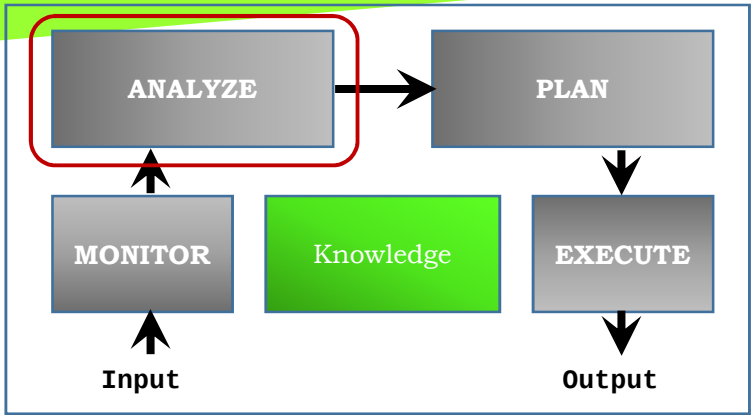
http://www.theverge.com/2016/7/26/12287118/tesla-autopilot-crash-images-speed-limit-ntsb

Brown's car was traveling at 74 miles per hour before it made impact with a tractor trailer that was crossing its path

Reason: The "high, white side of the box truck" and "a radar signature that would have looked very similar to an overhead sign" ⇒ no automatic braking

Input processing error

AUTONOMIC COMPUTING



A Tupolev 154M passenger jet and a Boeing 757-200 cargo jet ***collided in mid-air*** on July 1, 2002 at 21:35 (UTC) over Überlingen, Germany

http://www.baaa-acro.com

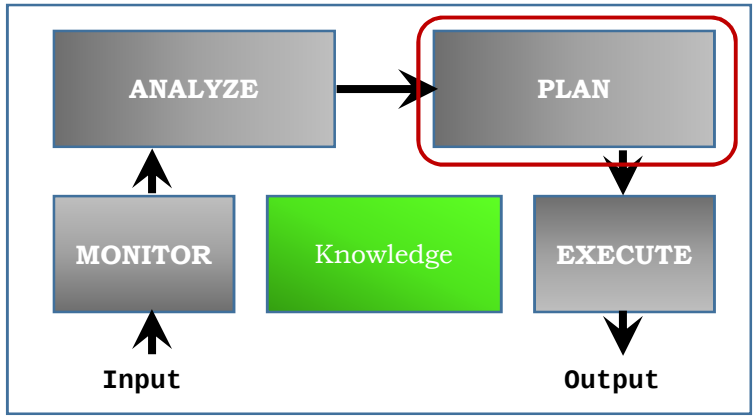
"The two aircraft were flying at flight level 36,000 feet on a collision course. The air traffic controller realized the fact less than a minute before the accident. He ***instructed the pilot of Flight 2937 to descend by a thousand feet*** to avoid collision with Flight 611"

"Seconds after the Flight 2937 initiated the descent their **Traffic Collision Avoidance System (TCAS)** instructed them to ***climb***, while at about the same time the TCAS on Flight 611 instructed the pilots of that aircraft to ***descend***."

https://elearning.flightsafety.com

Had both aircraft <u>followed</u> those ***automated instructions***, it is unlikely that the collision would have occurred

AUTONOMIC COMPUTING



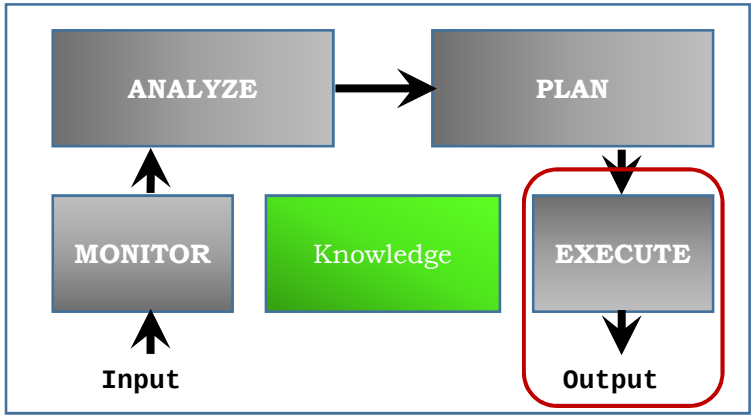
http://icnet.ppci.co.uk

http://thefinancialphysician.com

- Market stability?
- Market manipulation?
- Unfair advantages?

Last week, Ben Goertzel and his company, Aidyia, turned on a hedge fund that ***makes all stock trades using artificial intelligence*** – no human intervention required. "If we all die," says Goertzel, a longtime AI guru and the company's chief scientist, "it would keep trading."

https://www.wired.com/2016/01/the-rise-of-the-artificially-intelligent-hedge-fund/



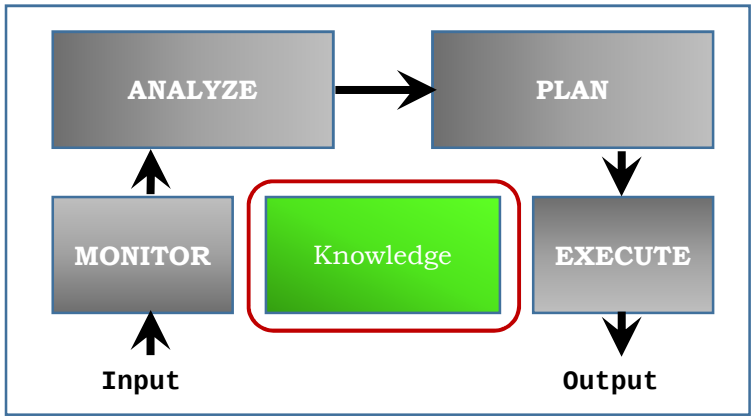
FBI Warning 17.3.2016:
It's been eight months since a pair of security researchers proved beyond any doubt that ***car hacking*** is more than an action movie plot device when they remotely killed the transmission of a 2014 JEEP Cherokee

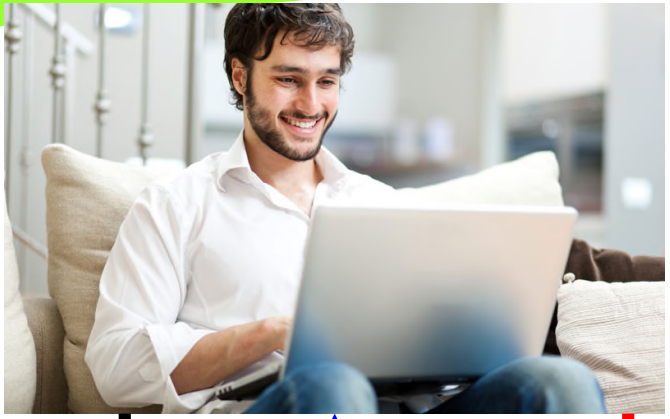
By sending carefully crafted messages on the vehicle's internal network known as a CAN bus, they're now able to pull off even more dangerous, unprecedented tricks like causing unintended acceleration and slamming on the car's brakes

https://www.wired.com/2016/08/

http://craigpeterson.com/automotive/hacking

AUTONOMIC COMPUTING





Proposed Results: ***Relevance***

Filter

Profile

Request

Results

Access

Request

Results

Access

Proposed Results: ***Accumulated Preferences***

AUTONOMIC COMPUTING

Accidents are unavoidable!

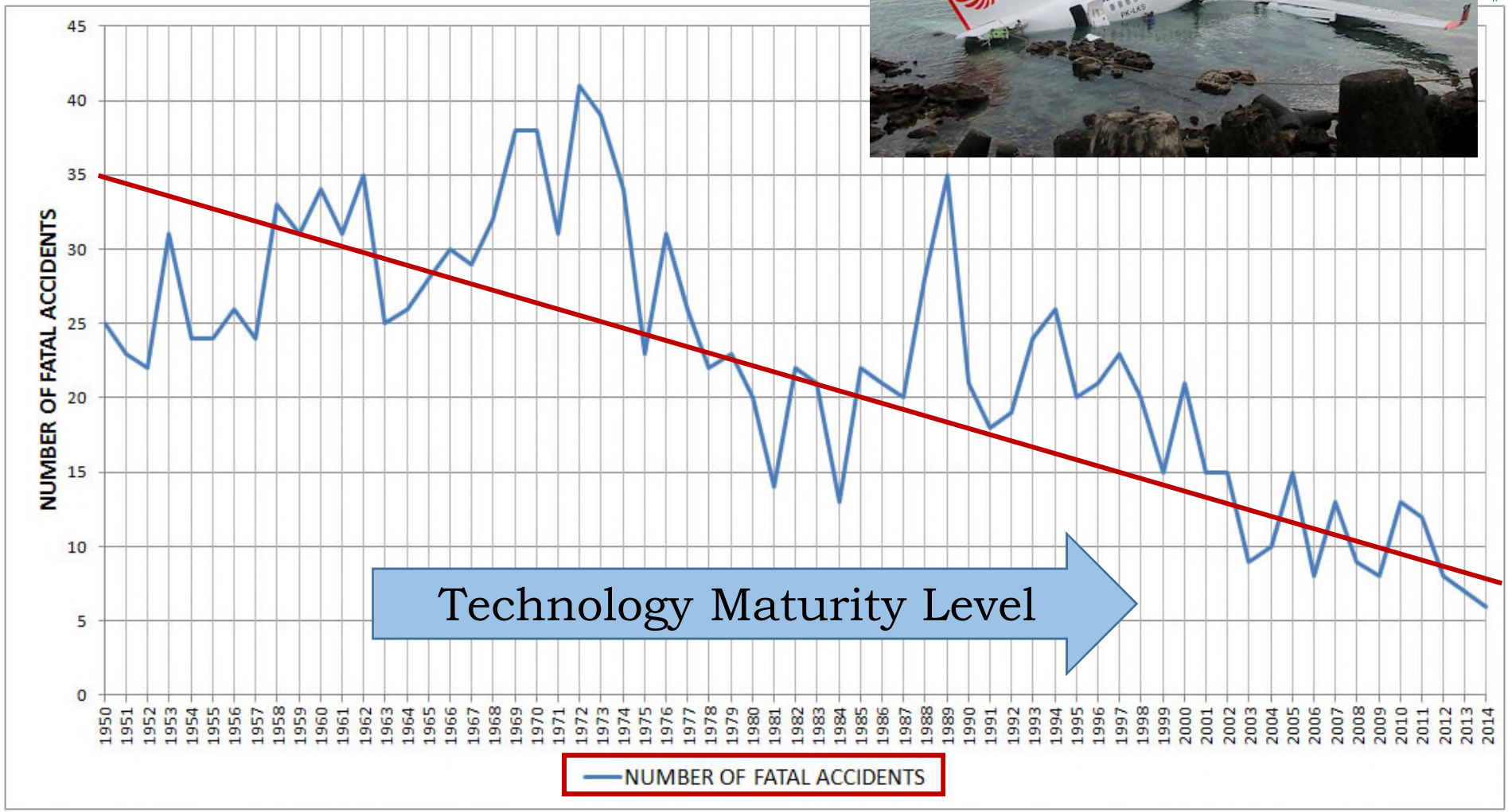
Technology Maturity Level

Autonomic Systems
Autonomous Systems
Intelligent CPS's

Government

Industry

http://a.abcnews.com



Source: http://www.planecrashinfo.com/cause.htm [16.1.2017]

Technology Maturity Level Improvement Loop

AIRBUS

BOEING

Emirates

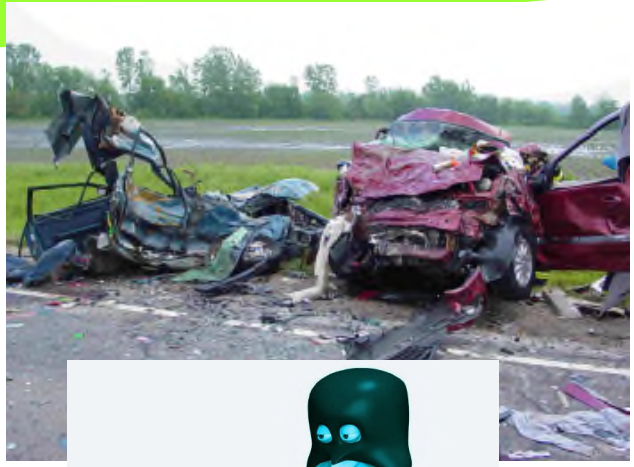
Sydney Airport

Lufthansa

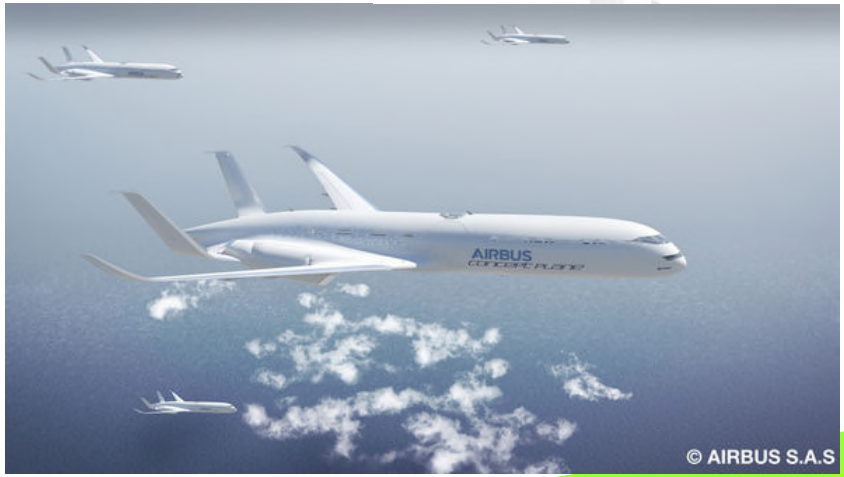
http://www.meaforensic.com

http://a.abcnews.com

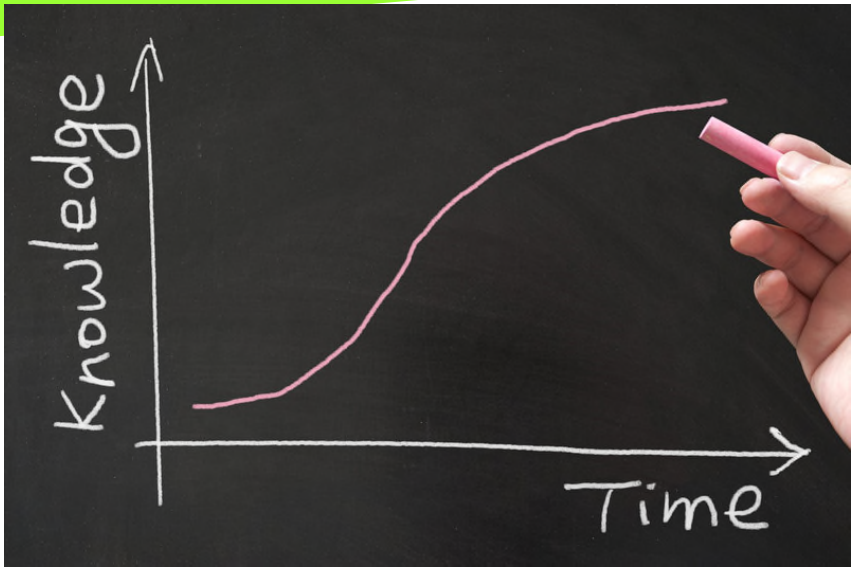
http://www.alaskapublic.org



Technology Maturity Level Improvement Loop



http://www.canstockphoto.de



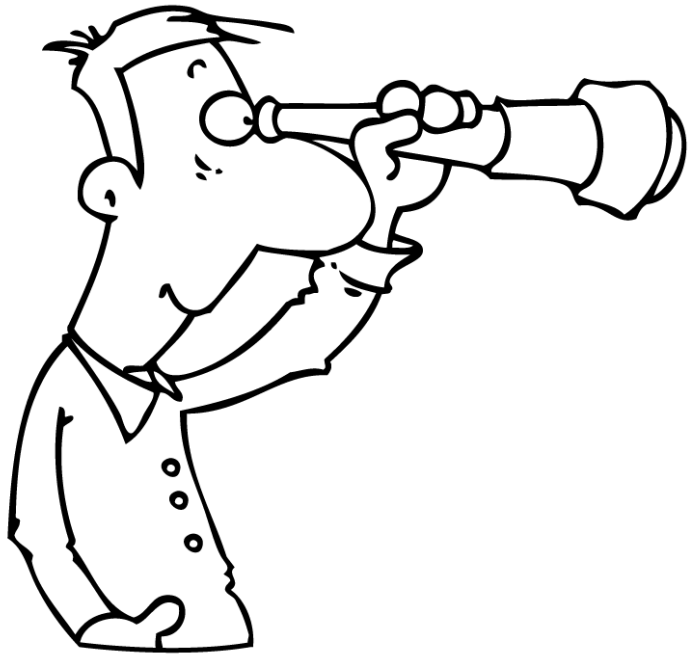
- … so – let us see and accept the ***risks***
- and continuously ***reduce*** them with the Technology Maturity Level Improvement Loop (Learning curve)

http://business-ethics.com

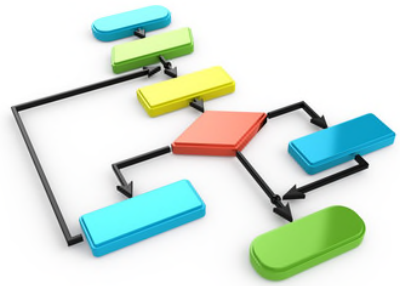
???? What with ethical questions ????

CONTENT:

1. Motivation
2. Definition
3. Architecture
4. Applications
5. Risks
6. Outlook



Conclusions & Outlook



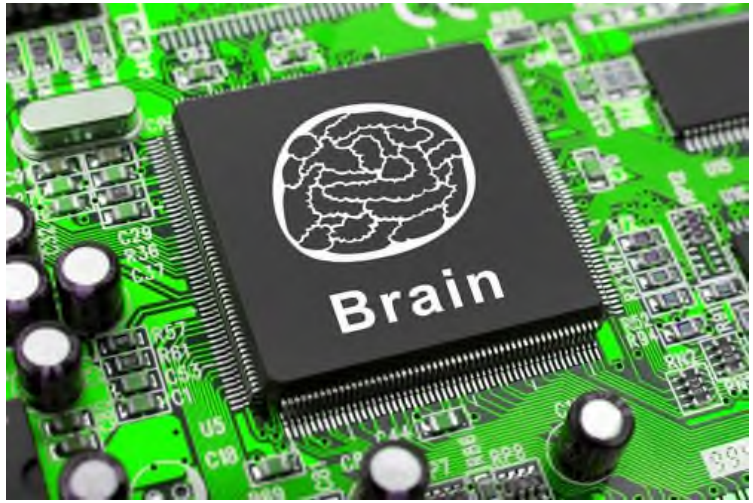
Algorithmic computing (based on *pre-defined* rule sets) has served us well (and still does in many applications)

Algorithmic computing, however, ***cannot*** handle situations:

- *where the problem is not fully defined*
- *the environment is uncertain*
- *is too complex to be predicted*
- *is rapidly changing dynamically*

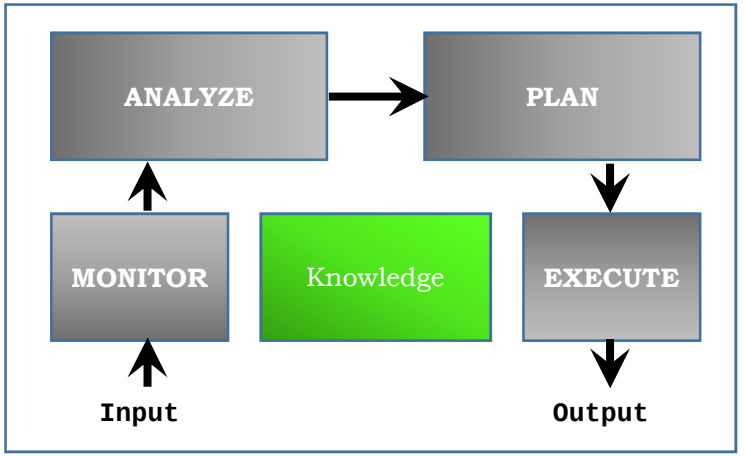
http://thedailynewnation.com

Conclusions & Outlook



To cope with such situations we need the support of ***software based on artificial intelligence*** (self-learning, inference, reasoning, …)

One promising avenue is «autonomic computing» - based on the reference ***architecture MAPE-K***



Conclusions & Outlook

Autonomic/autonomous systems – specifically Cyber-Physical Systems-of-Systems (**CPSoS**) – are indispensable to manage our complex technology future

Autonomic/autonomous systems have a tremendous positive potential – but also a significant risk

We (society) will exploit the ***benefits*** but must also mitigate the ***risks*** via a technology maturity improvement cycle

Defining, building and evolving cyber-physical systems-of-systems is a new, highly demanding, interdisciplinary ***engineering discipline***

Industry needs knowledgeable, competent CPSoS-engineers

References

Agoulmine10	Nazim Agoulmine (Editor): **Autonomic Network Management Principles – *From Concepts to Applications*** Academic Press, Burlington, MA, USA, 2010. ISBN 978-0-12-382190-4
Ardagna10	Danilo Ardagna, Li Zhang (Editors): **Run-time Models for Self-managing Systems and Applications** Birkhäuser-Verlag (Springer), Basel, Switzerland, 2010. ISBN 978-3-0346-0432-1
Babaoglu05	Ozalp Babaoglu, Márk Jelasity, Alberto Montresor, Christof Fetzer, Stefano Leonardi, Aad van Moorsel, Maarten van Steen (Editors): **Self-star Properties in Complex Information Systems** Springer Lecture Notes in Computer Science, Volume 3460, 2005. ISBN: 978-3-540-26009-7
Cong-Vinh11	Phan Cong-Vinh (Editor): **Formal and Practical Aspects of Autonomic Computing and Networking – *Specification, Development, and Verification*** Premier Reference Source, Information Science Reference Publishing, 2011. ISBN 978-1-60960-845-3
DARPA15	Defense Advanced Research Projects Agency (DARPA): ***2016 DARPA Cyber Grand Challenge Final Competition – The World's First All Machine Hacking Tournament*** Downloadable from: http://www.darpa.mil/news-events/2015-07-08 / https://cgc.darpa.mil/ [last accessed 15.3.2016]
DARPA16	Defense Advanced Research Projects Agency (DARPA): ***DARPA Cyber Grand Challenge Competitor Portal***. 2016 Downloadable from: https://cgc.darpa.mil/ [last accessed 15.3.2016]

AUTONOMIC COMPUTING

Dobson10	Simon Dobson, Roy Sterritt, Paddy Nixon, Mike Hinchey: ***Fulfilling the Vision of Autonomic Computing***. IEEE Computer Society, January 2010. Downloadable from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.376.1739&rep=rep1&type=pdf [last accessed 12.3.2016]
Fortes11	José Fortes (Director of the US National Science Foundation's Center for Autonomic Computing): ***What is autonomic computing?*** Interview, January 26, 2011. Downloadable from: https://sciencenode.org/feature/what-autonomic-computing.php [last accessed 9.4.2016]
GrammaTech16	GrammaTech, Inc., Ithaca, NY 14850: ***Autonomic Computing – Powering the Industry's Future Intelligent Devices.*** Downloadable from: http://www.grammatech.com/autonomic-computing [last accessed 15.3.2016]
Hariri06	Salim Hariri, Manish Parashar (Editors): **Autonomic Computing - *Concepts, Infrastructure, and Applications*** CRC Press Inc., Boca Raton, USA, 2006. ISBN 978-0849393679
Hildebrandt11	Mireille Hildebrandt, Antoinette Rouvroy: **Law, Human Agency and Autonomic Computing – *The Philosophy of Law meets the Philosophy of Technology*** Routledge (Taylor & Francis), Milton Park, UK, 2011. ISBN 978-0-415-72015-1
Huebscher08	Markus C. Huebscher, Julie A. McCann: ***A survey of Autonomic Computing — Degrees,*** ***models and applications***. ACM Computing Surveys (CSUR) Surveys Homepage archive, Volume 40 Issue 3, August 2008. Downloadable from: https://spiral.imperial.ac.uk/bitstream/10044/1/5738/1/autonomic-computing.pdf [last accessed 19.3.2016]

AUTONOMIC COMPUTING

IBM06	IBM Business Consulting Services: **An Architectural Blueprint for Autonomic Computing** IBM Autonomic Computing, 4th edition, June 2006. Downloadable from: http://www-01.ibm.com/software/tivoli/autonomic/
ICCAC16	2016 IEEE ***International Conference on Cloud and Autonomic Computing*** (ICCAC). Augsburg, Germany, September 12-16, 2016 (see also "history"). http://www.autonomic-conference.org/
IJAC16	International Journal of Autonomic Computing (IJAC): http://www.inderscience.com/jhome.php?jcode=ijac
Kurian13	Devasia Kurian, Pethuru Raj: ***Autonomic Computing for Business Applications*** (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 4, No. 8, 2013. Downloadable from: http://thesai.org/Downloads/Volume4No8/Paper_1-Autonomic_Computing_for_Business_Applications.pdf [last accessed 9.4.2016]
Lalanda13	Philippe Lalanda, Julie A. McCann, Ada Diaconescu: **Autonomic Computing – *Principles, Design and Implementation*** Springer-Verlag, London, 2013. ISBN 978-1-4471-5006-0
Menasce07	Daniel A. Menascé, Jeffrey O. Kephart: ***Autonomic Computing*** IEEE Computer Society, January/February 2007. Downloadable from: https://www.computer.org/csdl/mags/ic/2007/01/w1018.pdf [last accessed 9.4.2016]
Müller06	Hausi A. Müller, Liam O'Brien, Mark Klein, Bill Wood: ***Autonomic Computing*** Carnegie Mellon University, Technical Note CMU/SEI-2006-TN-006, 2006. Downloadable from: http://www.sei.cmu.edu/reports/06tn006.pdf [last accessed 14.1.2016]

AUTONOMIC COMPUTING

Murch04	Richard Murch: **Autonomic Computing** IBM Press, Prentice Hall PTR, NJ, USA, 2004. ISBN 978-0-13-315319-3
Parashar06	Manish Parashar, Salim Hariri (Editors): **Autonomic Computing - *Concepts, Infrastructure, and Applications*** CRC Press Inc., Boca Raton, USA, 2006. ISBN 978-0849393679
Rak15	Jacek Rak: **Resilient Routing in Communication Networks** Springer International Publishing, Switzerland, 2015. ISBN 978-3-319-22332-2
SciAm02	W. Wayt Gibbs: ***Autonomic Computing – Programs crash, people make mistakes, networks grow and change. That¿s life, and computer scientists are finally building systems that can deal with it*** Scientific American, May 2002. Downloadable from: http://www.scientificamerican.com/article/autonomic-computing/ [last accessed 9.4.2016]
Tianfielda04	Huaglory Tianfielda, Rainer Unland: ***Towards autonomic computing systems*** Engineering Applications of Artificial Intelligence 17 (2004), 689–699 Downloadable from: https://www.researchgate.net/profile/Rainer_Unland3/publication/222433987_Towards_autonomic_computing_systems/links/00b7d51d039fb794b1000000.pdf [last accessed 5.4.2016]
Tschudin07	Christian Tschudin, Christophe Jelger, Lidia Yamamoto: ***Autonomic Computer Systems CS321: IBM's "autonomic computing" initiative, Self-Star, Control Loops, Policies.*** ETHZ lecture, January 15, 2007. Downloadable from: http://www.csg.ethz.ch/education/lectures/ATCN/ws06_07/doc/tschudin-ethz-autonomic1-2up.pdf [last accessed 9.4.2016]
TTU16	***Cloud and Autonomic Computing Center*** Texas Technical University (TTU) http://www.depts.ttu.edu/cac/

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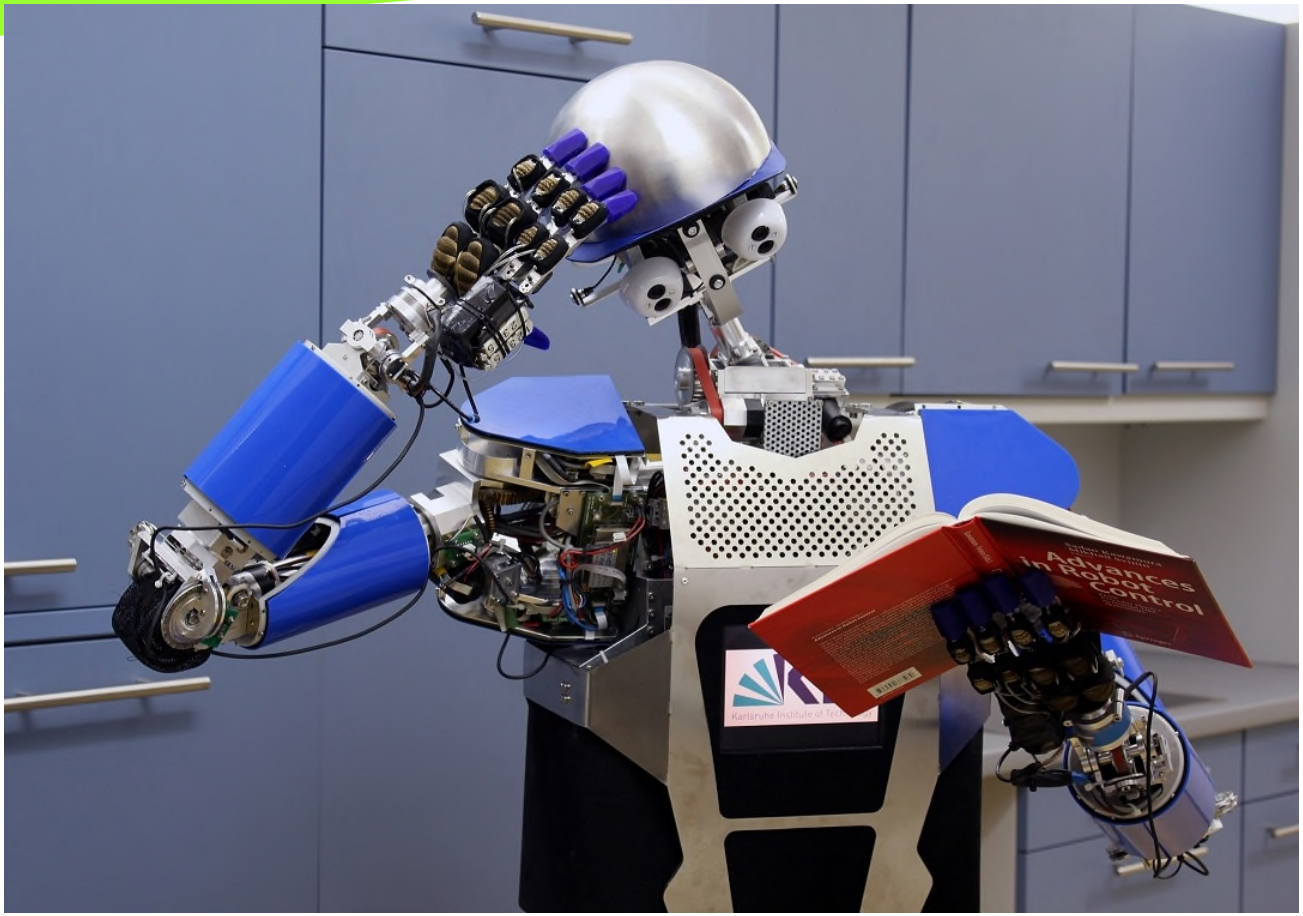

Thank you – Questions please?