5º SEMINARIO DE ACERCAMIENTO TECNOLOGICO
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TENDENCIAS Y PERSPECTIVAS EN AUTOMATIZACION, ROBOTICA Y CONTROL Y SU IMPACTO EN LA INDUSTRIA MINERA

Prof. Dr. Aldo Cipriano
Pontificia Universidad Católica de Chile & Dictuc S.A.
aciprian@ing.puc.cl

CONTENIDO

- Historia
- Presente
- Futuro
- Aplicaciones
- Conclusiones

HISTORIA

ARC: los inicios

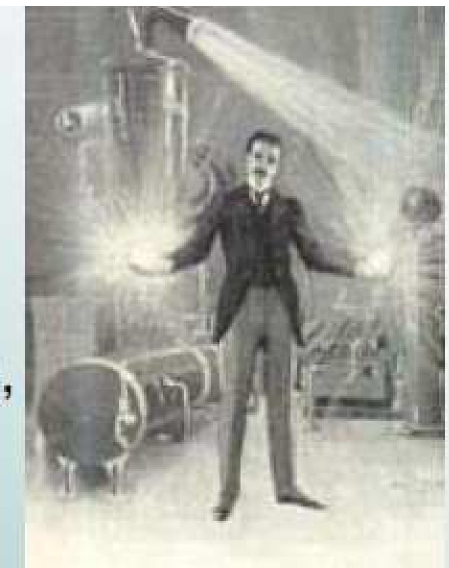
The notion of **putting machines to work** for us to perform routine tasks on command can be credited to great thinkers like **Aristotle** (384-322 BC).

HISTORIA

❑ ARC: los inicios

- 1890: **Thomas Edison** used a condensed version of his phonograph invention in the design of the famous **talking doll**.

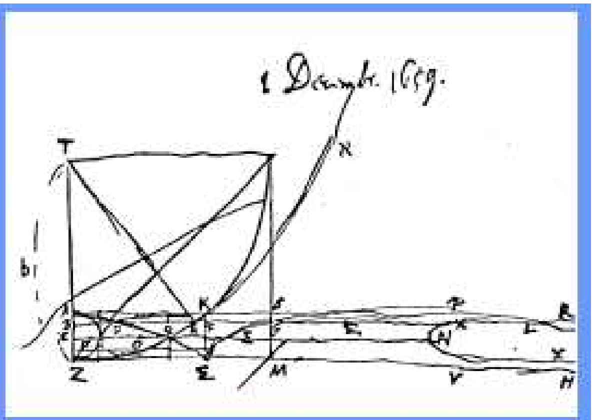
- 1898: **Nikola Tesla**, a famous inventor, patents the first remote controlled device. The **'teleautomaton'** was a crewless boat that was controlled from a distance without wires.



HISTORIA

❑ ARC: los inicios

- Some of the earliest control included:
  - Time keeping with water clocks
  - Clocks with a conical pendulum
  - Windmills:
    - facing sails into the wind,
    - controlling the sail speed with a governor,
    - adjusting the crushing parameters (gap and supply rate).
  - No theory backing. Control was empirical.



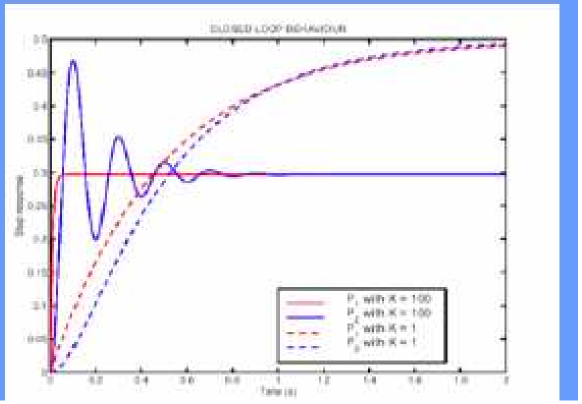
HISTORIA

ARC: Los inicios

- Application (centrifugal governor) motivated:
  - Differential equation modelling
  - Formulation of a stability problem (roots of a polynomial had to lie in the left half plane)
- Solution was achieved for low order polynomials.
- Regulation accuracy versus overshoot trade-off became understood
- Many modest inventions tweaked the ideas.

$$\frac{d^3x}{dt^3} + 3\frac{d^2x}{dt^2} + 2\frac{dx}{dt} + 3x = r$$

Maxwell recognized, but could not solve, the general stability problem.

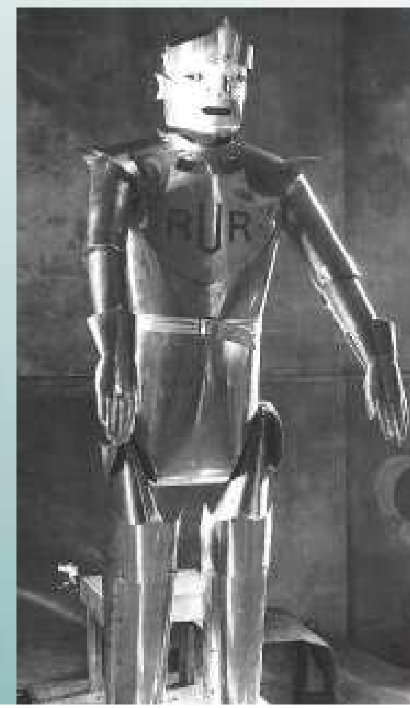


HISTORIA

ARC: los inicios

- 1921: The first reference to the word **robot** is made in a play by Czech writer **Karel Capek** (1890 - 1938) - R.U.R (Rossum's Universal Robots). The word comes from the Czech "robota" which means serf or one in subservient labour.

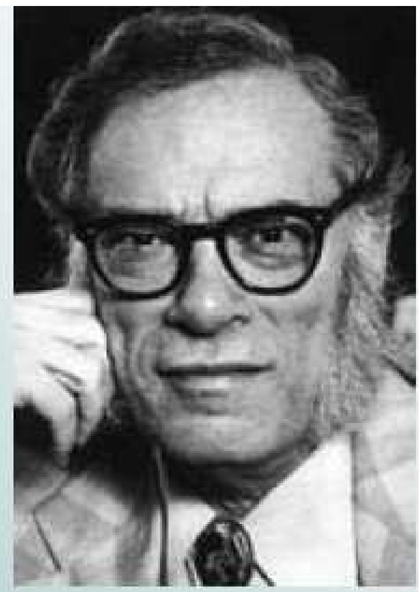
- In the play, the Czech robot is defined as "a worker of forced labour". After this play, electromechanical automatons were referred to as robots.



HISTORIA

ARC: los inicios

- 1940: Westinghouse Electric Corp. creates two of the **first robots** that use the **electric motor** for entire body motion. Elektra could dance, count to ten and smoke, while his dog companion Sparko, could walk, stand on its hind legs and bark.

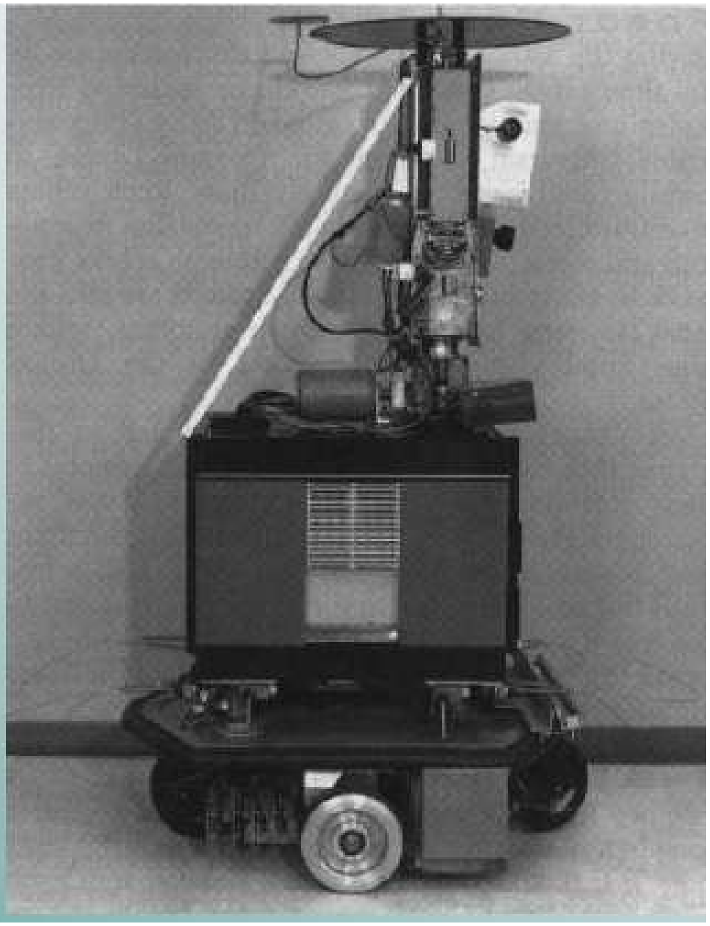


- 1941: **Isaac Asimov** first uses the term **'robotics'** to describe the technology of robots. He predicted the rise of the robot industry.

HISTORIA

❑ ARC: los inicios

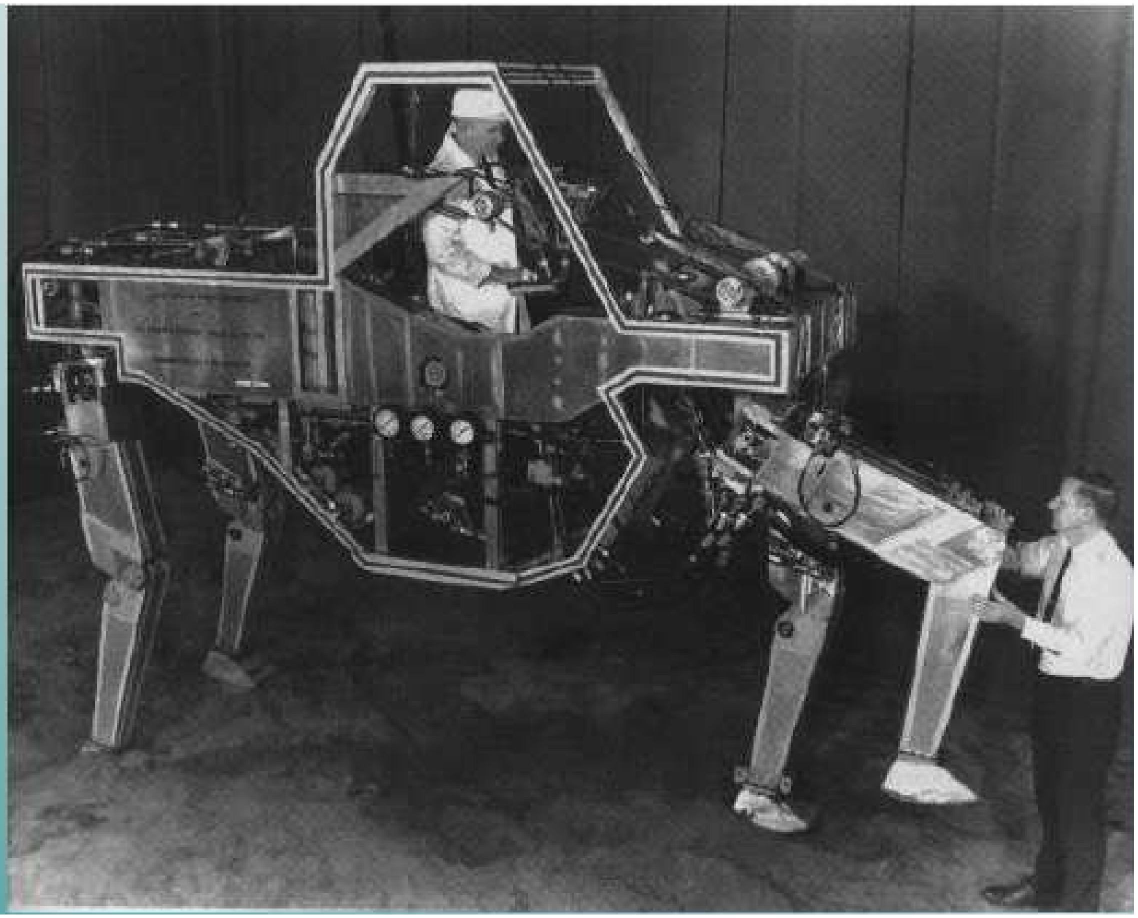
- 1968: SRI International, formerly known as the Stanford Research Institute, builds and tests the **first mobile robot with vision capability**. 'Shakey' was equipped with a television camera, a range finder and sensors.
- **Shakey** was the first mobile robot that could **think** and **respond** to the world around it.



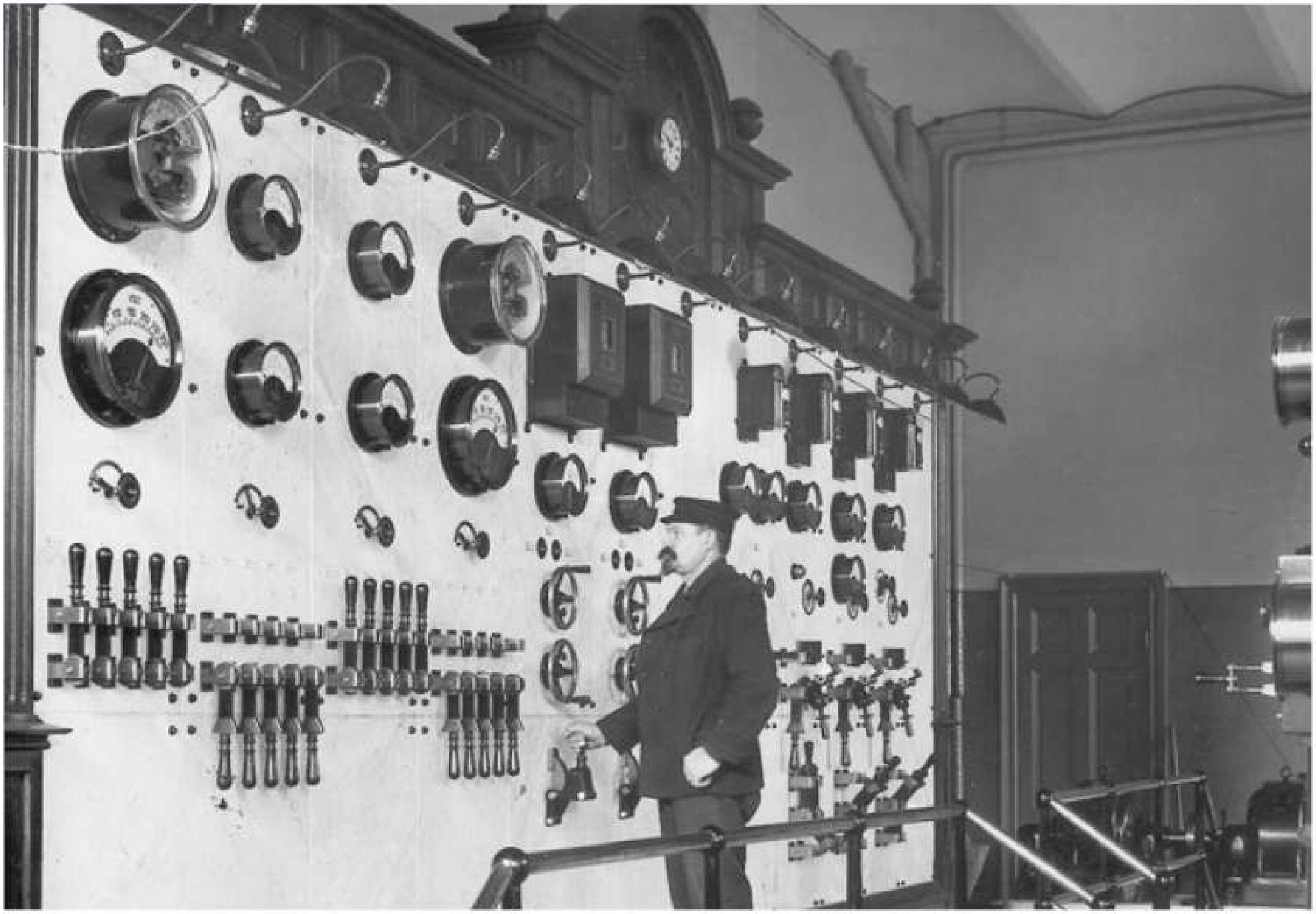
HISTORIA

ARC: los inicios

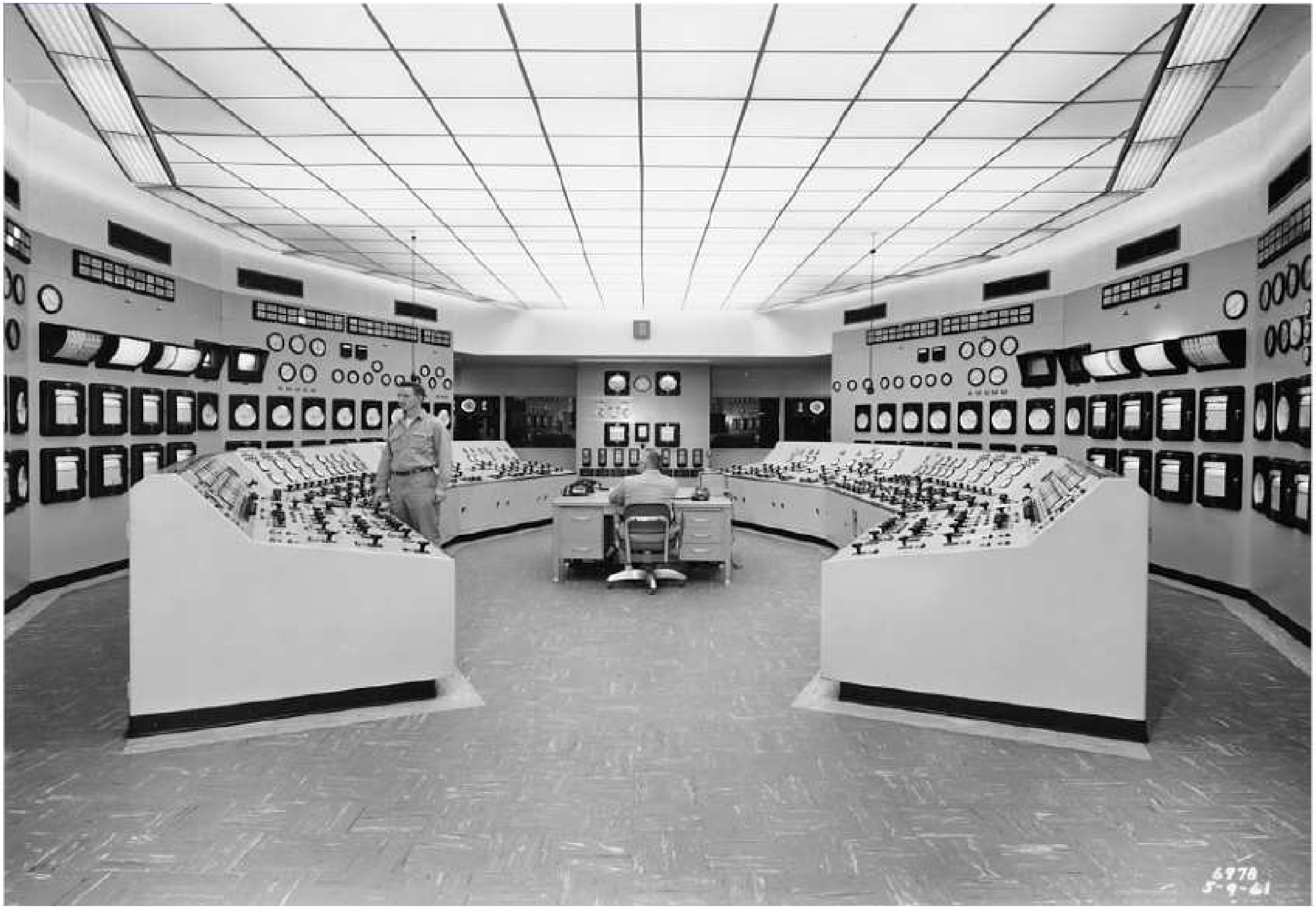
1968: The General Electric **Walking Truck** was the first manual controlled walking truck.



HISTORIA



HISTORIA



HISTORIA

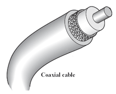
ARC: Tecnología digital

- The digital computer arrived--first as a design tool, and later as a control system component
  - Progressively removed many limitations on design methods
  - Reduced restriction on graphical schemes, low order designs, small numbers of parameters, etc
  - Motivated sampled-data control and lately, hybrid systems

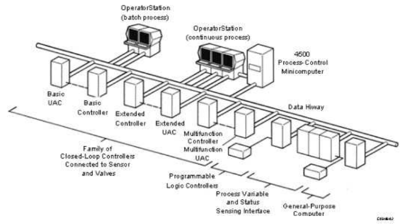
Control de Procesos

1960
Primeros instrumentos electrónicos miniatura

Salas de Control de paneles



1970
Xerox desarrolla la primera versión experimental de Ethernet usando un cable coaxial



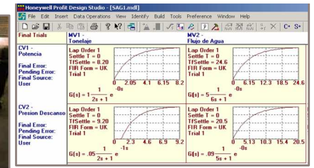
1975
Sistemas de Control Distribuidos (DCS), TDC2000 de Honeywell

Control predictivo basado en modelo (MPC) de 1ª generación

1985
Control adaptivo en Los Bronces

1987
Foxboro IA Series: Primer sistema en adoptar sistema operativo UNIX y tecnología ethernet

1988
Tecnología Fieldbus



1995
MPC de 4ta generación

1993
Bus de campo Profibus DP

2003
Experion de Honeywell basado en ethernet tolerante a falla y plataforma Windows

1960 | 1970 | 1980 | 1990 | 2000

1959
Computador RW-300 controla en línea un proceso en la refinería de Texaco en Port Arthur, Texas

1968
Controlador Lógico Programable Modicon 084

1972
PDP8 en planta Colón

1982
TDC 2000 en Salvador

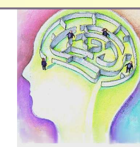
1983
Primer transmisor digital inteligente con salida 4-20 mA

1985
TDC 3000 en Teniente

1985
Estándar ANSI/IEEE 802.3 para ethernet

IEEE ETHERNET

1988
Sistema Experto en El Soldado



2004
Instrumentación inalámbrica (wireless) de 1ra generación

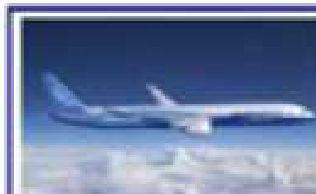
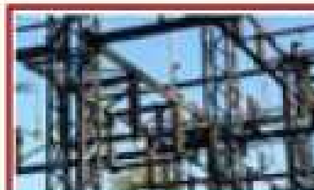
2007
Instrumentación inalámbrica 2ra generación

PRESENTE

❑ ARC: Lo actual

PRESENTE

❑ ARC: Algunos sectores

Transportation	▪ Faster and more energy efficient aircraft ▪ Improved use of airspace ▪ Safer, more efficient cars	
Energy and Industrial Automation	▪ Homes and offices that are more energy efficient and cheaper to operate ▪ Distributed micro-generation for the grid	
Healthcare and Biomedical	▪ Increased use of effective in-home care ▪ More capable devices for diagnosis ▪ New internal and external prosthetics	
Critical Infrastructure	▪ More reliable and efficient power grid ▪ Highways that allow denser traffic with increased safety	

PRESENTE

❑ ARC: Aeronáutica

- The real subsystems were often one or more of:
  - Multivariable
  - High dimension
  - Nonlinear
  - Time-Varying
  - Poorly modelled
- Thus they were often ***outside the bounds of existing classical theory, and/or existing computational tools***

PRESENTE

❑ ARC: Medicina

- **Control, communications and computer devices in medicine:**
  - The technologies can be the basis of medical and veterinary interventions.
  - Technologies used include safety critical systems, adaptive systems, sensors, low power, optimal control.

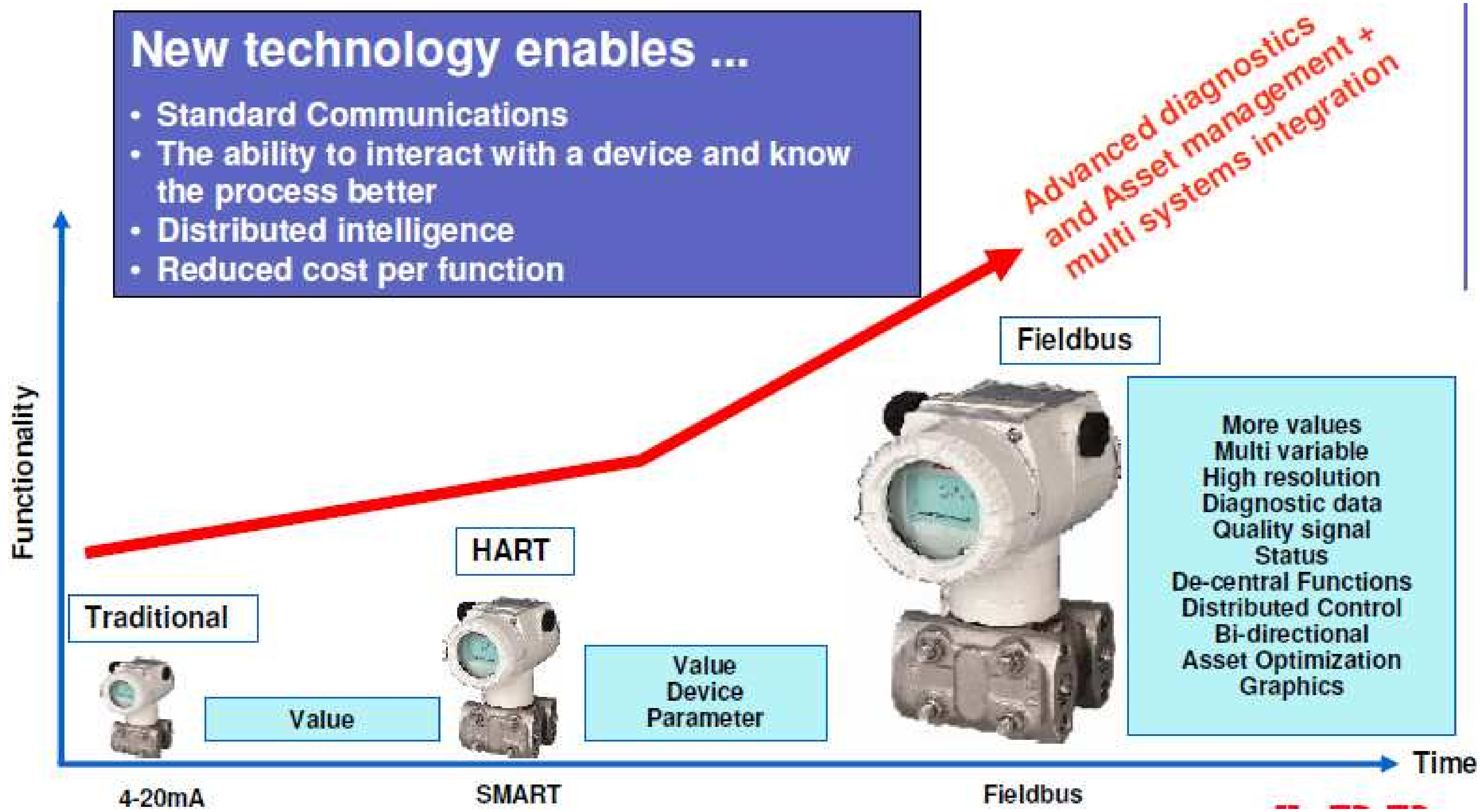
Cardiac Pacemaker:

Many pacemakers are adaptive.

Some contain a defibrillator.

PRESENTE

❑ Intelligent Field Devices

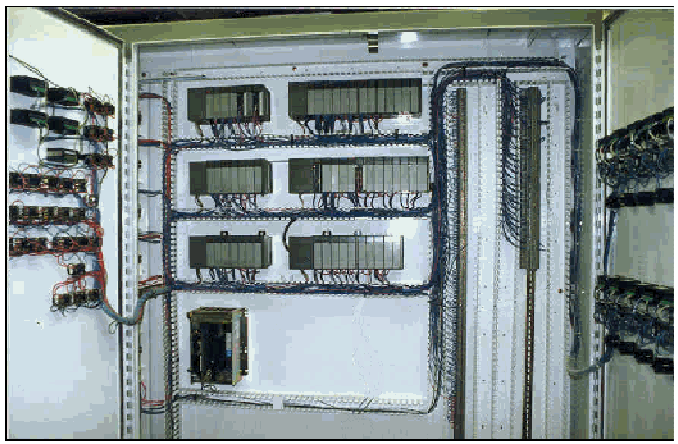


PRESENTE

- Controladores

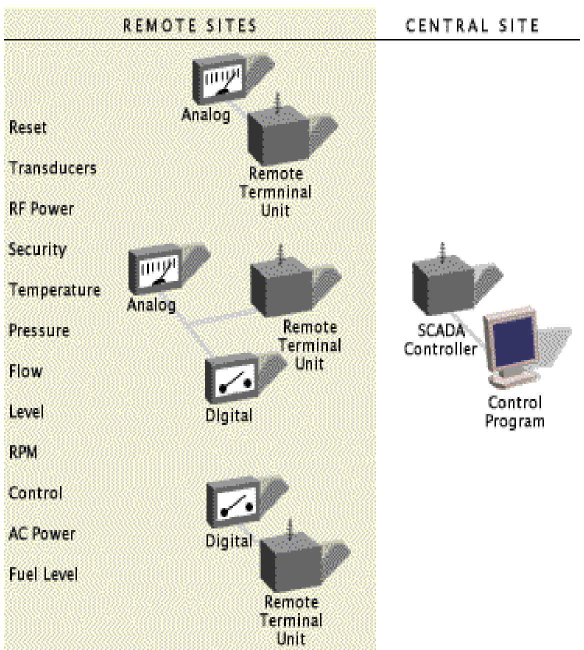
PRESENTE

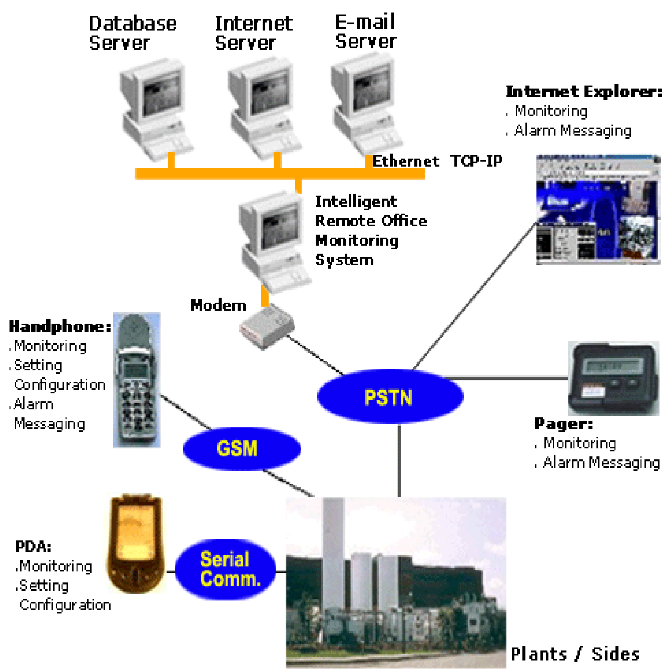
- PLC: Programmable Logic Controllers

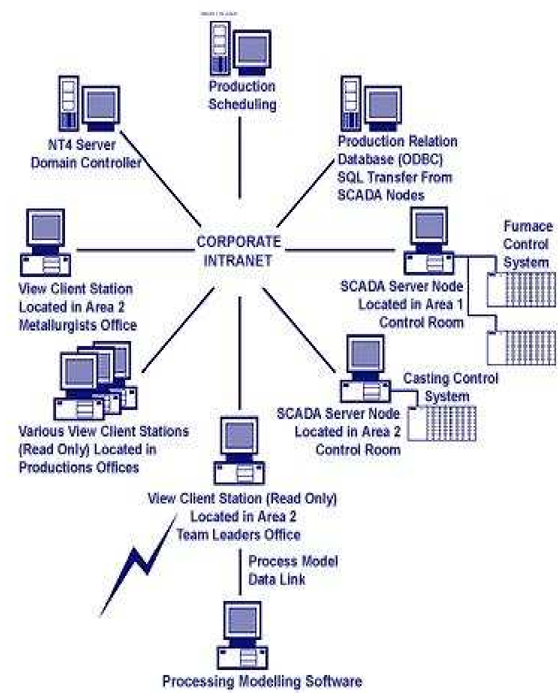


PRESENTE

❑ SCADA: Supervision Control and Data Acquisition







PRESENTE

Processing Industries
(Continuous)

DCS,
Motion Control

Hybrid Industries
(Continuous/Batch) + Discrete)

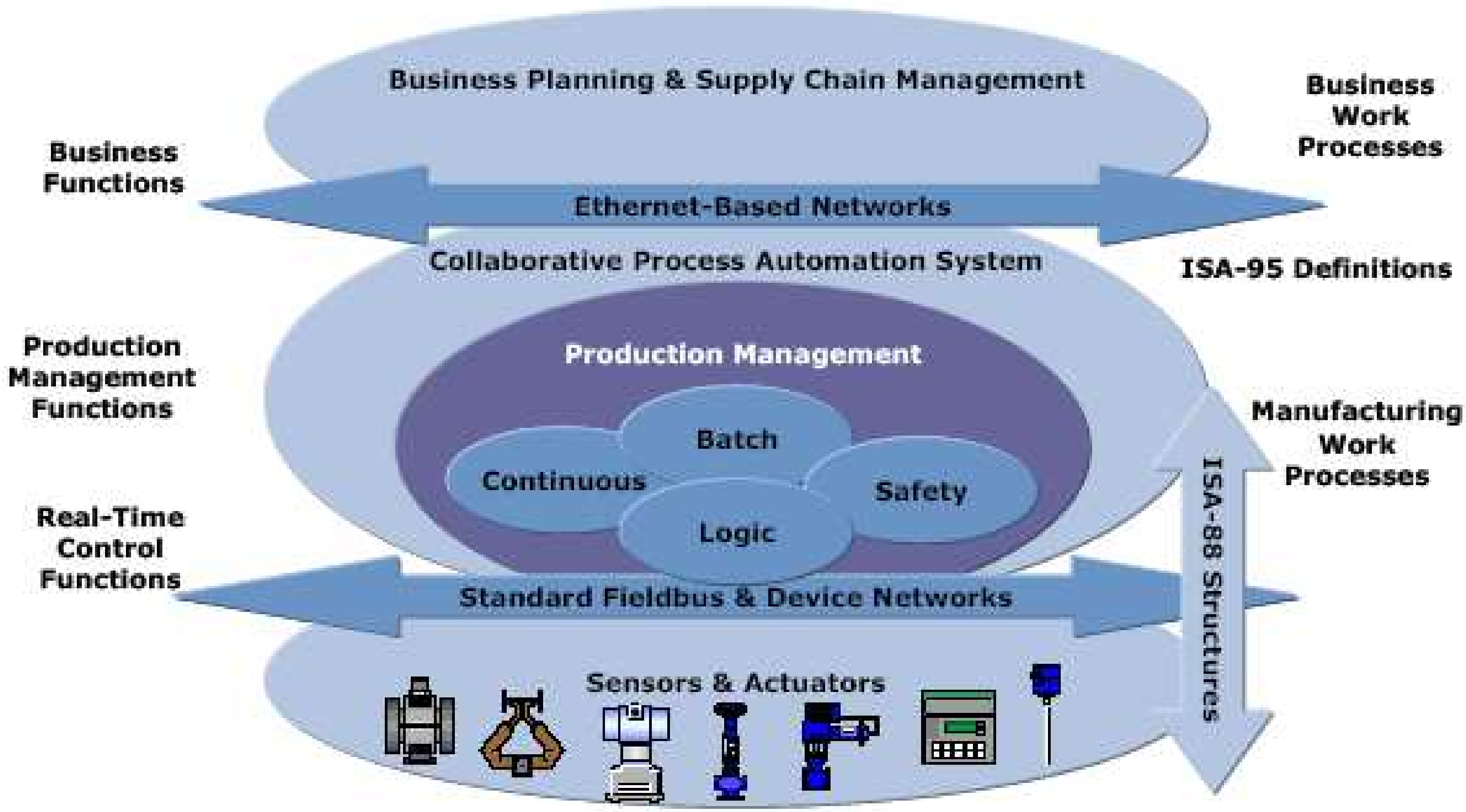
DCS + PLC,
Motion Control

Manufacturing Industries
(Discrete)

PLC, CNC,
Motion Control

PRESENTE

❑ Arquitectura

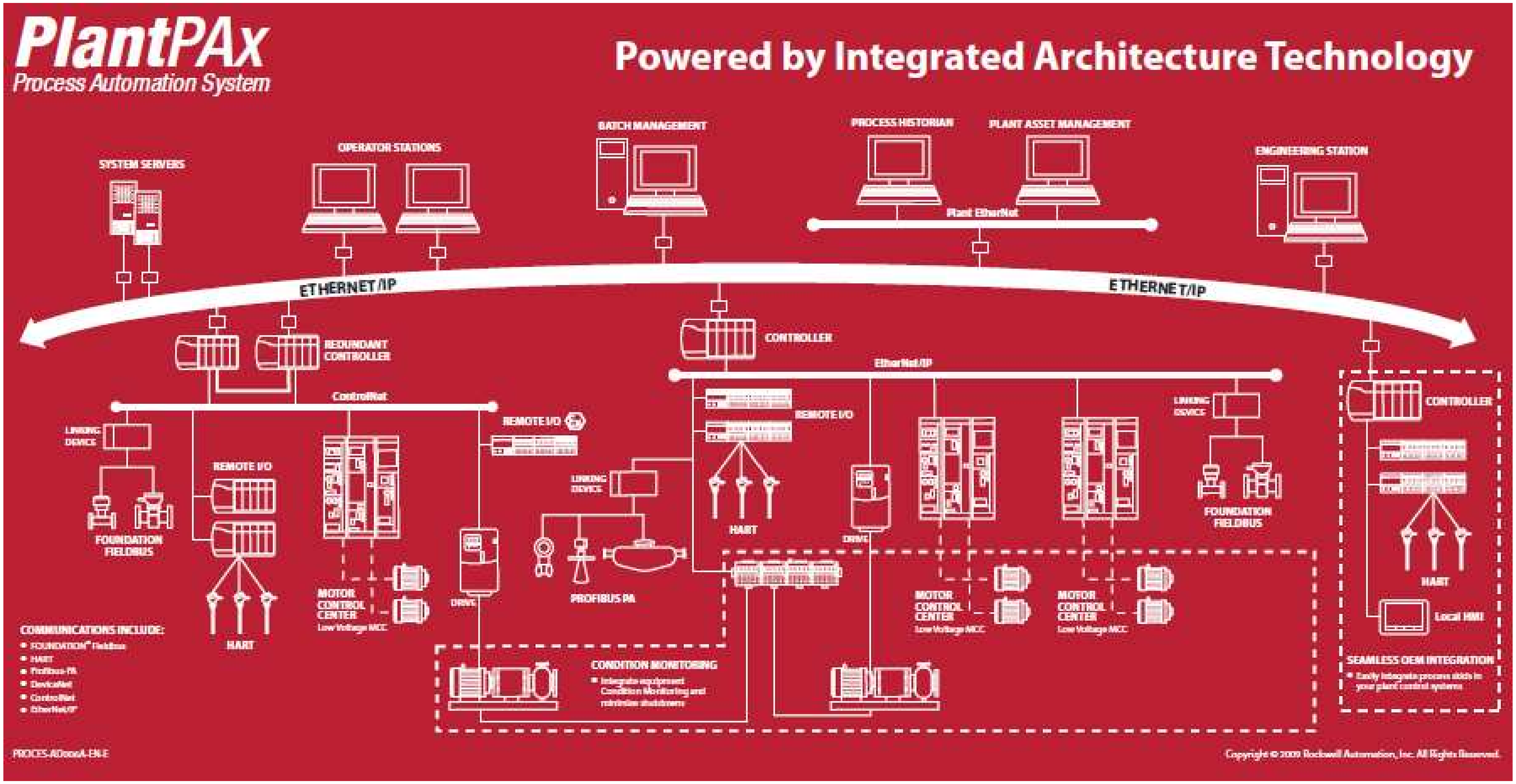


PRESENTE

DCS: 800xA de ABB

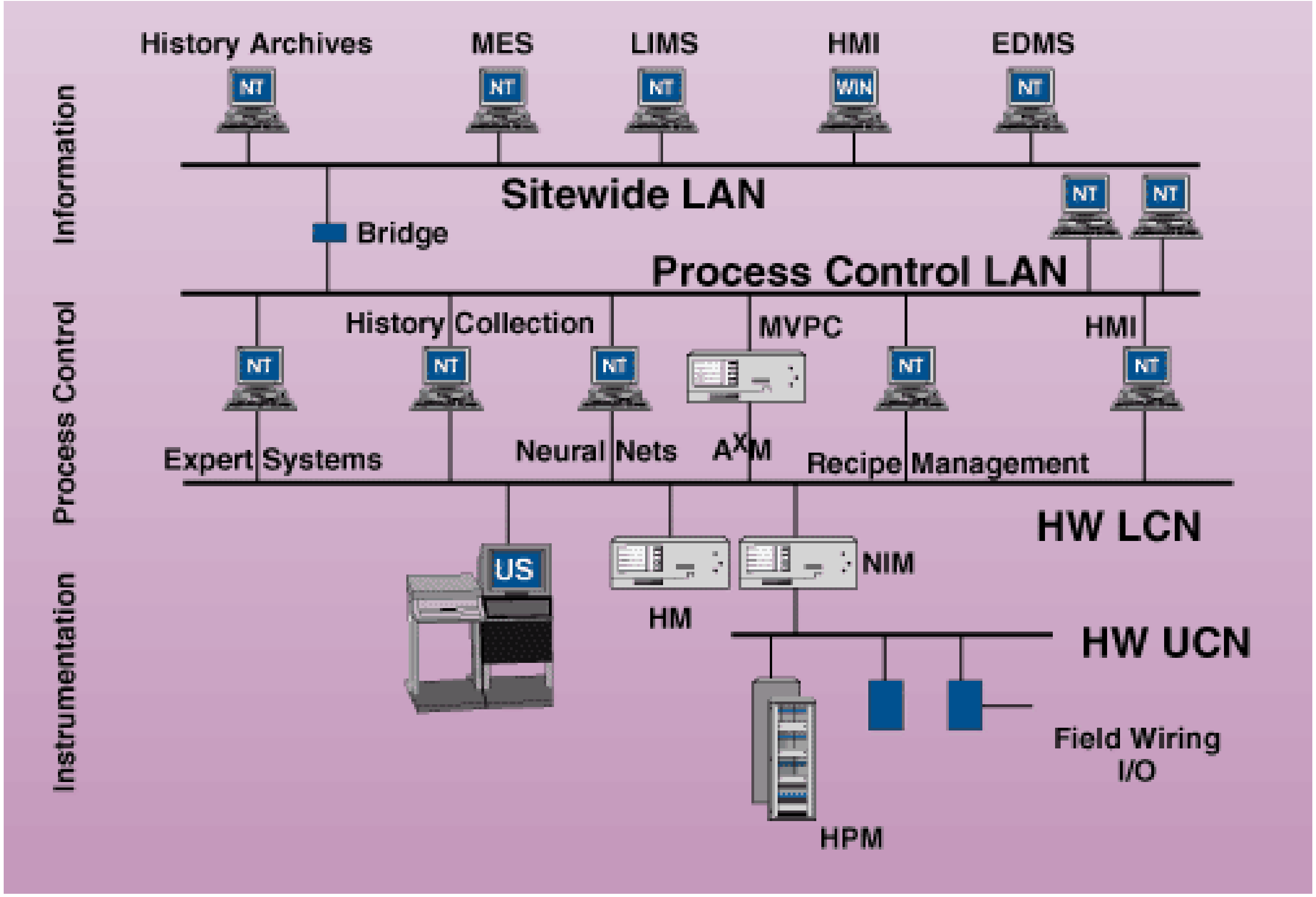
PRESENTE

❑ DCS: PlantPAx de Rockwell



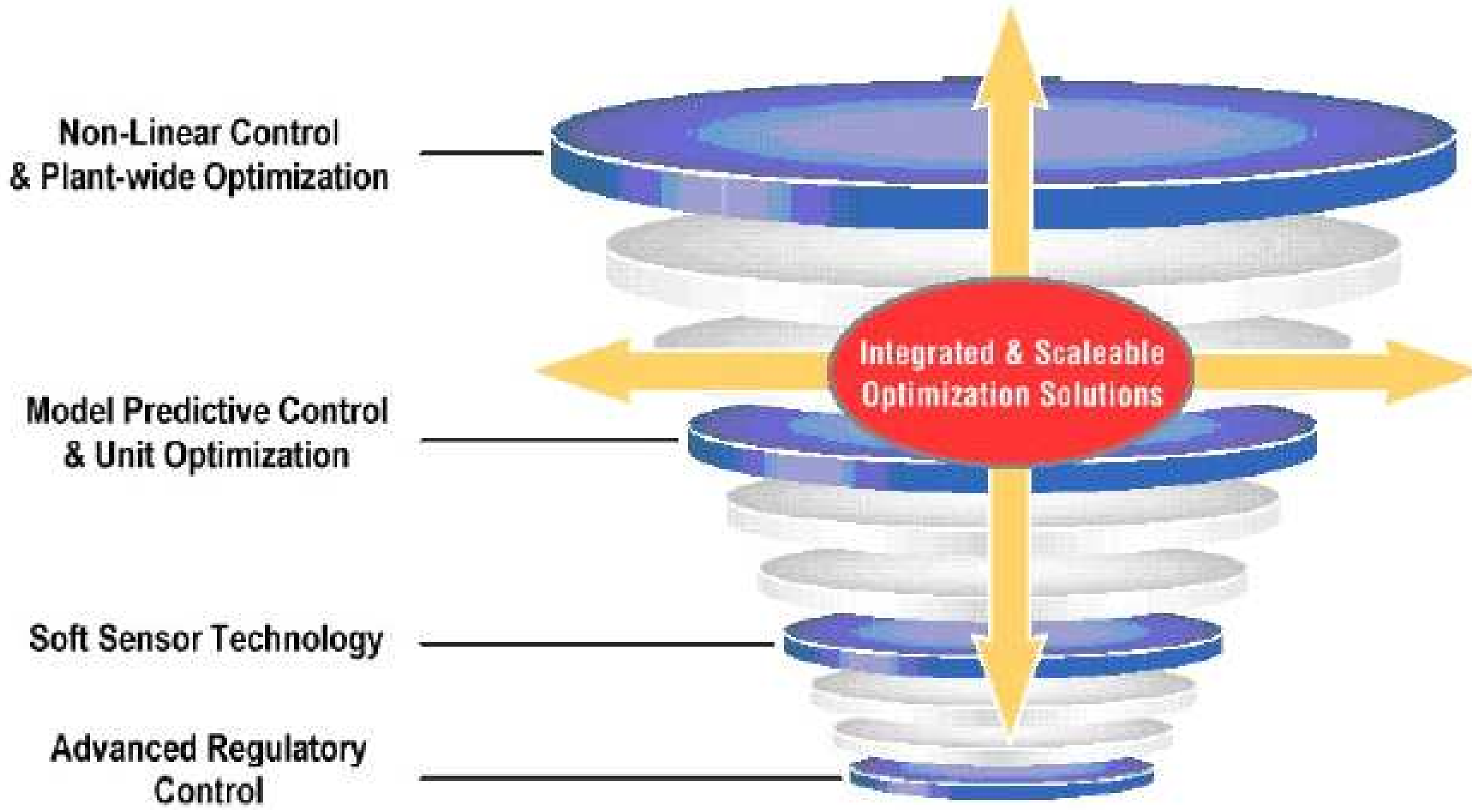
PRESENTE

- DCS: Experion de Honeywell



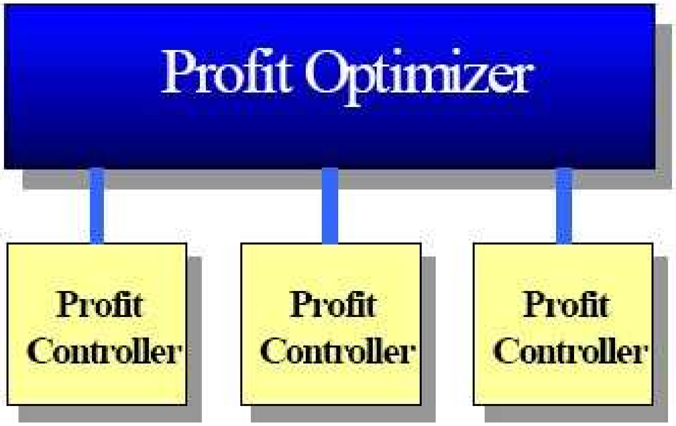
PRESENTE

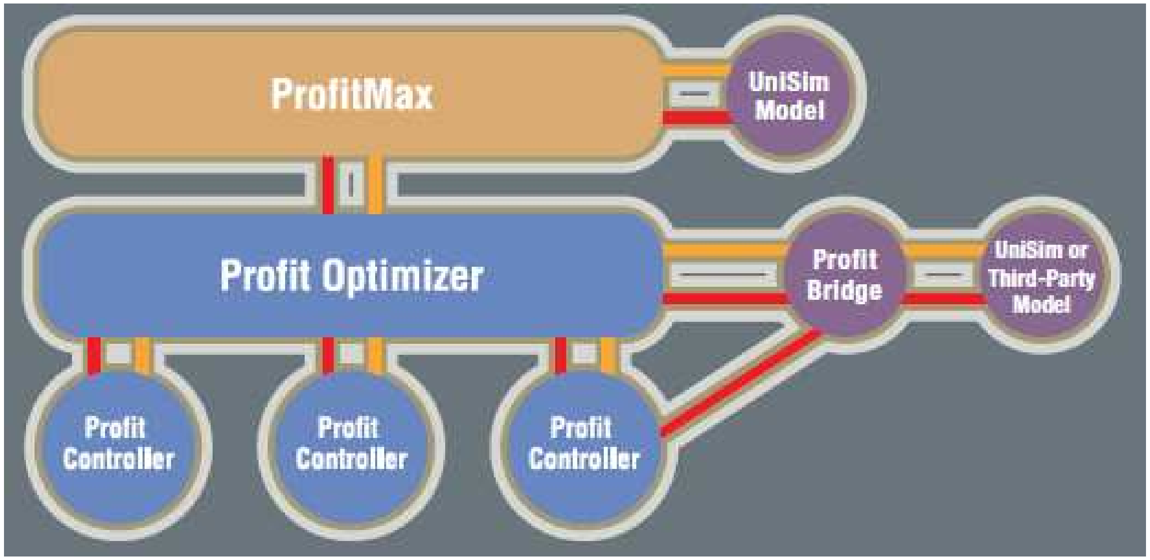
- Arquitectura



PRESENTE

Arquitecturas de Control Descentralizado





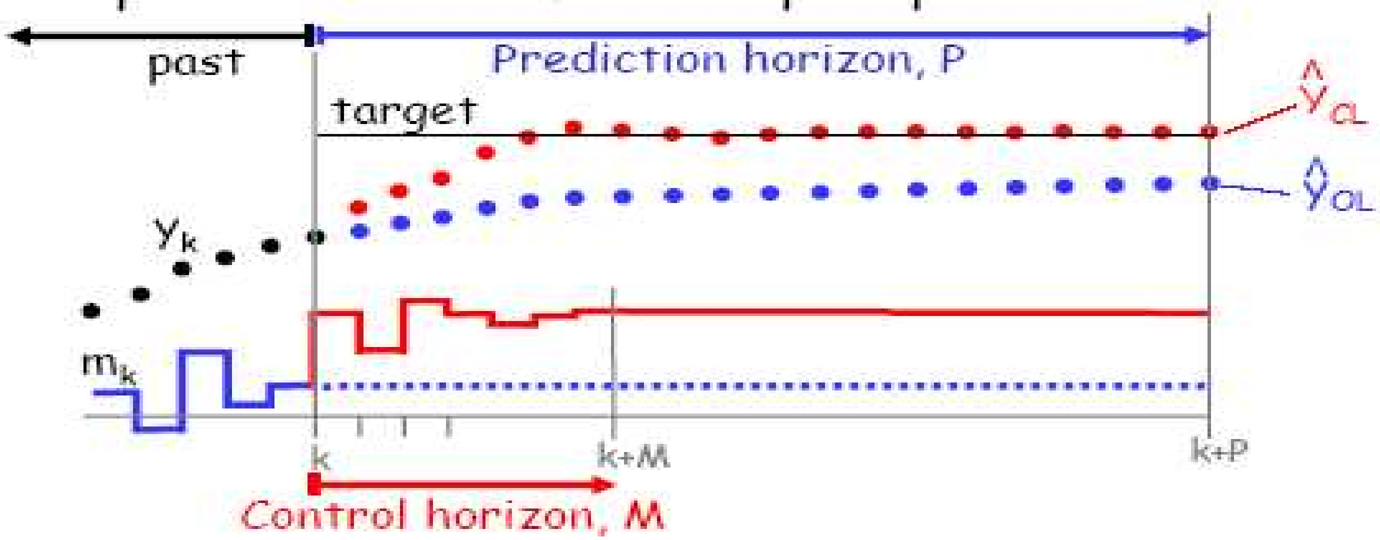
PRESENTE

❑ Control Predictivo Basado en Modelo (MPC)

MPC made simple...

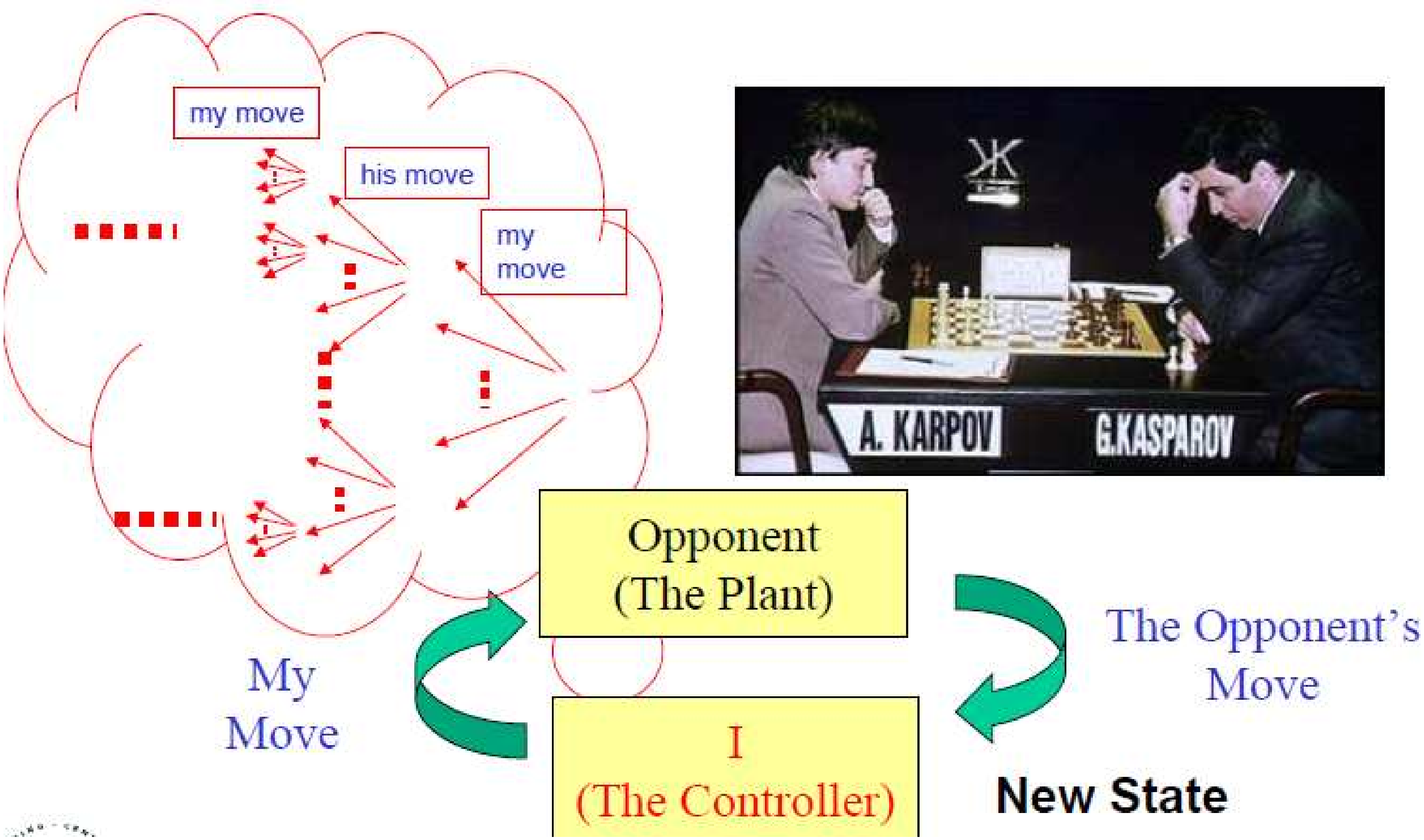
MPC is a model-based control strategy using models in 2 ways:

- Uses a reliable **model** to predict effect of past control moves on P future outputs, assuming no future moves.
- Uses the same **model** to compute the optimal M controller moves. Implement first move and repeat procedure.



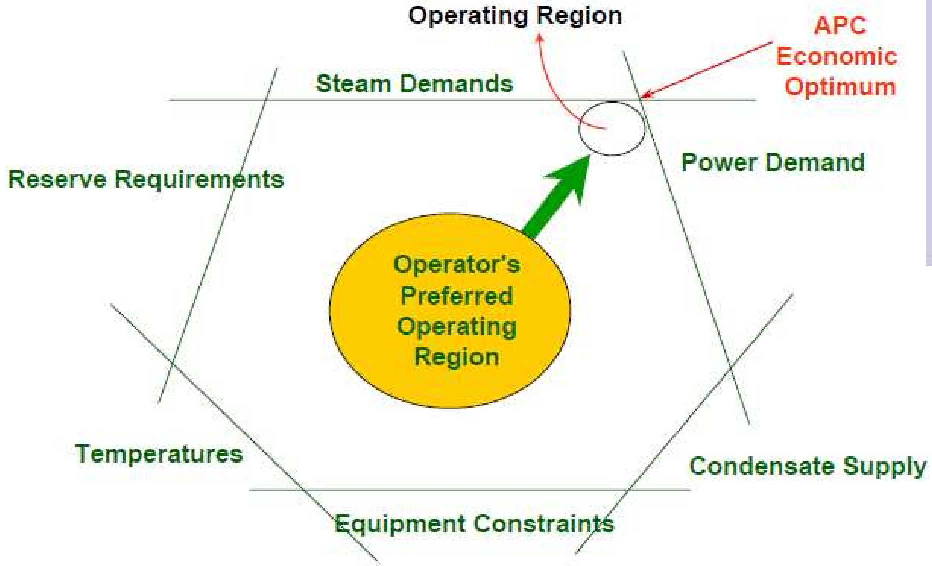
PRESENTE

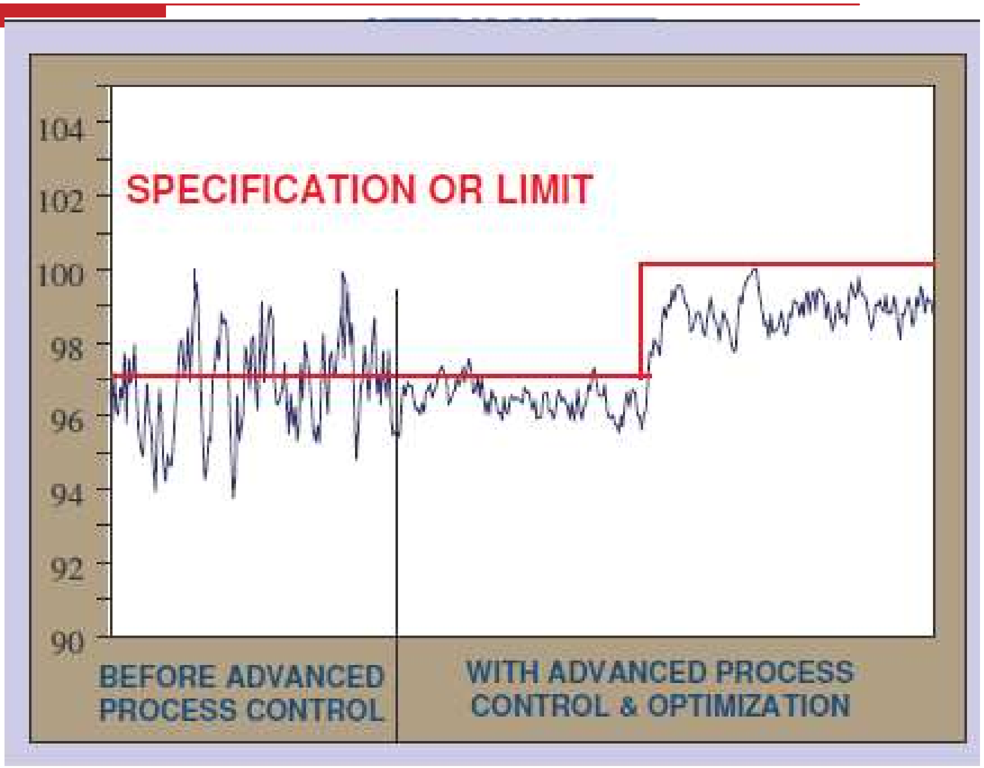
❑ MPC: Analog to Chess Playing



PRESENTE

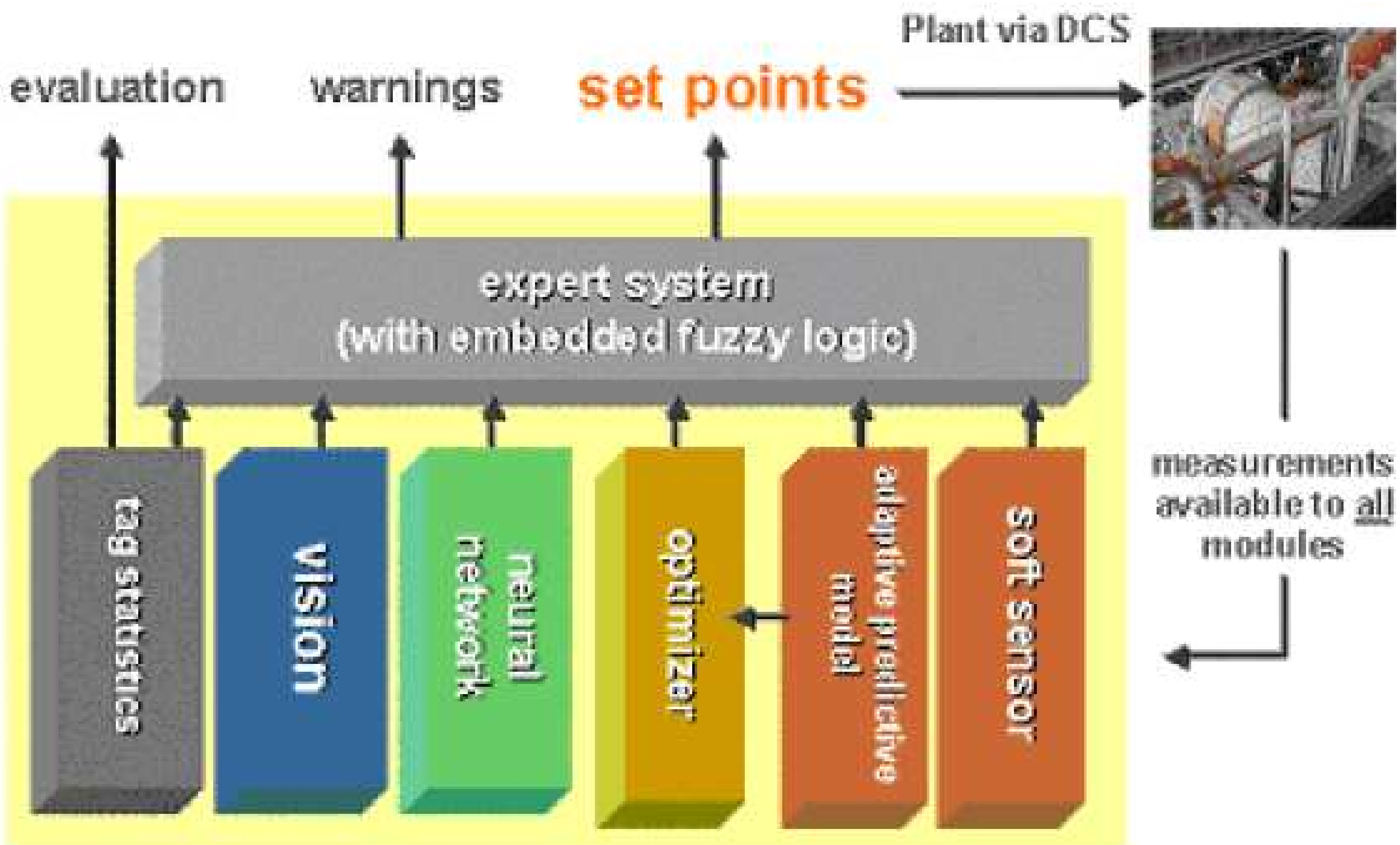
❑ MPC





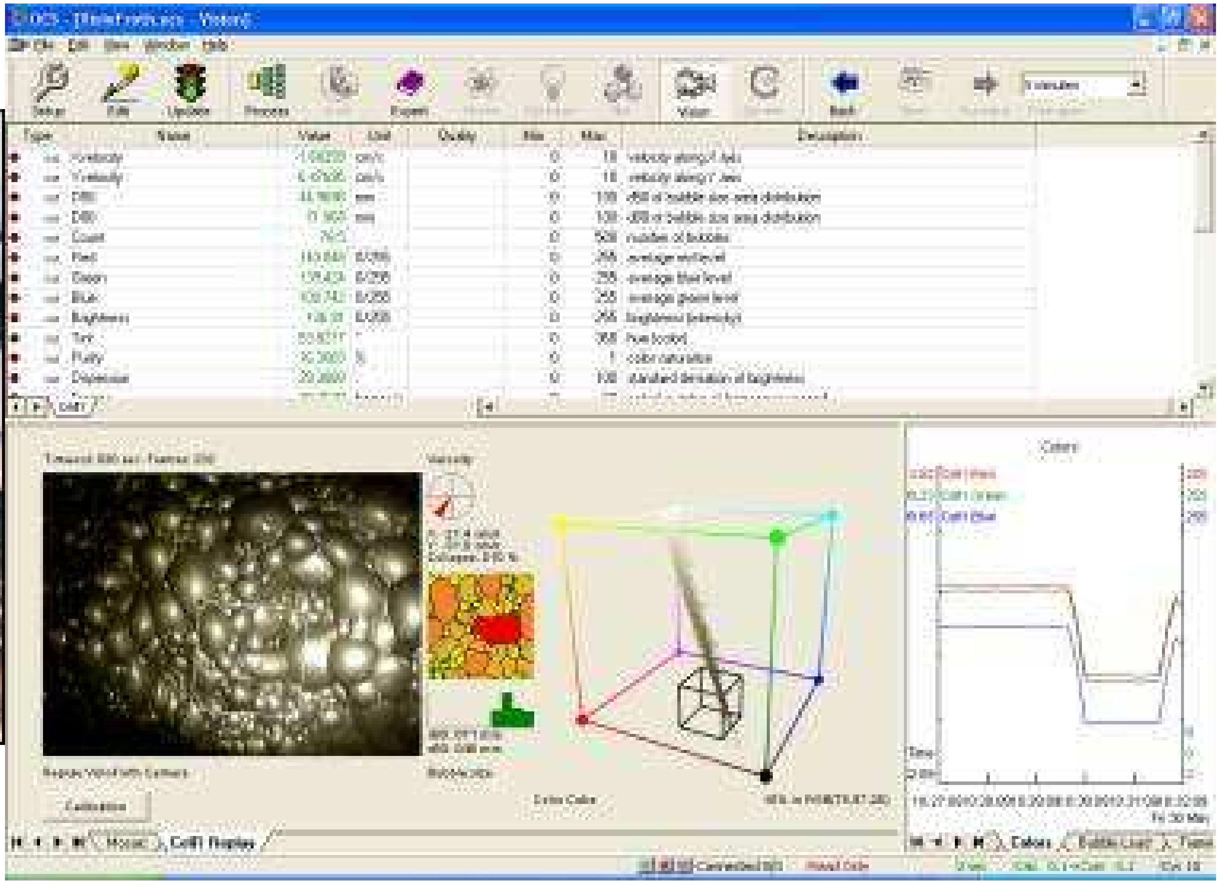
PRESENTE

- OCS Expert System, Metso CISA



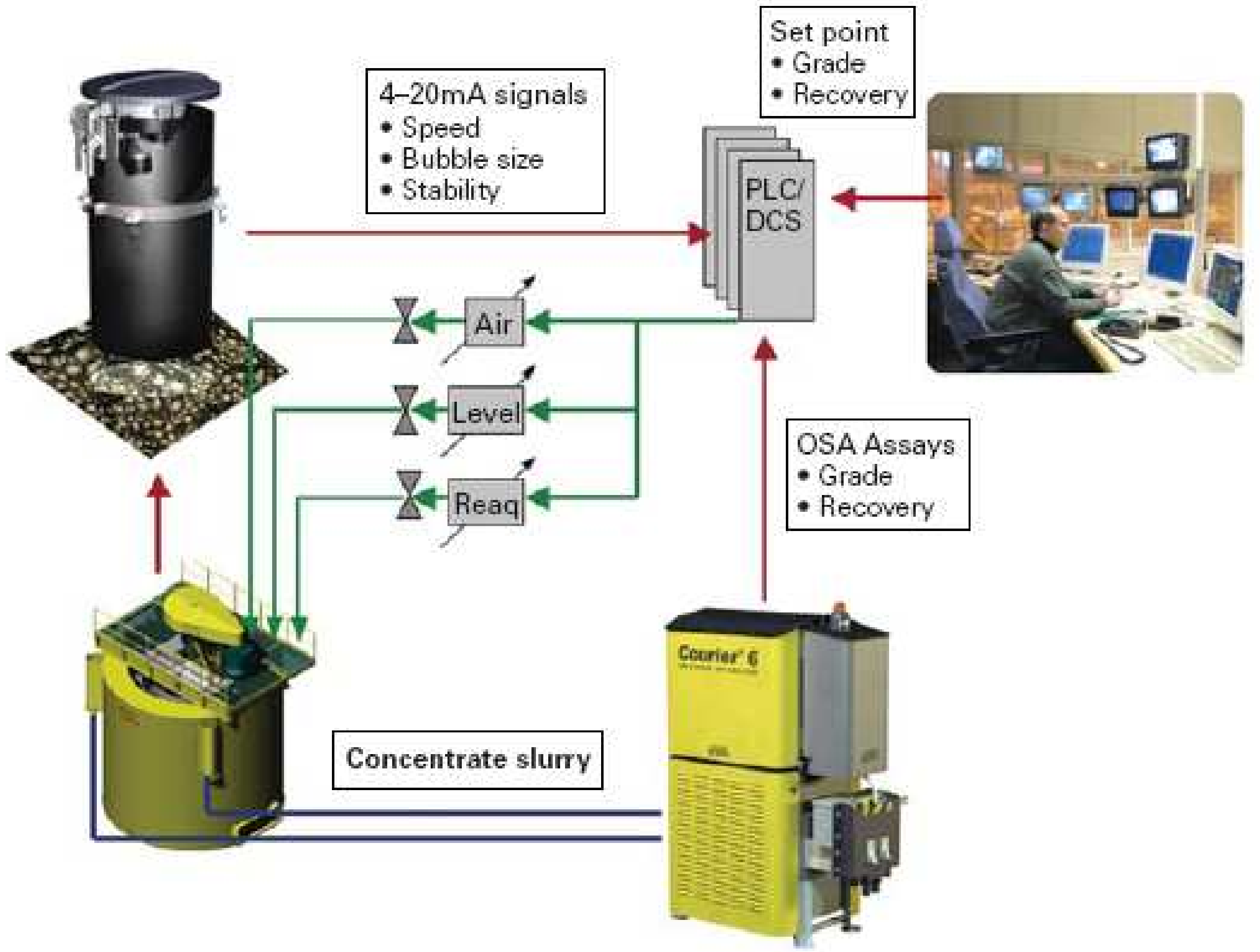
APLICACION

- VisioFroth, Metso Minerals



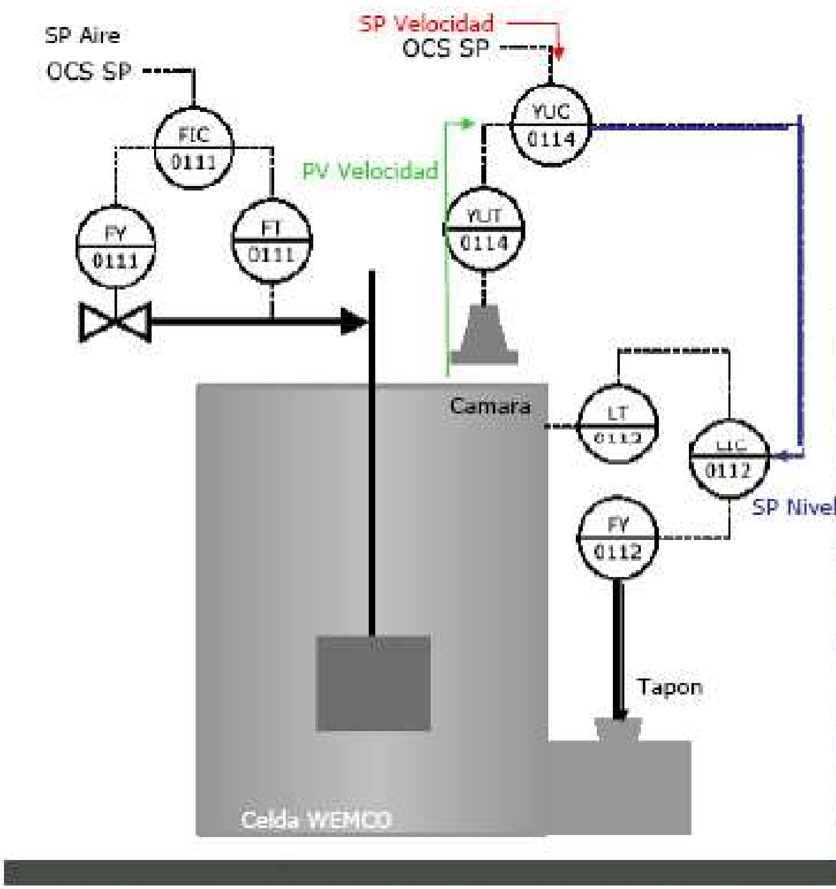
APLICACION

❑ FrothMaster™ 2, Outotec



APLICACION

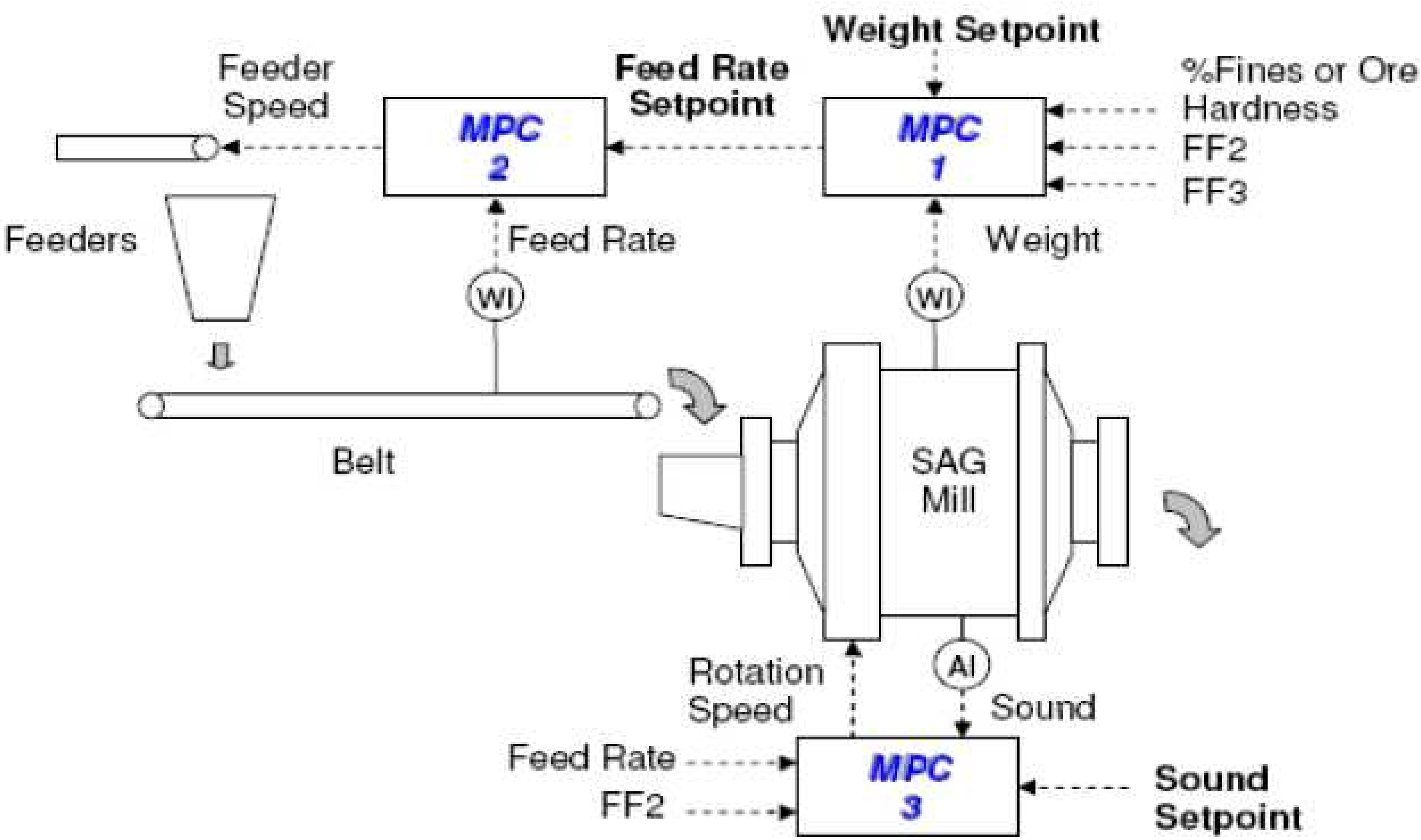
❑ Control con Sensores Visuales



Escondida: Instalación en la Flotación Primaria Líneas 1,2,3,4,5,6 (54 Cameras)

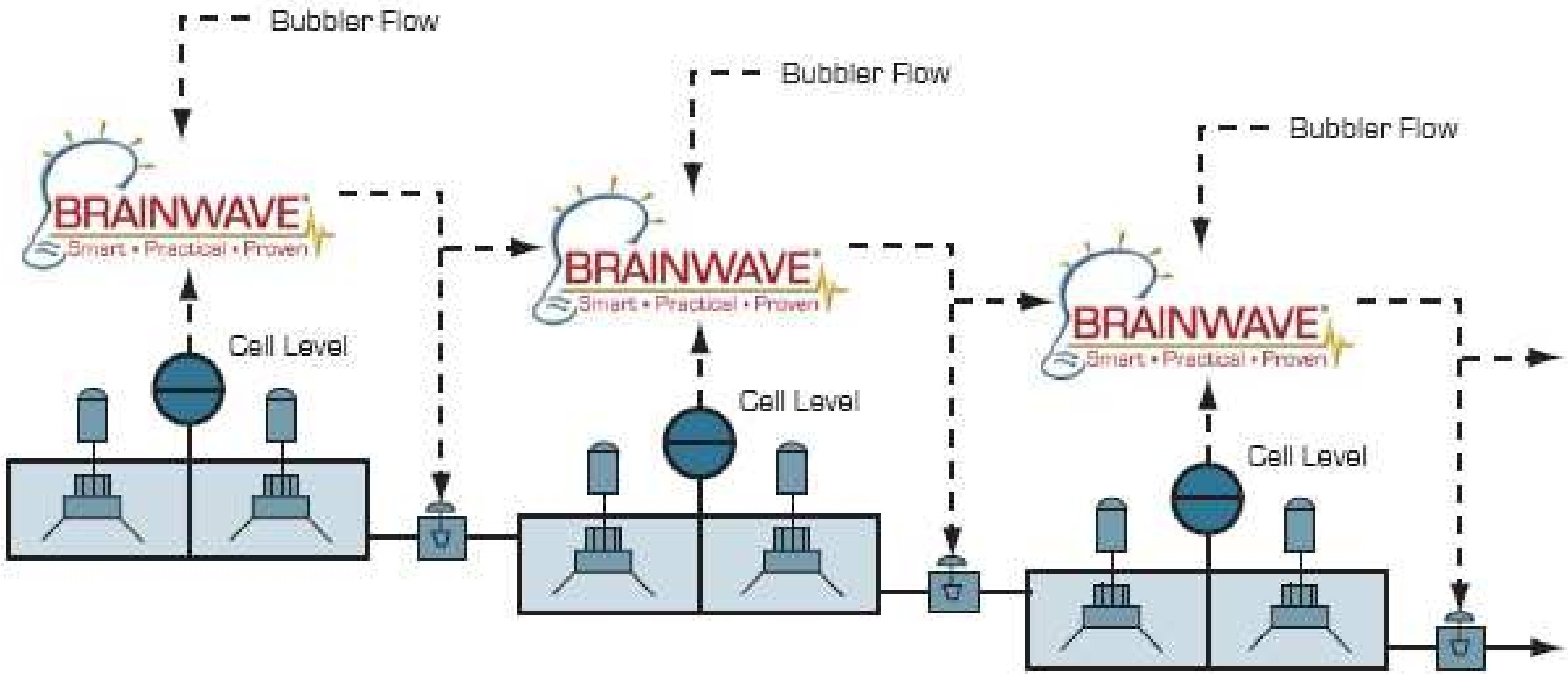
APLICACION

- MPC en Molienda SAG de Minera Pelambres



APLICACION

❑ Control Predictivo de Flotación



APLICACION

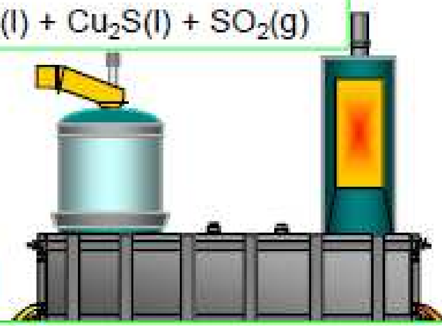
MPC para Horno Flash, Codelco Norte

Oxidación de Carga:

- Calcopirita : $CuFeS_2(s) + O_2(g) ==> FeS(l) + Cu_2S(l) + SO_2(g)$
- Pirita : $FeS_2(s) + O_2(g) ==> FeS(l) + SO_2(g)$
- Bornita : $Cu_5FeS_2(s) + O_2(g) ==> FeS(l) + Cu_2S(l) + SO_2(g)$

Formación de Magnetita:

- $FeS(l) + O_2(g) ==> FeO(l) + SO_2(g)$
- $FeO(l) + O_2(g) ==> Fe_3O_4(l)$



PRODUCTOS

- EJE
- ESCORIA
- POLVO METALURGICO
- GASES

Reducción de magnetita y formación de fayalita en el baño :

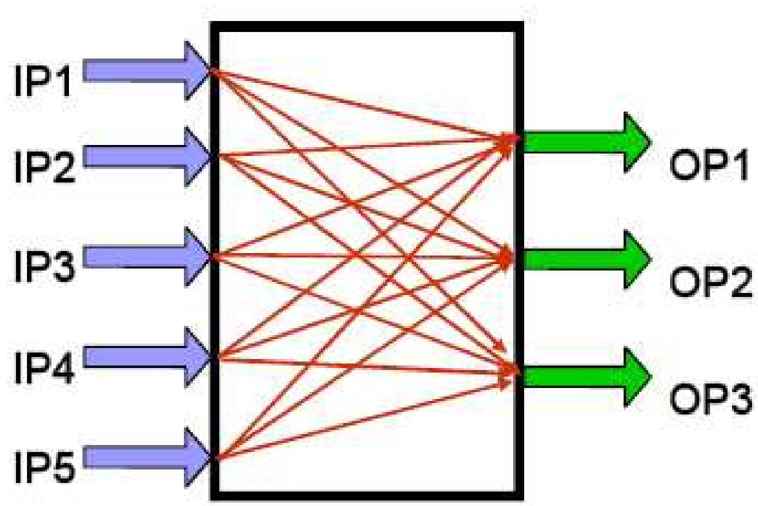
- $3Fe_3O_4(l) + FeS(l) + 5SiO_2(s) ==> 5Fe_2SiO_4(l) + SO_2(g)$

Sulfatación de Polvos Metalúrgicos:

- $Cu_2S(s) + 3O_2(g) + SO_2(g) ==> 2CuSO_4(s)$

APLICACION

MPC para Horno Flash, Codelco Norte



Variables Manipuladas:

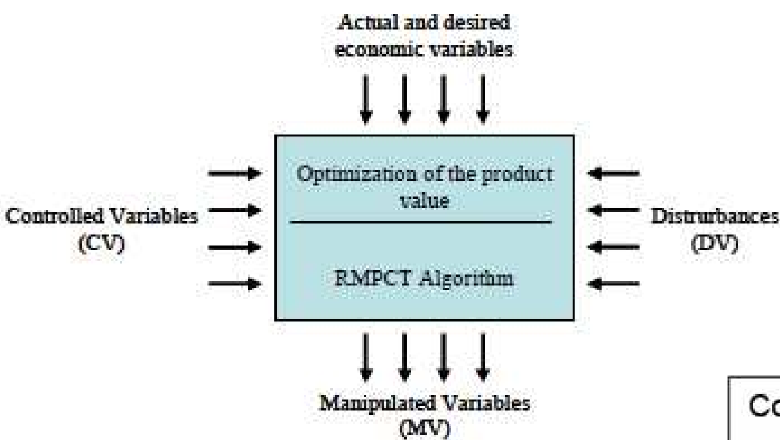
- Flujo de Oxígeno de proceso
- Flujo de aire de proceso
- Flujo de alimentación
- Adición de polvo
- Razón alimentación SiO_2

Variables Controladas:

- Temperatura del eje
- Ley de Cobre en el Eje
- Concentración de Magnetita en escoria
- Enriquecimiento de Oxígeno
- Presión de Oxígeno

APLICACION

Robust MPC on SAG Mills, Codelco Teniente



Controlled Variables (CV)

- Bearing Pressure
- Power
- Pebbles Produced

Manipulated Variables (MV)

- Fresh Feed
- SAG Mill Speed

Disturbance Variables (DV)

- Percentage of coarse feed ore

Optimization Objective:

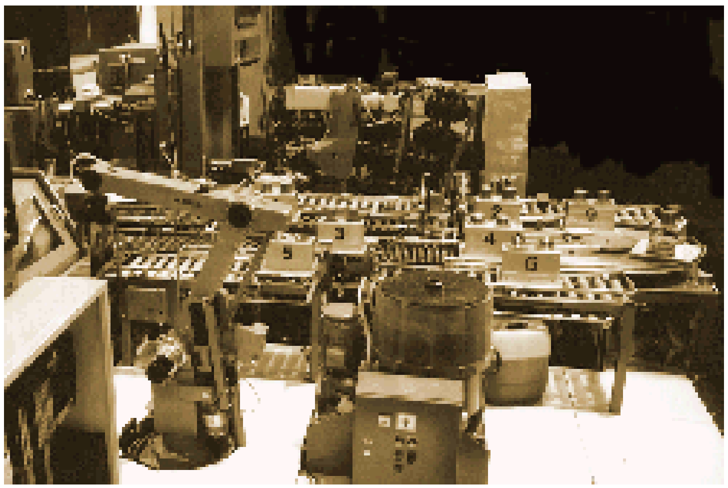
Maximize fresh feed whenever possible

Restrictions:

- Maximum engine power of the SAG mill.
- Maximum capacity of pebbles strap produced

PRESENTE

❑ Manipuladores Robóticos



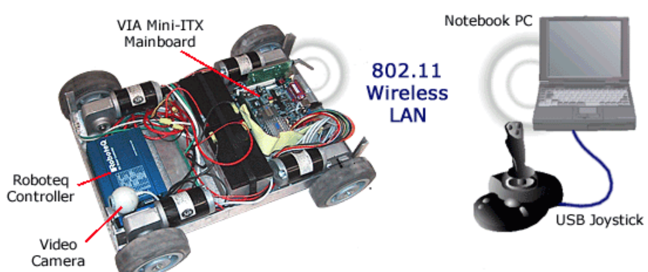
Sistema de manufactura flexible

Juntura rotatoria.

Grúa articulada

Grúa industrial

Suburu – Sistema Manipulador



Componentes de un vehículo robotizado

PRESENTE

❑ Robótica en la Industria Automotriz

One of the most important partners in the development of robotic technologies

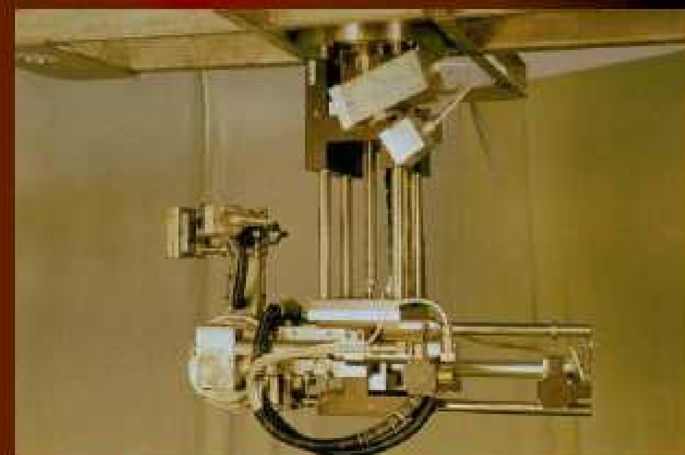
- Welding robots
- Robustness and precision of the assembly of pieces
- Manipulate very heavy loads
- Found in painting rooms
- Used for places that are hard to reach

PRESENTE

❑ Robótica en Centrales Nucleares

Nuclear generator installations are places where we can find a large number of robotic applications.

- Used for maintenance of nuclear reactors.
- Used for the replacement of radioactive fuel tubes.
- Seal off radioactive leakages in contaminated zones.
- Cleaning and decontaminating radioactive areas without compromising the health of workers was also necessary.



PRESENTE

❑ Robótica en Exploración Espacial

Spatial probes sent for many years to explore and discover our universe

- Like the Viking I and II probes sent to explore Mars in 1976,
- Telemanipulator used to collect samples of soil
- The famous Canadian spatial manipulator Canadarm mounted on American spaceships and the new space station remote manipulator system (SSRMS) that is used to assemble the international space station.
- Mars Rover in 1998 explored the neighbor planet while being teleguided from the Earth.
- Provided an incredible amount of new information about this unknown environment.

PRESENTE

❑ Robótica en Entretenimiento

"playing" with sophisticated toys dedicated for funny applications.

- Robots that are supposed to do house cleaning
- AIBO, built by Sony, that have all the nice characteristics of a real dog but without its obvious disadvantages.
- Remotely controlled robots used to do fun painting
- Considered as a very positive and innovative way of evolution in robotics.

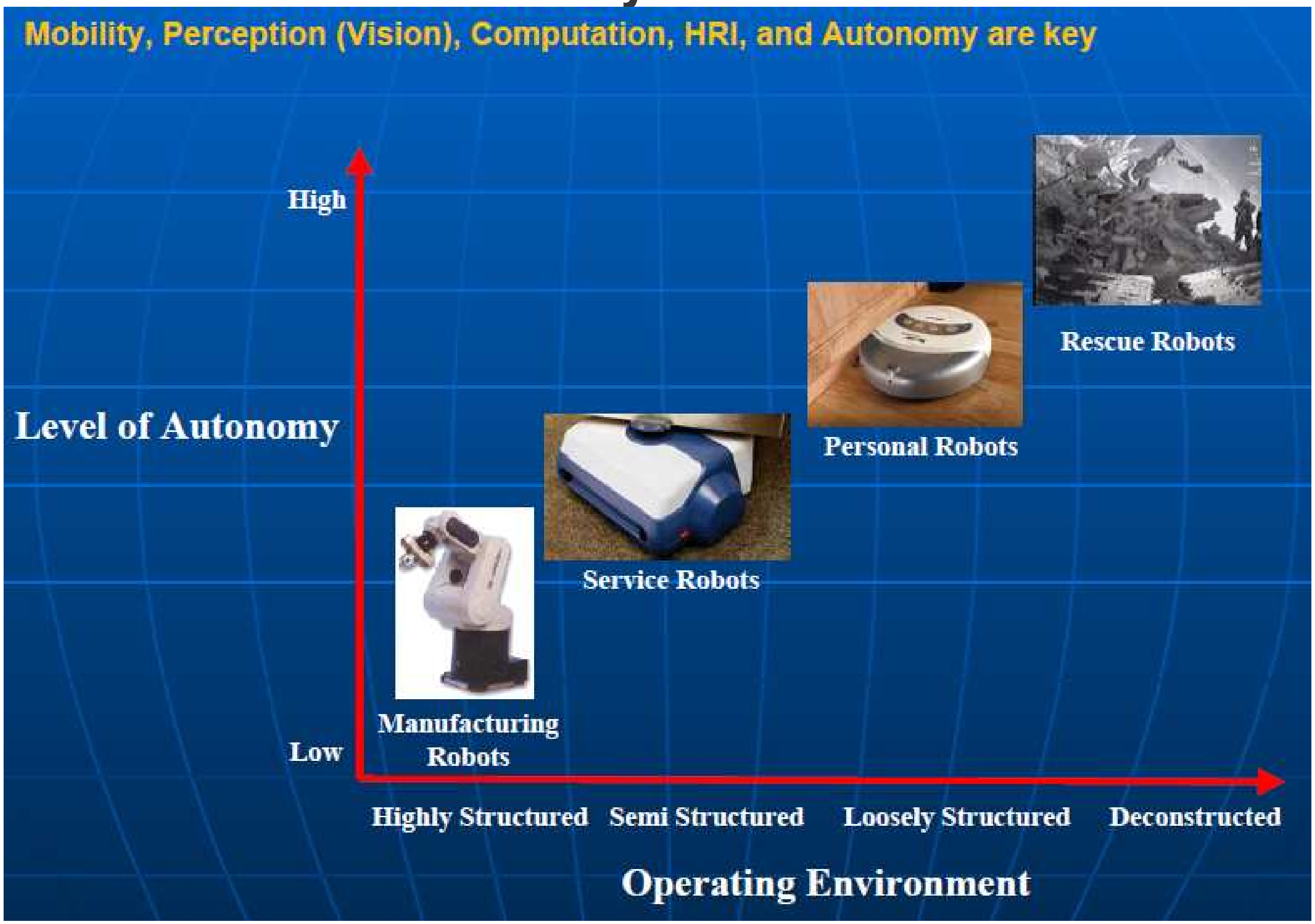
PRESENTE

❑ Robótica en Medicina

The idea of robots performing **open-heart surgery** sounds like science fiction but recently this idea has become a reality.

PRESENTE

- Robótica Personal y de Servicio



PRESENTE

- Nómade, Carnegie Mellon University, exploró la Antártida y el Desierto de Atacama

APLICACION

- **Limpieza de Horno de Tostación de Molibdeno, Codelco Norte**

APLICACION

- Robotización de la Toma de Muestras de Concentrado de Molibdeno, Molymet

APLICACION

- LHD y Vehículos Autónomos

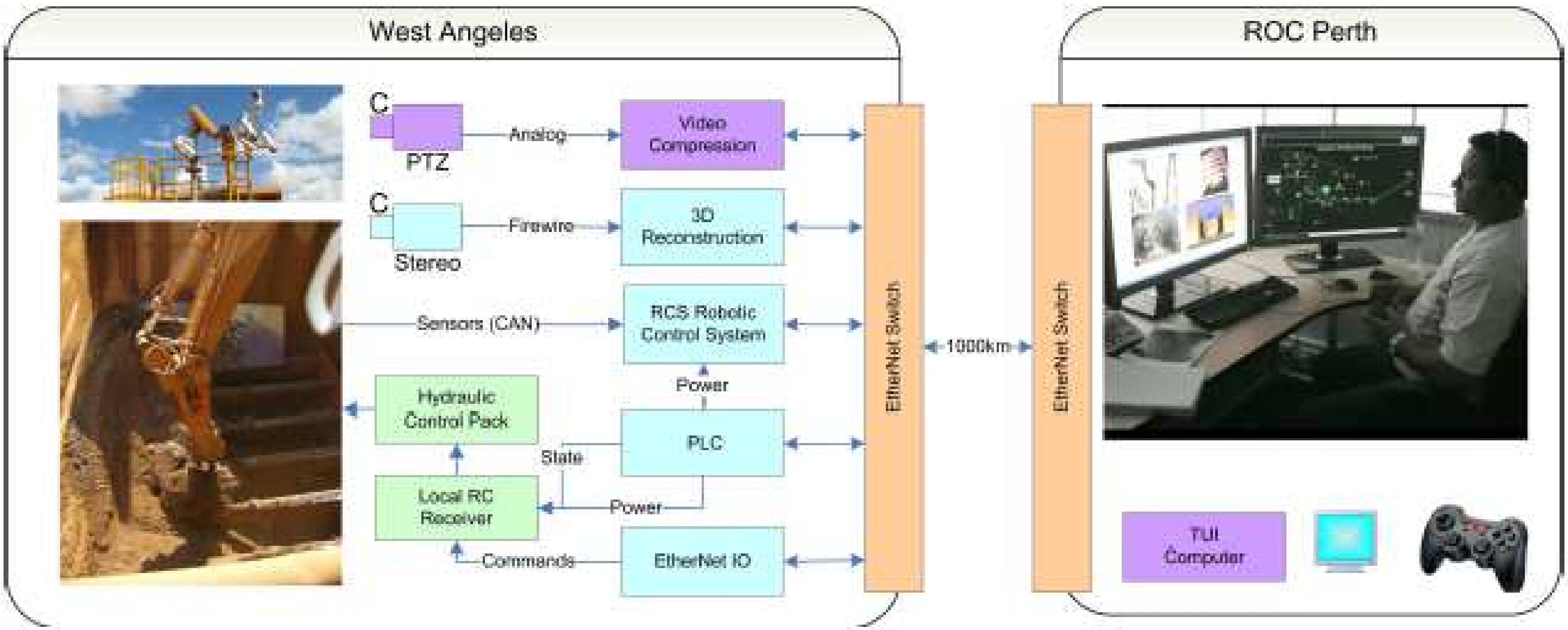
APLICACION

- Camiones Autónomos, Komatsu

APLICACION

❑ Remote Control System

Located at the West Angelas more than 1000 kms from the Remote Operations Center in Perth



FUTURO

❑ The Engineer of 2020: Context

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❑ The Engineer of 2020

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❑ The Engineer of 2020

Economic/societal forces

- High speed communications / Internet
- Removal of trade barriers
- Terrorist attacks; wars in Iraq, Afghanistan
- Emergence of technology-based economies in other nations
- Sustained investment in higher education in countries like China, India

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The Engineer of 2020: Highlights

- Emphasis on innovation.
- Systems approach.
- Larger context for engineering and technology.
- Non-engineering career tracks.
- Global perspective.
- Market forces, macroeconomics.
- Sense of urgency.

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The Engineer of 2020

ENG Research and Education Themes

- Cognitive engineering: Intersection of engineering and cognitive sciences
- Competitive manufacturing and service enterprises
- Complexity in engineered and natural systems
- Energy, water, and the environment
- Systems nanotechnology

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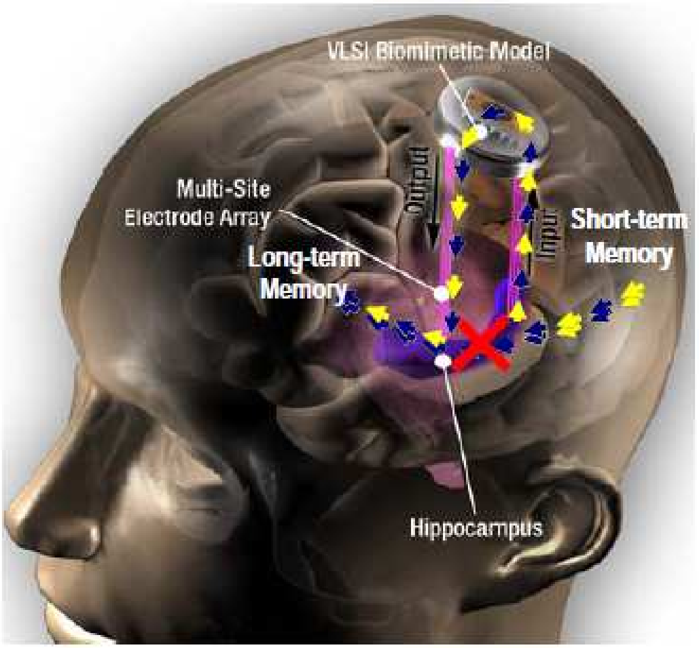
The Engineer of 2020

Cognitive Engineering

- Invests in improving understanding of the brain and nervous system to enable the engineering of novel systems and machines
- Examples include:
  - Devices that augment the senses
  - Intelligent machines that analyze and adapt



A neural prosthesis restores cognitive function lost due to damage or degenerative disease. Credit: Biomimetic MicroElectronic Systems ERC, Univ. of Southern California

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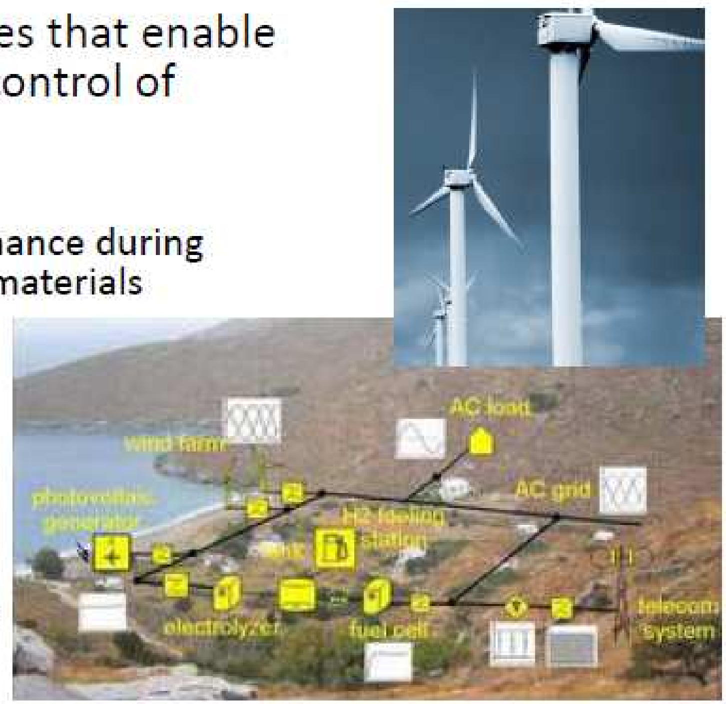
Complexity in Engineered and Natural Systems

- Addresses unifying principles that enable modeling, prediction, and control of emergent behavior
- Examples include:
  - Improving structural performance during disasters through advanced materials
  - Advancing quantum information processing
  - Making infrastructure more resilient and sustainable



Design of sustainable distributed energy systems relies on modeling diverse waveforms. Credit (T to B): Microsoft; Computational Science & Engineering, LLC

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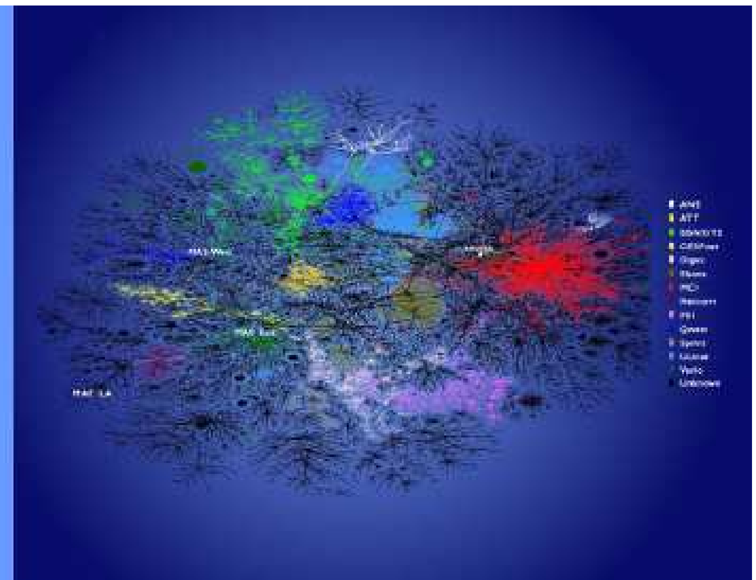
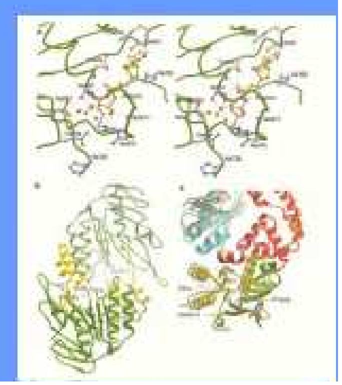
❑ Sistemas Complejos

- At the highest level, the complexity is *overwhelming* designers and managers
- Examples: telecom network, power system, a national economy, the human body, natural language processing, automatic real-time language translation, chips with 10^7 components, etc



www and a biological system



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❑ Sistemas Complejos

- Very long range interconnections required, with many legacy systems, and different operators
- Stability problem exists! It is made worse by:
  - —Frequent lack of central coordinating entity
  - —Unpredictability of fault type and timing
  - —Economic incentives on operators to minimise stability margins
- Dynamic modelling would require nonlinear equations with hundreds or thousands of variables
- Big dollars!

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Sistemas Complejos

- Rendezvous
- Consensus and flocking
- Station keeping
- Maintaining shape of a moving formation
- Splitting and merging formations
- Giving autonomy to a collection of agents to execute different classes of missions
- Self-repair

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Sistemas Biológicos

- Control, communications and computer devices in medicine
- **Biological structures and capabilities may inspire mimicry:**
  - The body's control systems exhibit hierarchy, learning and adaptivity, nonlinearity, multi-loop interaction.
  - Biological sensors and signal processing are different to what we are used to, and may be nonlinear--think how an insect lands on a flower.
  - What can we learn from nature's way of doing things?

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Desarrollos Tecnológicos en Codelco
MINERÍA SUBTERRÁNEA CONTINUA
MINERÍA CIELO ABIERTO
MINERÍA AUTÓMATA
TECNOLOGÍAS INFORMACIÓN, COMUNICACIÓN & AUTOMATIZACIÓN
CODELCO

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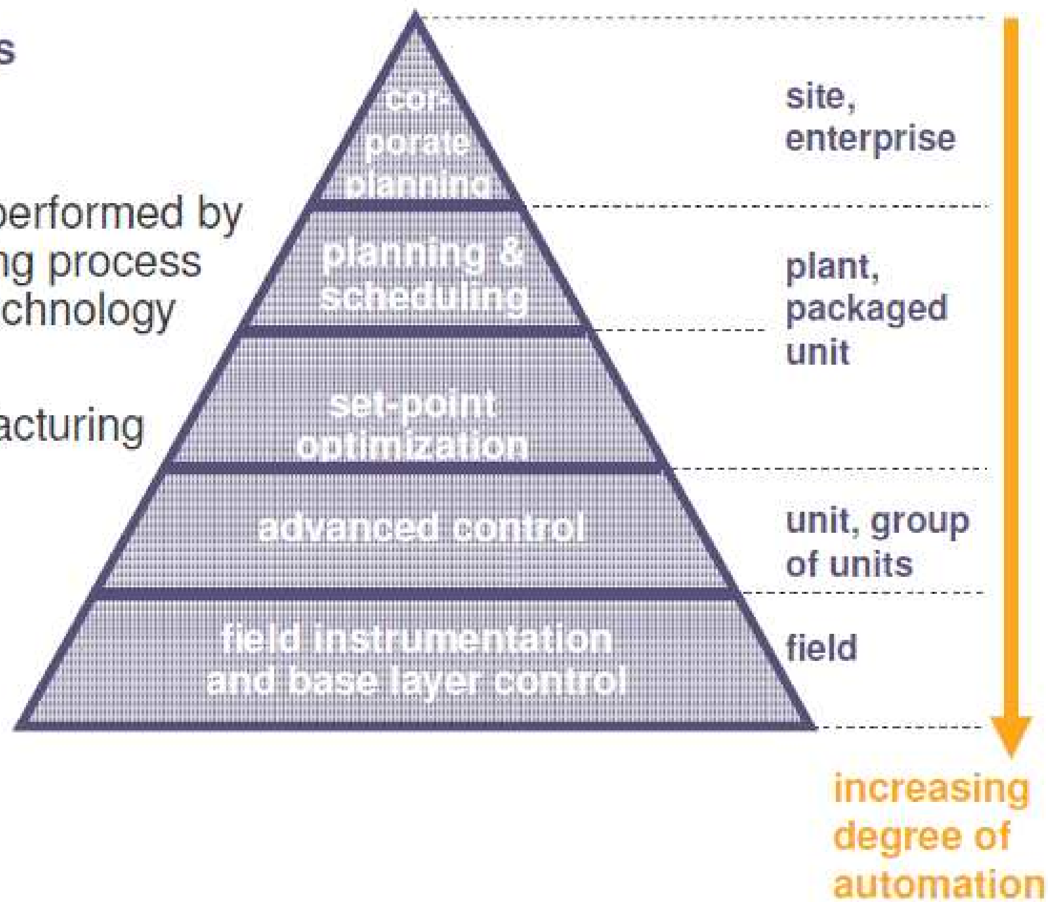
❑ Real-time Business Decision Making

Real-time Business Decision Making

- the set of activities performed by humans and assisting process operation support technology
- to manage a manufacturing process
- for profibability and agility



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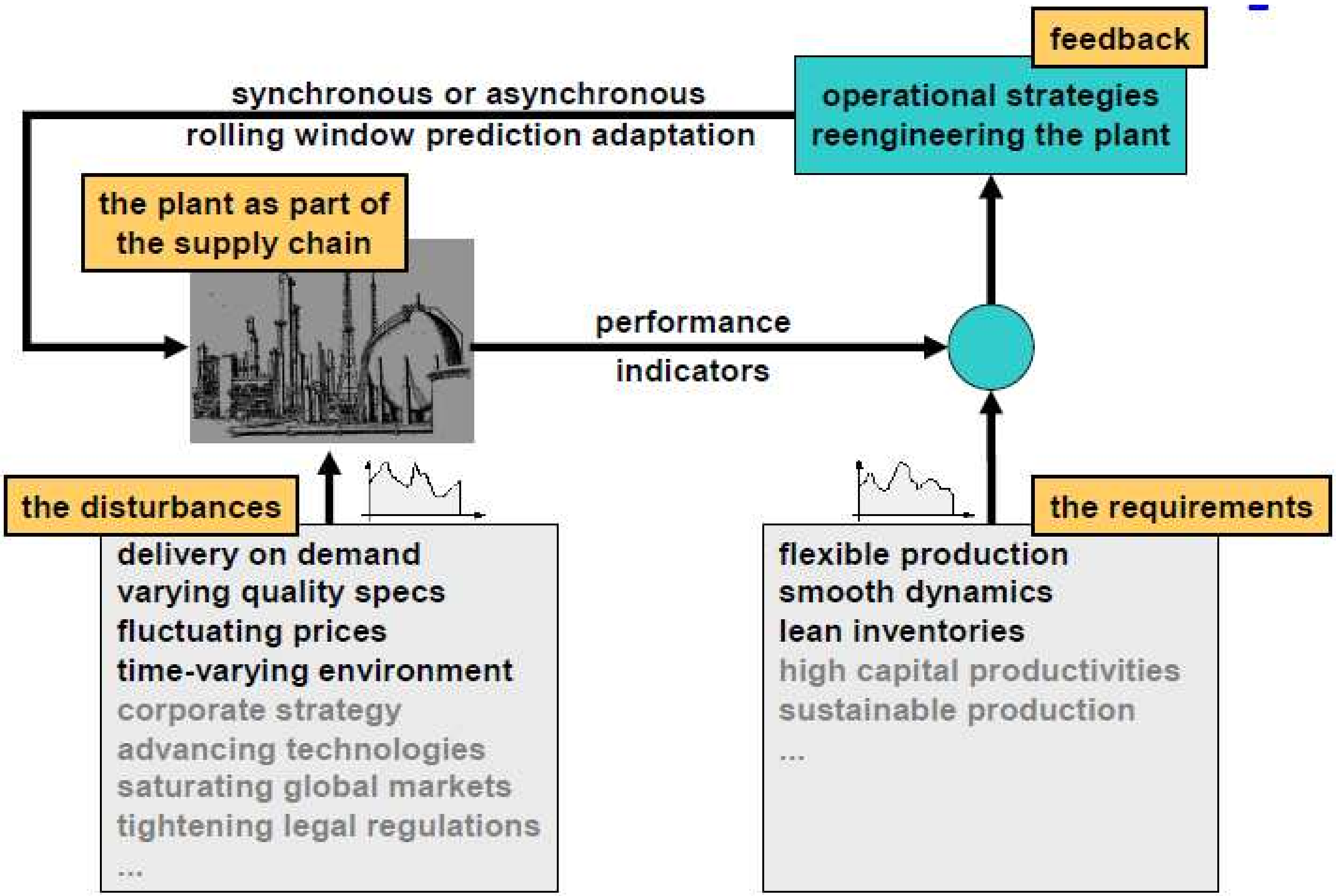
- Real-time Business Decision Making: Manufacturing in the future



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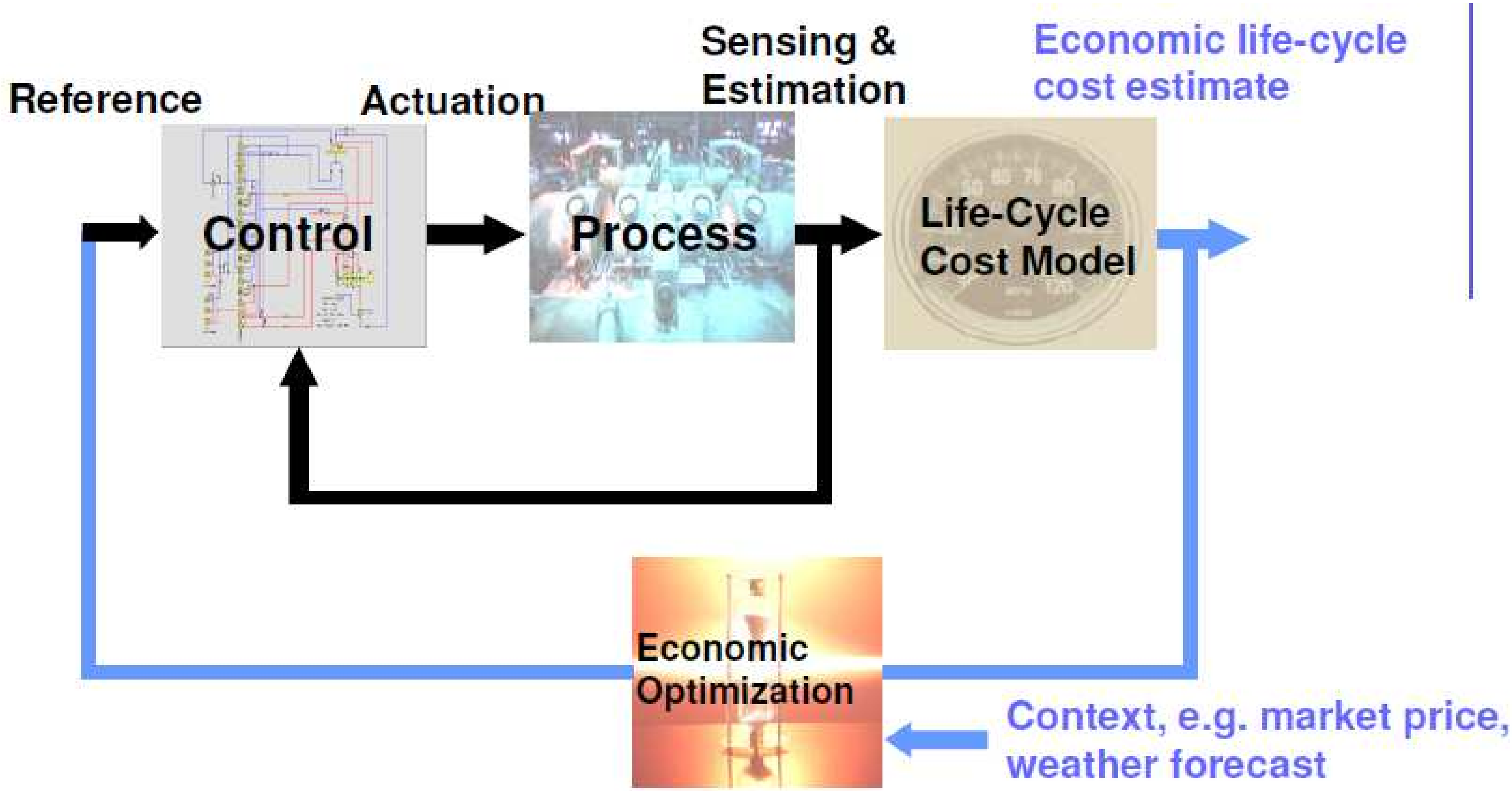
❑ Life-cycle optimization: The next loop



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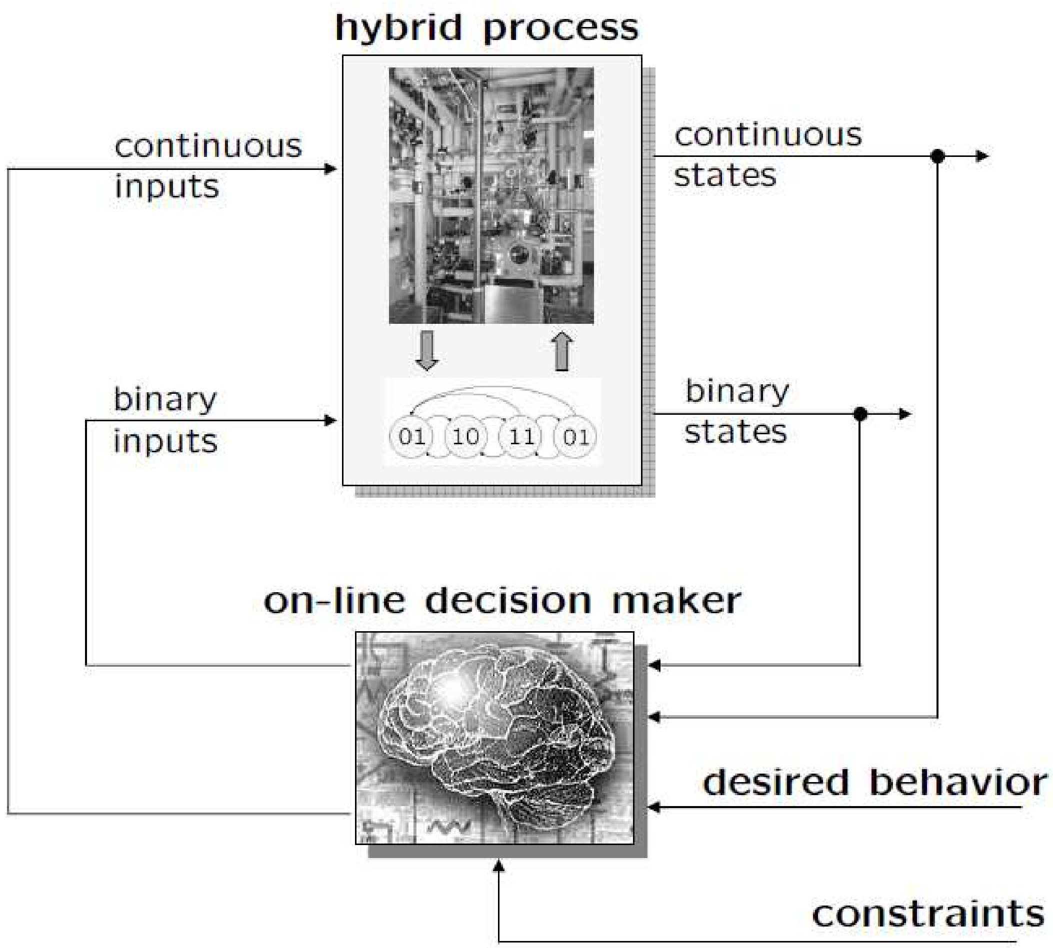
❑ Real-time Business Decision Making



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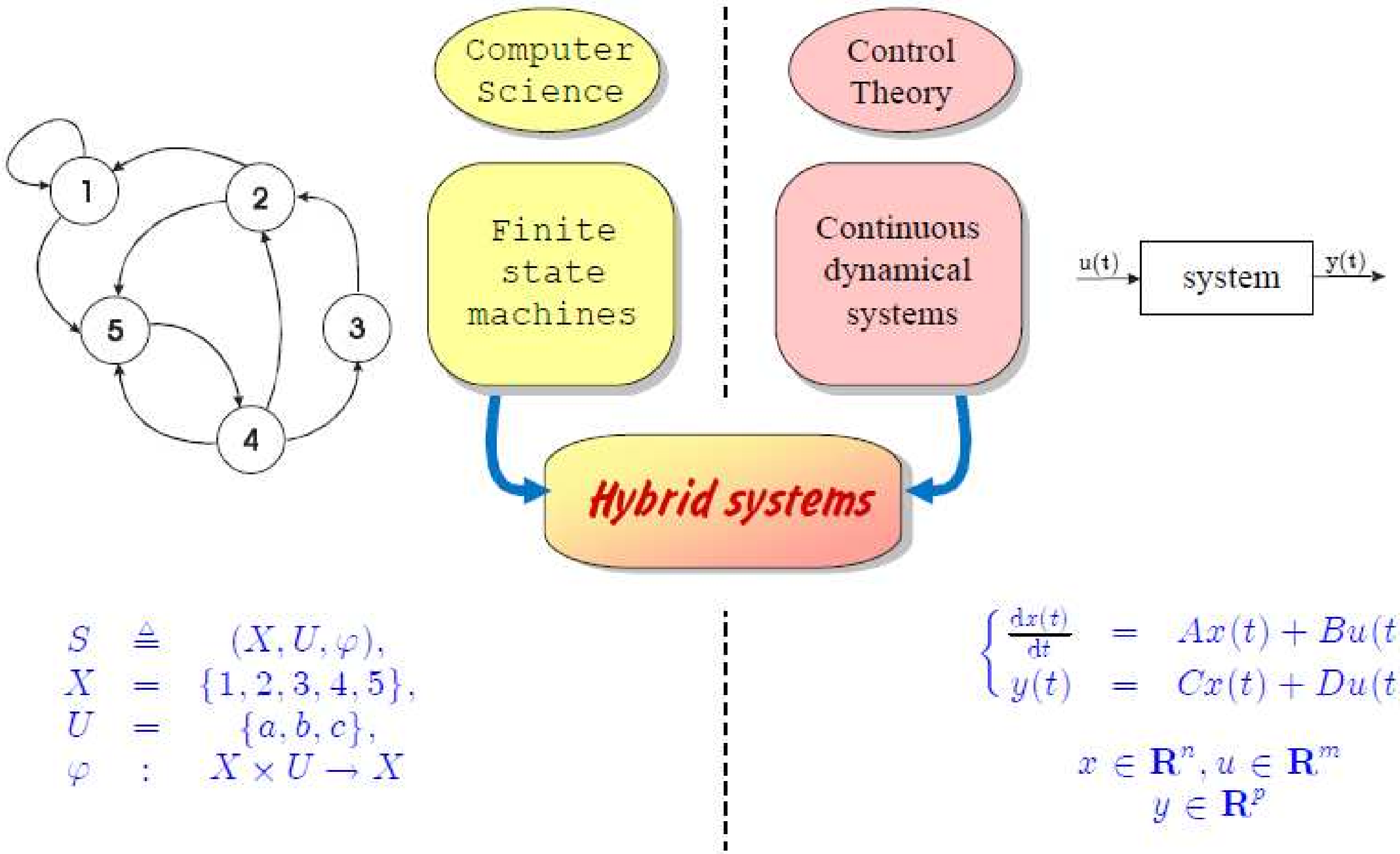
Hybrid systems



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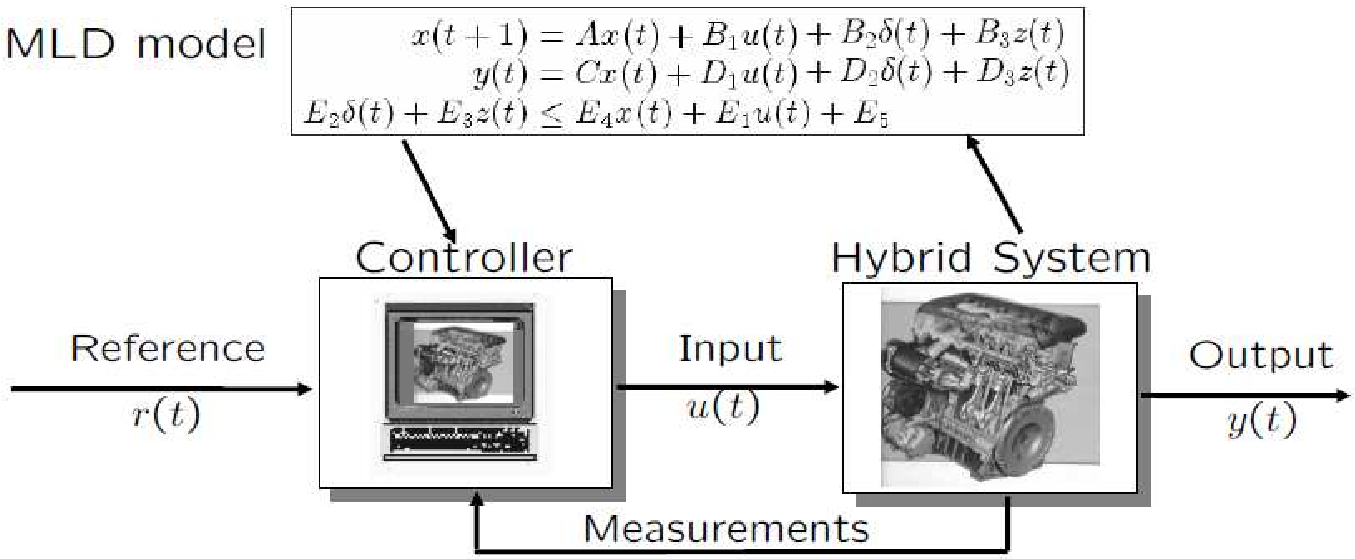
Hybrid Systems: Mixed Logical Dynamical



- MODEL: use an MLD (or PWA) model of the plant to predict the future behavior of the hybrid system
- PREDICTIVE: optimization is still based on the predicted future evolution of the hybrid system
- CONTROL: the goal is to control the hybrid system

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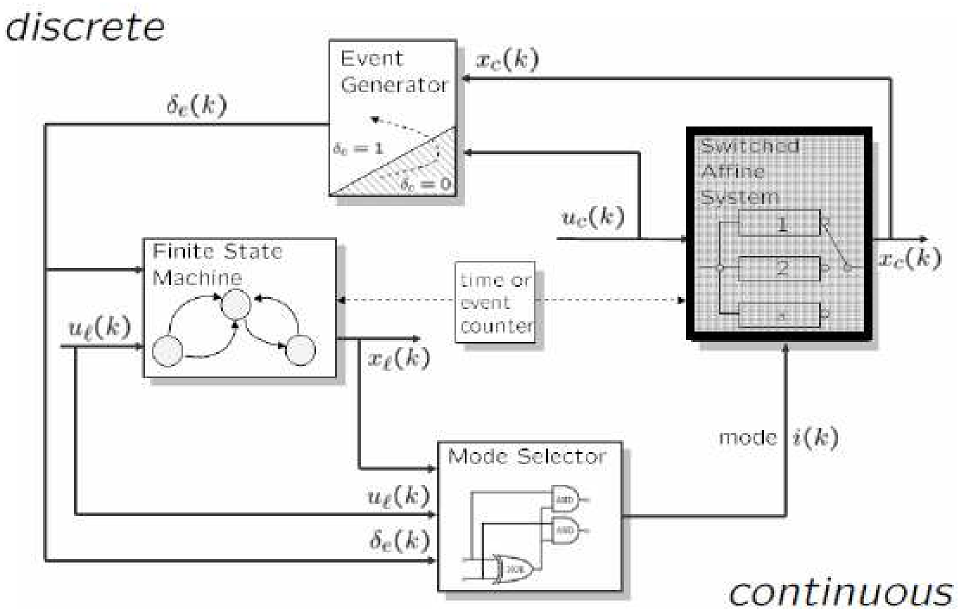
Hybrid Systemas: Peacewise Affine Systems



The affine dynamics depend on the current mode $i(k)$:

$$x_c(k+1) = A_{i(k)} x_c(k) + B_{i(k)} u_c(k) + f_{i(k)}$$

$x_c \in \mathbb{R}^{n_c}, \quad u_c \in \mathbb{R}^{m_c}$

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Hybrid MPC: Applications

- Traction control (Ford Research Center)
- Gas supply system (Kawasaki Steel)
- Batch evaporator system (Esprit Project 26270)
- Anesthesia (Hospital Bern )
- Hydroelectric power plant ( )
- Power generation scheduling ( )

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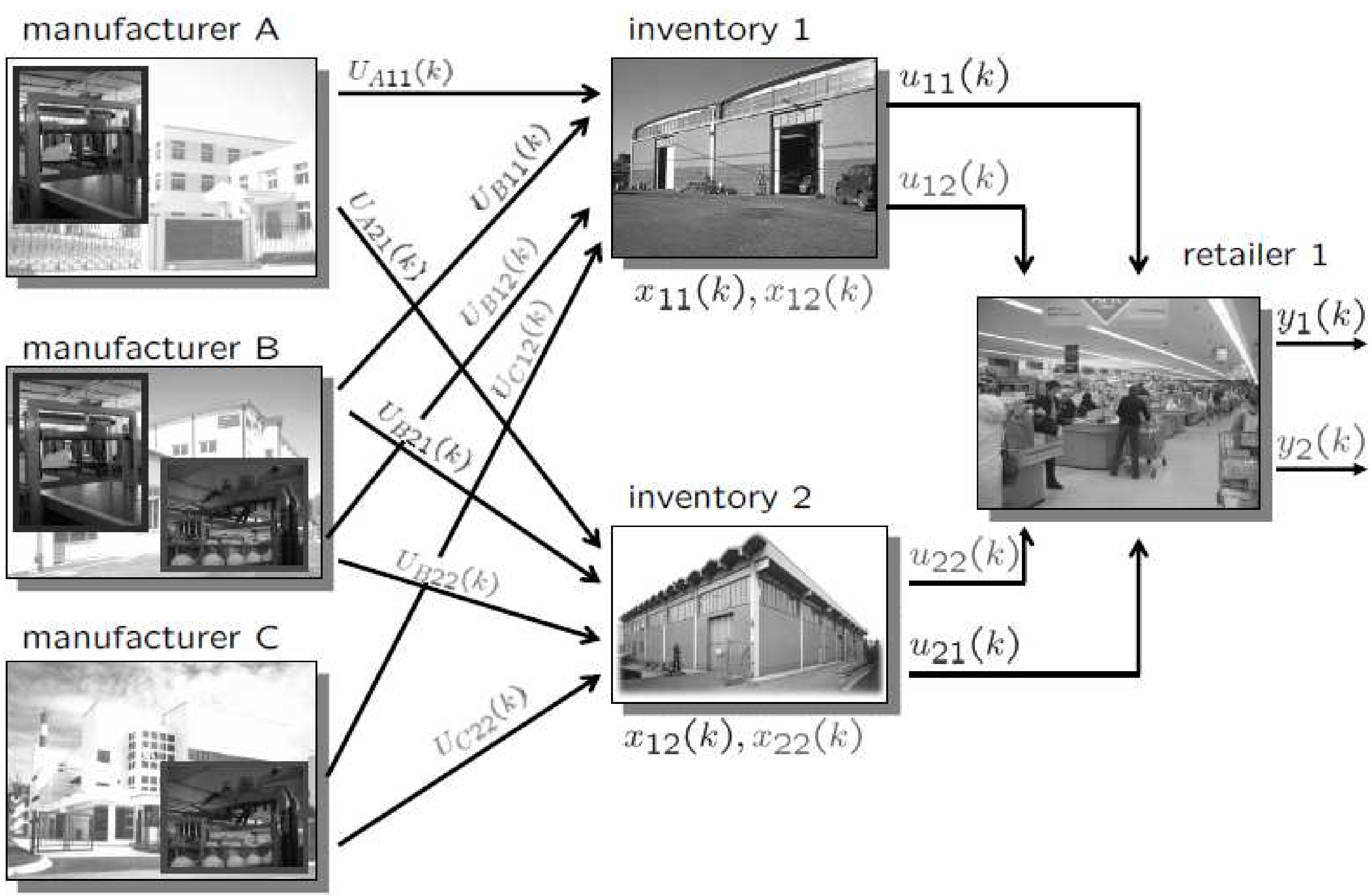
Hybrid MPC: Supply Change Management



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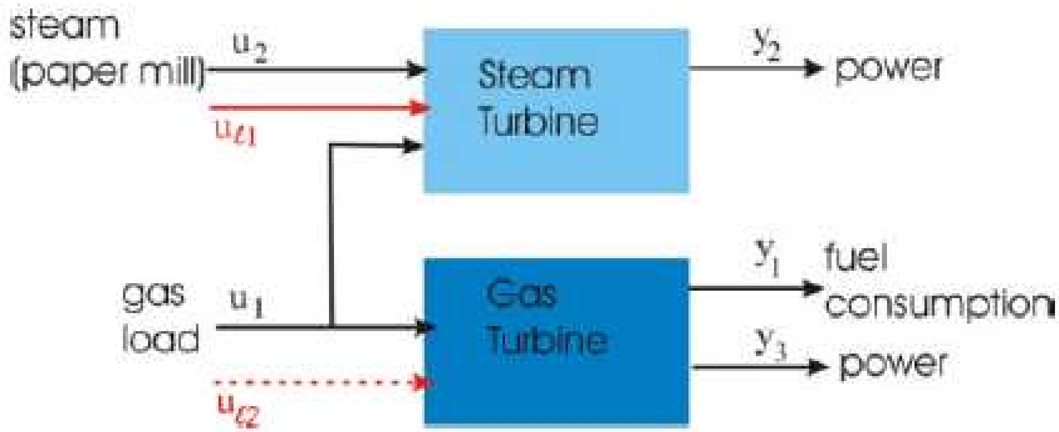
Hybrid MPC: Combined Cycle Power Plant

Simple plant:



- Two turbines and two binary inputs (on/off commands)

Other plants:

- Several gas/steam turbines, firings ...

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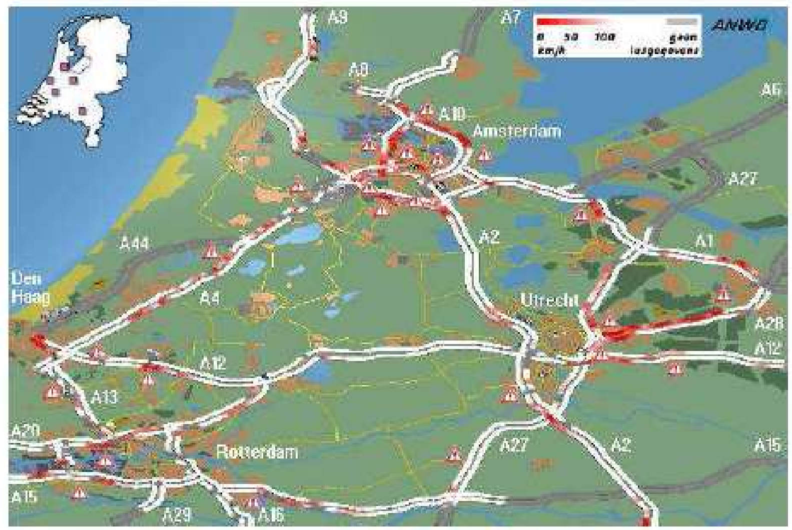
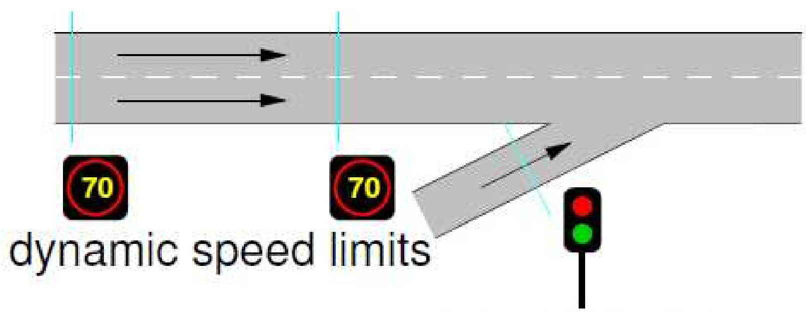
Hybrid MPC: Traffic Control

Motivating examples

- Traffic control systems





APLICACION

❑ Nuevas Tecnologías para el Convertidor Teniente

Actuadores:

- Desarrollo de sistema mecatrónico para la apertura y cierre de las compuertas.

Sensores:

- Desarrollo de sensores en línea para la medición de los niveles de fases líquidas.

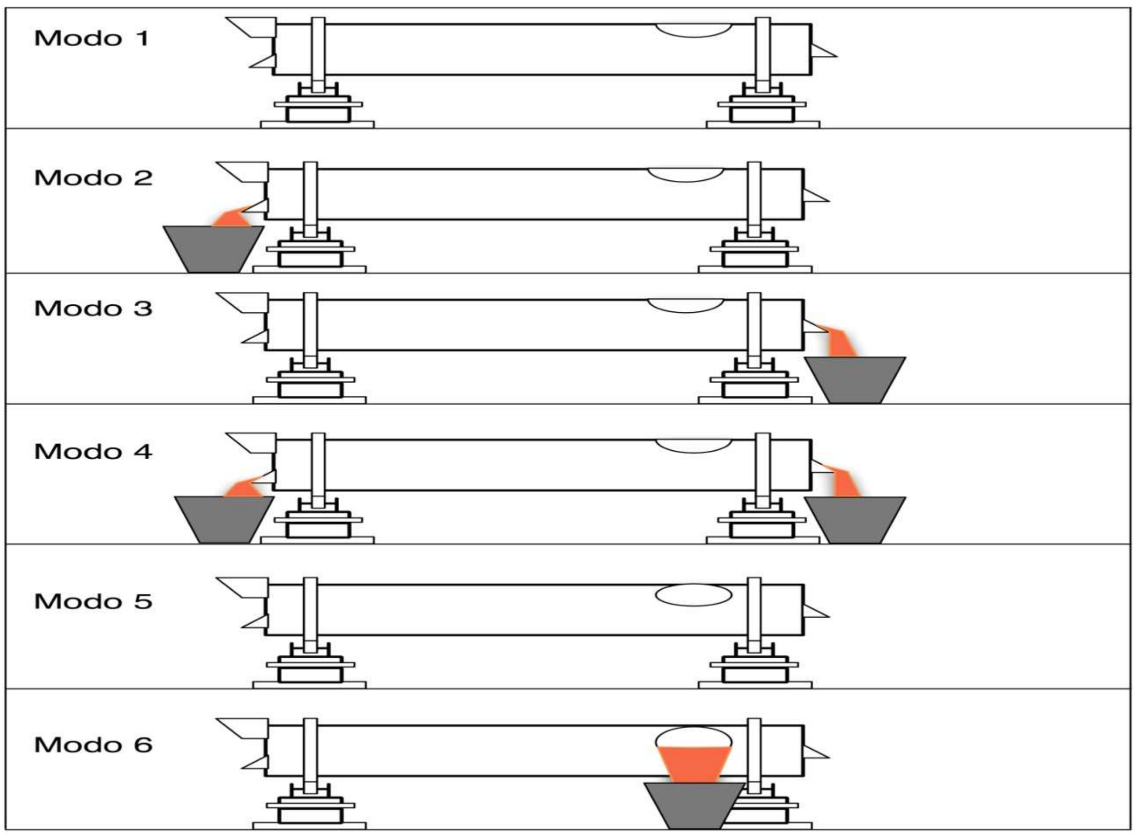
Control:

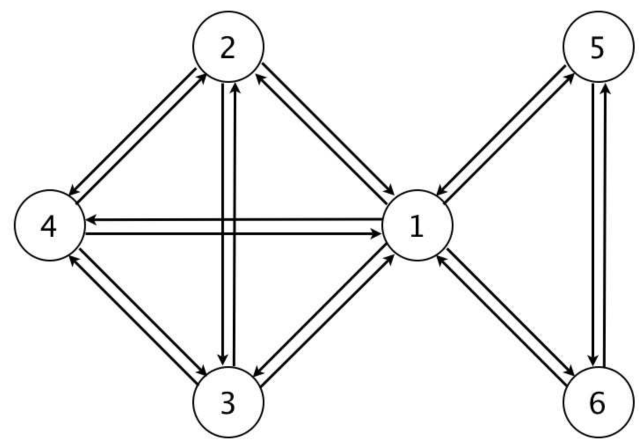
- Satisfactorios resultados con la técnica de control predictivo multivariable tradicional.
- Desarrollo de herramientas basadas en Scheduling.

¿ Es posible integrar estos desarrollos ?

APLICACION

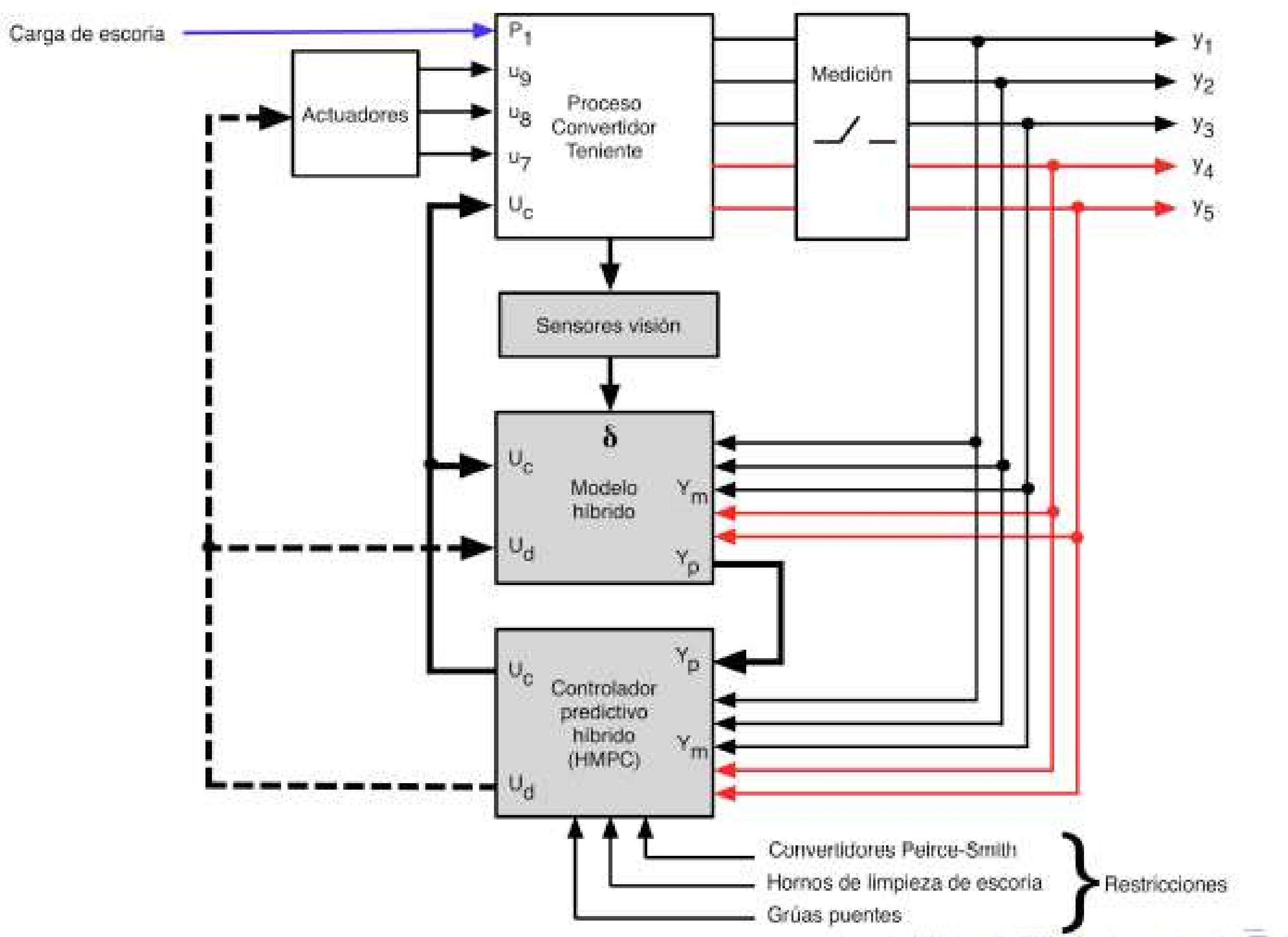
- Modelo híbrido del Convertidor Teniente





APLICACION

Control Predictivo Híbrido del Convertidor Teniente



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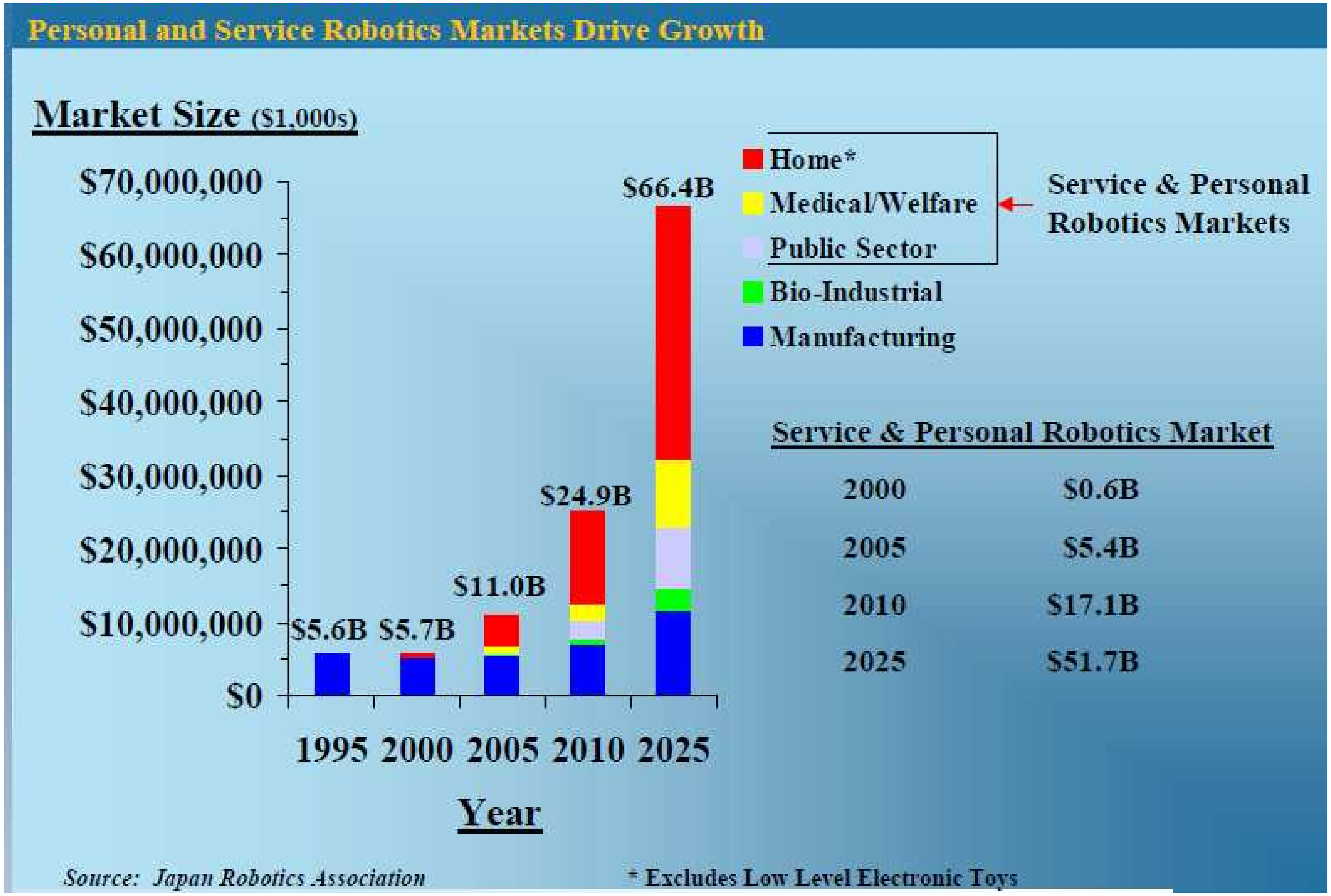
World Wide Robotics Market Growth



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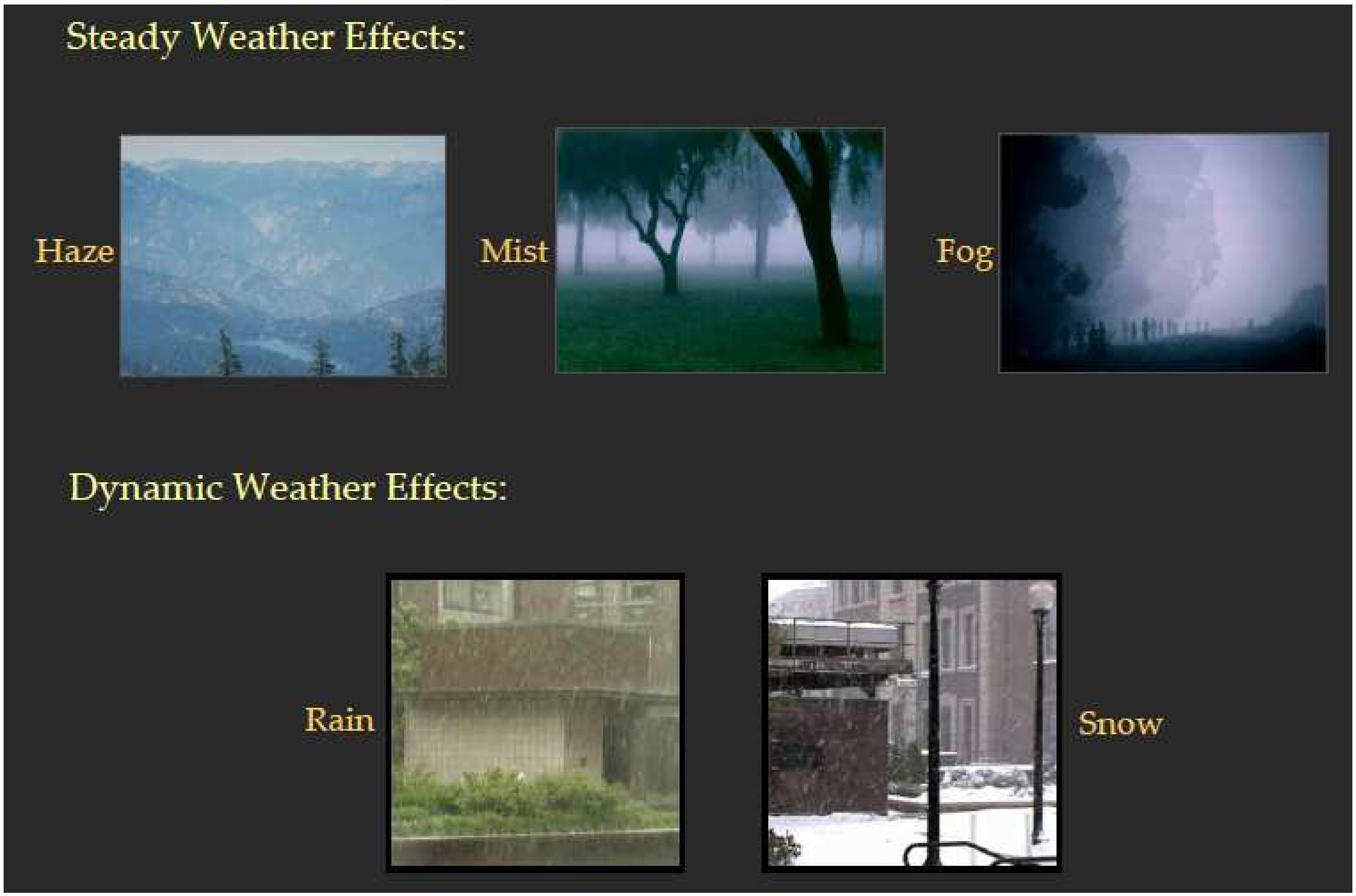
Challenge: Computer Vision



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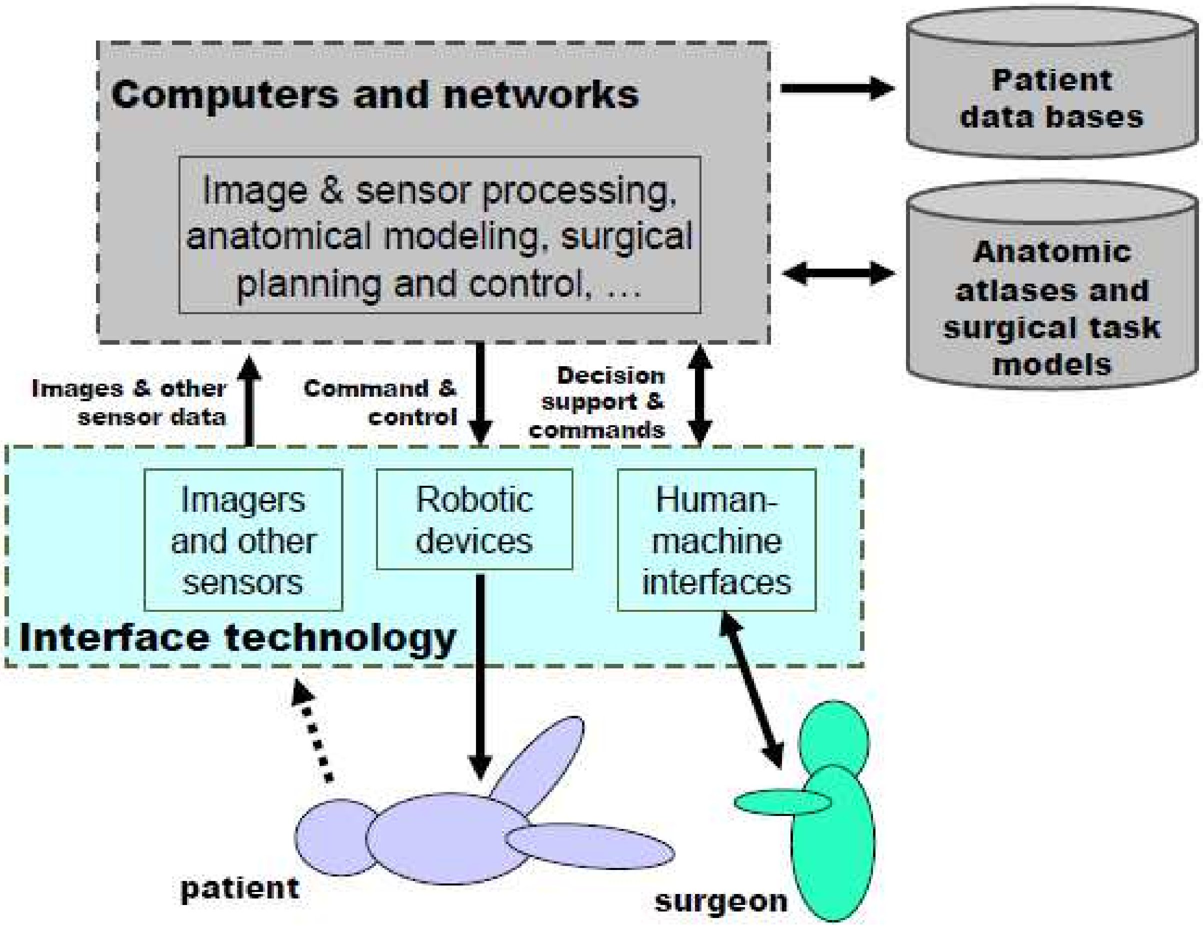
❑ Challenge: Information-intensive surgery



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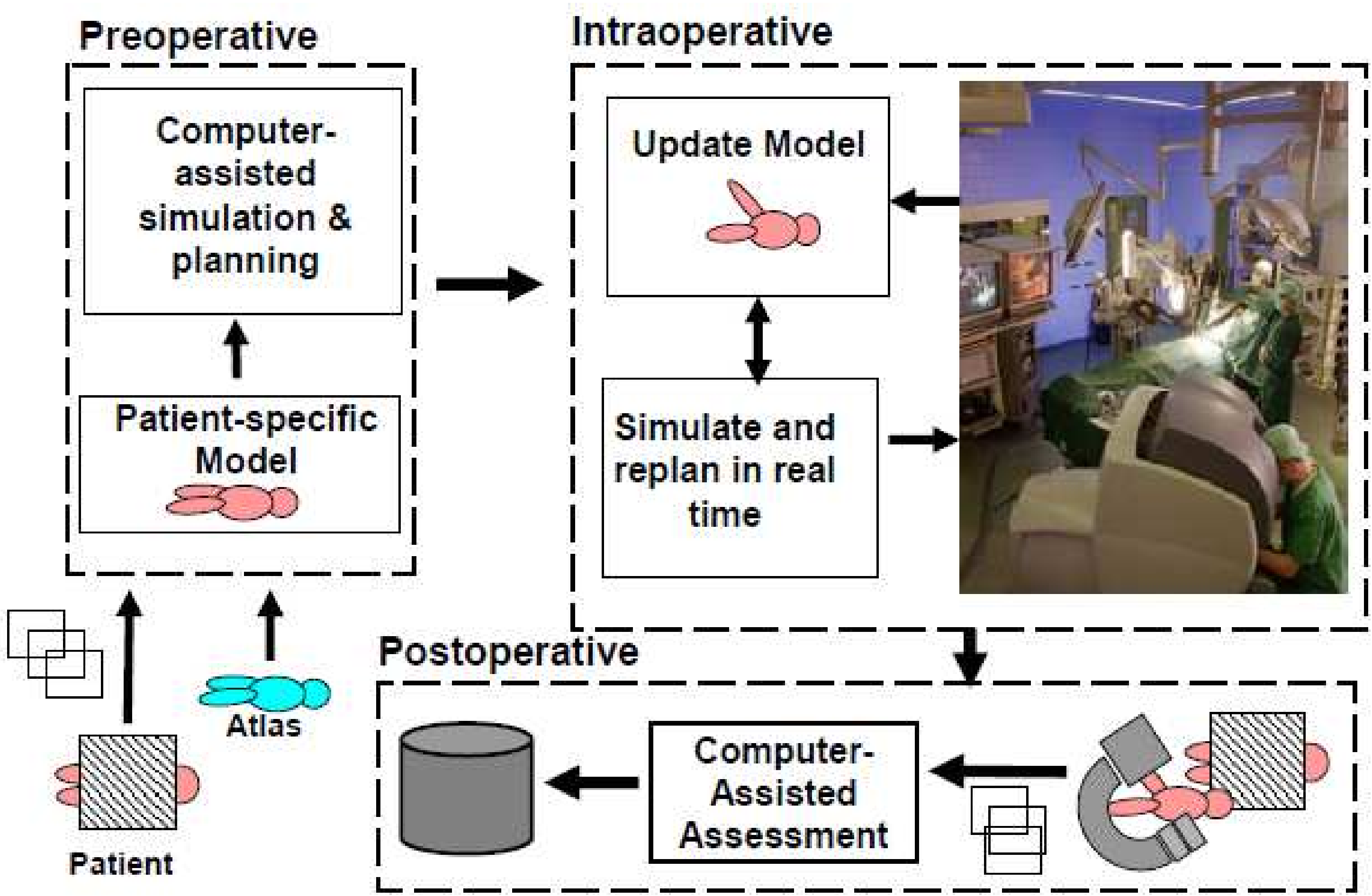
❑ Challenge: Grand Unified System



APLICACION

Mining: Advanced Operator Assist

- Operator positions vehicle, Digging is automated (AutoDig)
- Available on Wheel Loaders (surface mining) and LHDs (underground mining)
- Excavator version in R & D
- Recent versions can adapt automatically to variety of soil types and conditions
- Operation rivals expert operator

APLICACION

❑ Mining: Autonomous Excavator Truck Loading

- Accomplishment: proof-of-concept excavator autonomously loading hundreds of trucks at rate comparable to expert human operator
- Unsolved problem/challenge: surface mines are complex with many types of machines and operational scenarios
- Goal: find the best way to marry autonomous control with human control in an integrated surface mine

Fully Autonomous Excavator Truck Loading: Caterpillar/CMU

APLICACION

Mining: Network of Autonomous Vehicles

Future concept: integrated autonomous systems for

- Dozing
- Loading
- Excavating
- Drilling
- Grading

Concept from Caterpillar

CONCLUSIONES

- Una extensa trayectoria de conceptualización y materialización, acelerada drásticamente con el surgimiento de la electrónica digital, han permitido que la Automatización, la Robótica y la Ingeniería de Control se transformen en elementos centrales del progreso humano.

- Estas tecnologías han llegado también a convertirse en componentes fundamentales para el desarrollo de la industria minera, si bien ello ha ocurrido, en general, con retraso en relación a otros sectores.

- Actualmente las empresas mineras han reconocido el potencial que las tecnologías de automatización, robótica y control poseen para aumentar la seguridad, reducir los costos y mejorar la operación de sus procesos.

- Proveedores con extensa trayectoria en la minería han potenciado su oferta y propuesto nuevas formas de hacer negocios, para lo cual están invirtiendo en desarrollar o adaptar tecnologías para el sector.

- Como consecuencia, la oferta de productos y servicios para la aplicación de estas tecnologías está creciendo significativamente.

CONCLUSIONES

- Las proyecciones muestran que en los años siguientes se fortalecerá la actividad científica y tecnológica que buscará explicar fenómenos de gran complejidad, frecuentemente encontrados en la naturaleza y en el propio ser humano.

- Estas investigaciones permitirán incorporar cada vez más inteligencia en los componentes de la Automatización la Robótica y el Control, mejorando significativamente las capacidad de percepción, modelación y predicción.

- Resulta aconsejable poner atención a estos avances, pues varios de ellos pueden ser transferidos directamente a la industria minera, sirviendo de base para enfrentar los desafíos que la misma industria se ha planteado.

- Como elementos que aún requieren mayor elaboración se encuentran: una visión más integrada de los procesos y de las soluciones, una mejor interacción hombre-máquina, y una capacitación del recurso humano más acorde con las nuevas tecnologías que están surgiendo.