# Real-Time Intelligent System Design

★入选2020年校级研究生课程思政建设项目
★入选2021年校级研究生课程思政示范课程

**ZHANG Kailong**
Professor，Ph.D Supervisor
School of Computer Science and Technology
NPU-Paristech MINES Joint lab of Robot and Swarm Intelligent Systems
kl.zhang@nwpu.edu.cn

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## Class versions, WHICH ONE?

① **English Slides + English Presentation?**

② **English Slides + Chinese Presentation?**

③ **Chinese Slides + English Presentation?**

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## One question of philosophy of science and technology

**Scientist OR Engineer?**

this linear model of innovation is in fact how things work. For example, About.com, an advertising-funded website centered around articles on a huge variety of subjects, collects reader commentary. On the question of "Engineer vs Scientist - What's the Difference?" some of the reader answers are:[5]

Scientists are the ones who create the theories, engineers are the ones who implement them. They compliment [sic] each other...

Science is a lot of high level theory and engineering is implementation and optimization.

Engineers deal with math, efficiency and optimization while Scientist [sic] deal with "what is possible."

Engineers trained [sic] for Using tools, where Scientists are trained for Making them.

Scientists develop theories and work to verify them, Engineers search in these theories to "optimize" things in real life.

A scientist invents a law and an engineer applies it.

Scientist for invention of new theories [sic], Engineers for applying those theories for piratical [sic] applications.

**Question**: What i , and an engineer?

**Answer**: An optimist glass half empty. An engineer s to be.

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## Science VS Engineering

- **What' s Science? Engineering?**
  - [S] Discover from nature，[E] Human-made?
  - [S] Theory research，[E] Design & implementation?
  - [S] Innovation，[E] Application & Optimization?
  - [S] Superior，[E] Hard work & Inferior/LOW?
  - [E] is the LITTLE SISTER of [S]?
- **Wiki item**
  - **Engineering** is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, and processes. ( 2016)
  - The term Engineering is derived from the Latin ingenium, meaning "cleverness" and ingeniare, meaning "to contrive, devise.

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## Questions about our course

- **What does "REAL-TIME" mean?**
  - **Please summary and write down**
- **What' s "INTELLIGENCE" , especially with digital technology?**
  - **Please summary and write down**
- **Why do we focus on "SYSTEM" ?**
  - **Please summary and write down**

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## Contents



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- Objective
  - To discuss the composition, characteristics, modeling and design method of real-time intelligent systems from a system perspective on the basis of learning embedded computing technology, network communication and artificial intelligence.
- Class Mode
  - Theoretical Explanation + Topic Discussion + System Design
  - Each group – One Project – One presentation – Reports
- Assessment Method
  - Project: 50% + Topic Discussion: 30% + Class: 20%

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- **Reference Material**
  - **嵌入式系统体系、原理与设计**, 张凯龙, 清华大学出版社, 2017;
  - **智能系统：结构、设计与控制**, Meytel A.M, 翻译版, 电子工业出版社, 2005;
  - ***Real-Time Systems and Programming Languages* (4th ed.)**, Alan Burns and Andy Wellings, Addison-Wesley, 2009;
  - **实时系统**, Jane W.S.Liu, 翻译版, 高等教育出版社, 2003;
  - **Journal of Real-Time Systems**, Springer US, 1989-2014;
  - **Embedded Systems & Robots**, Subrata G., Cengage Learning, 2009;
  - ***智能控制（第2版）***, 刘金琨, 电子工业出版社, 2012;
  - ***计算智能***, 黄竞伟等, 科学出版社, 2010;
  - ***人工智能控制***, 蔡自兴, 化学工业出版社, 2005;
  - ***机器学习***, Mitchell T.M., 翻译版, 机械工业出版社, 2008;
  - ***IEEE***: http://www.ieee.org/index.html
  - 智能时代—大数据与智能革命定义未来, 吴军, 中信出版集团. 2017

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Online resources: coming

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- Previous Students' Works
  - Yang Ansheng ,et al. Inverted Pendulum Based on Fuzzy Control
  - Su Hang, et al. Vehicle License Plate Recognition
  - Zuo Panfei ,et al. Quad-rotor Unmanned Aircraft
  - Zhao Hua ,et al. Visual Recognition Robot
  - .....

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- **2017 students' work video**
- **2019 students' work video**

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## Outline

- Development Background Extension
- The Intelligence of Embedded System
- A Variety of Intelligent Systems
- Research on Intelligent Embedded Computing
- Embedded Intelligent Research in Europe
- Our Related Work

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## Part I: Hello Embedded 1.0
## Background Extension

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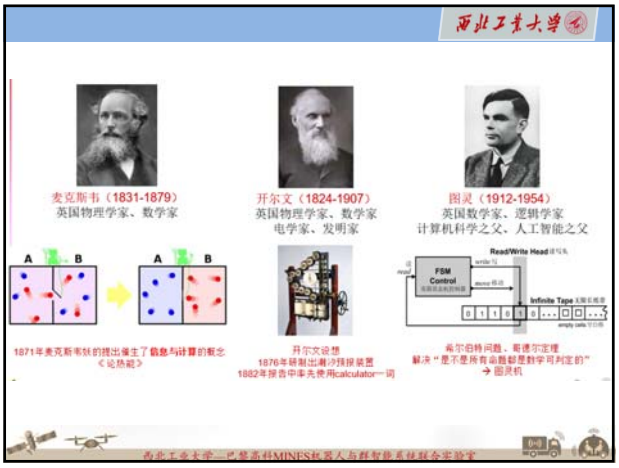


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- From the assumption of Kelvin to the emergence of the automatic computing device
  - The development of computing technology stems from the expect… …onal efficie…
  - In the… …), a gradua… …is in the fa… …n as tidal … …been accom… …but calcul… …ht to be fou…


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- In 1876, Kelvin designed and implemented a tidal device for forecasting tide;
- Kelvin first used the word "Calculator" in an academic report in 1882;

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- **Differential Analyzer（微分分析仪）**
  - **Developed by Van Geneva Bush in 1931 . It was a typical implementation of Kelvin's assumption and the first mechanical computer that was used to solve differential equations;**
  - **Electronic components are further used to replace certain mechanical parts , and computing device is optimized to form the "Rockefeller Differential Analyzer 2 ".**

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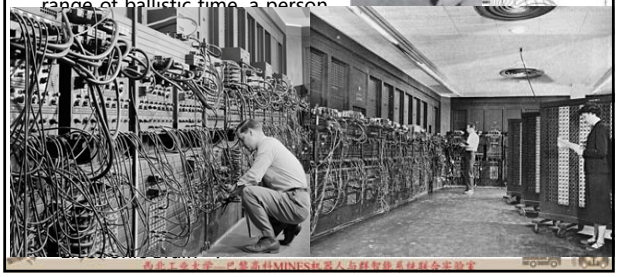
- Ballistic trajectory and Fire Table calculation is very important to improve the hit rate;
- A fire table has more than 3000 parameters. For a 60 second range of ballistic time, a person

Electronic computer technology provides high efficiency, high precision and complex computing ability to replace part of the work of "man"!



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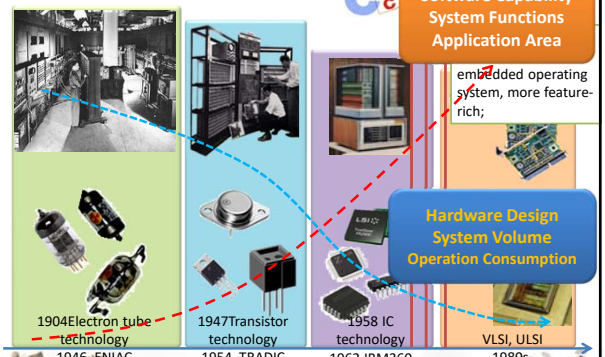
☐ **Digital Computing Technology**

Computing Capability
Peripheral Component
Software Capability
System Functions
Application Area

embedded operating system, more feature-rich;

Hardware Design
System Volume
Operation Consumption

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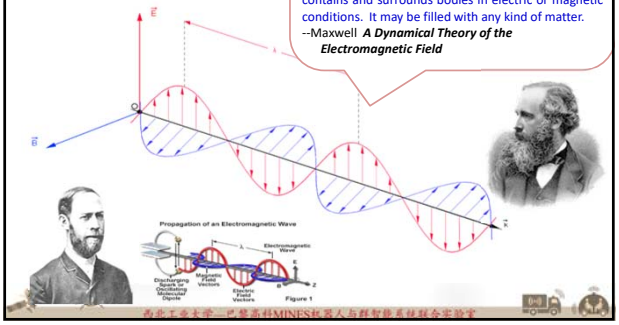
- **Foundations of Con**
  **Electromagnetism**

•We can scarcely avoid the inference that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena.-
-Maxwell ***On Physical Lines of Force***

•The electromagnetic field is that part of space which contains and surrounds bodies in electric or magnetic conditions. It may be filled with any kind of matter.
--Maxwell ***A Dynamical Theory of the Electromagnetic Field***



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Tip：Stand on the shoulders of giants with awe and the sense of mission!

- Communication and Net
  - In 1962, Professor Lickli
    paper that proposed the
    network, which links glo
  - In 19
    establ

Communication and network technology realize the inter-connection of computing devices, as well as automatic and reliable information exchange!



was

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- The emergence and application of embedded computing technology achieve the integration of "**mechanical + electronic + software**", so that equipment has a digital capacity , with a certain "**thinking and control**" ability, partially replace, even beyond the role of "**human**" factor;

- **Key notations**
  - **Real-time → Physical rules**
  - **Intelligence → Biological characteristics**
  - **System → Organic aspect: thought and ability**

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未来已来，智能系统的发展与挑战！

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**Part II : Some Typical**
**Intelligent Embedded Systems**

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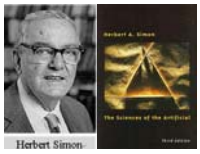
## Artificial & Natural

- **List what are natural**
  - 自然物, things the nature provides.
- **List what are artificial**
  - 人造物、人工制品
  - political systems, economies,
  - engineered artifacts, and administrative organizations
- **Think about what is artificial**
  - The thesis is that certain phenomena are "**artificial**" in a very specific sense: ***they are as they are only because of a system's being molded, by goals or purposes, to the environment in which it lives***.——《The Sciences of the Artificial》, Simon, 1996
  - Herbert A. Simon, winner of both the Turing Award in computer science and the Nobel Prize in economics

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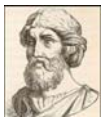
## Design and Discovery

- In contrast to Simon's "sciences of the artificial," the "**sciences of the natural**" study what nature has given us. **The goal** is to uncover the "**secrets of nature**," presupposed to exist disembodied, independent of humans.
  - Physical, Chemical, Celestial Laws……
  - Lao-zi's DAO（道）, or Plato's Form（型相）→ Good（善）



- **《道德经》：道反映自然规律、个体修行，是宇宙本源；德反映世界观、方法论、处世之法等，体现社会法则；**
- **柏拉图认为世间的一切皆为理念界的摹本，只有理念界才是真实的。**

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Plato's Allegory of the Cave

The School of Athens
Plato and his student, Aristotle

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## An example

- **A surprised Teddy**
  - **Natural or Artificial?**
  - **Discovery or Design?**

- https://tech.sina.com.cn/roll/2020-09-17/doc-iivhvpwy7308538.shtml

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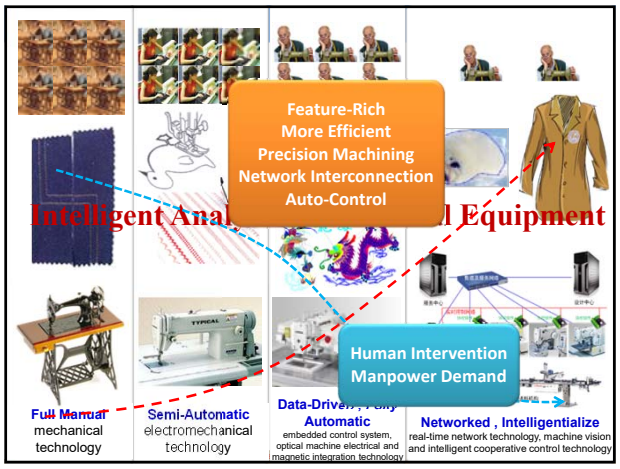


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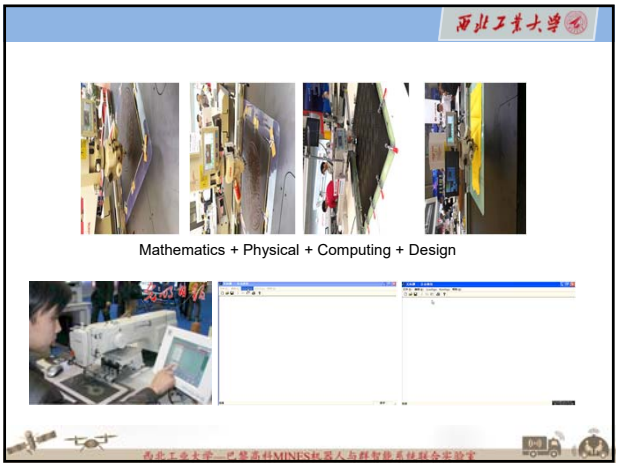


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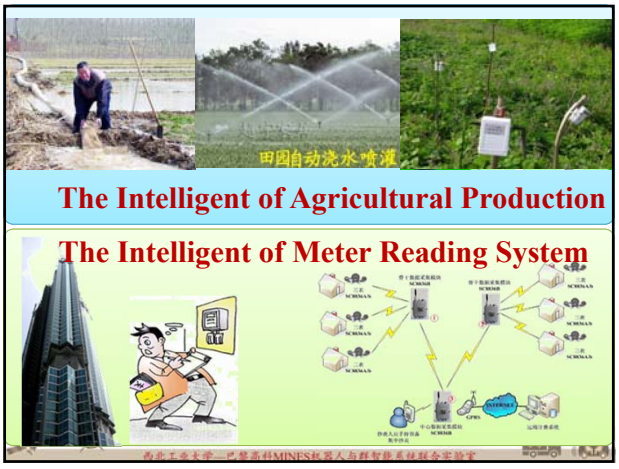


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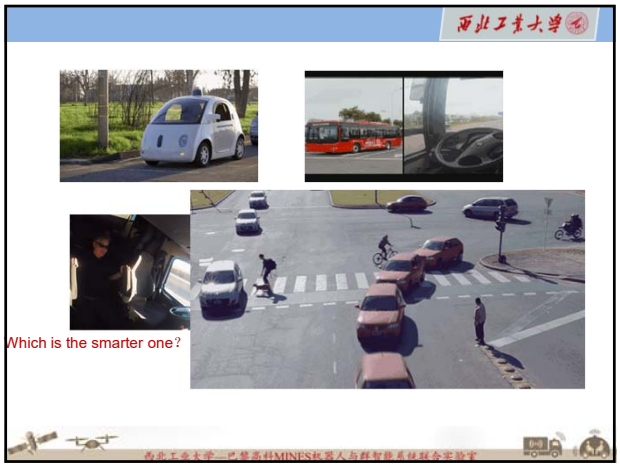


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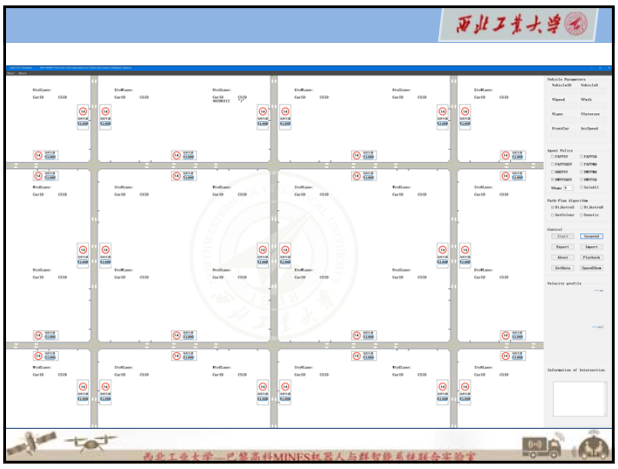

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## Questions

- **If any example here is smart, but without time constraint?**
  - **Please summary and write down**
- **What' s the general features of these smart systems?**
  - **Please summary and write down**

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[A Variety of Intelligent Systems]

[Era of the Intelligence]

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[Embedded Intelligent Research in Europe]

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## Part III : Embedded (Real-time) Intelligent Technology

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- Definition of Embedded System
- Connotation : Based on embedded computing technology, effectively improve the equipment

The Definition of Barr Group——An International Research Organization

An embedded system is a combination of compu-ter hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function. In some cases , embedded sys-tems are part of a larger system or product, as in the case of an antilock braking system in a car.

(译文：嵌入式系统是一组计算机软、硬件的综合体，还可以附属机械或其他组件，被设计来执行特定的功能；在很多情形下，嵌入式系统是大系统或产品的一个组成部分，例如汽车中的防抱死系统（ABS））

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多选题 1分 设置

此题未设置答案，请点击右侧设置按钮

Which devices are embedded systems? 提交

A HDD

B PDA

C Mobile Phone

D Flight-Management Computer

E Engine Controller

F Radar

G Heart Pacemaker

H HIL Simulator

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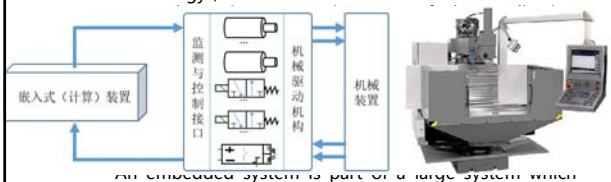
- **General Definitions for Embedded Systems**
  - **Technically**
    - Embedded system is a dedicated computer system that is application-centric and based on computer technology , software and hardware can be tailored to




performs a particular function;

- An embedded system can include multiple embedded subsystems.

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- **Brief Summary of the Connotation of The Concept**
  - Embedded system technology is based on computer technology and combines with domain technology;
  - A dedicated computing system that oriented application customization and development of software and hardware.

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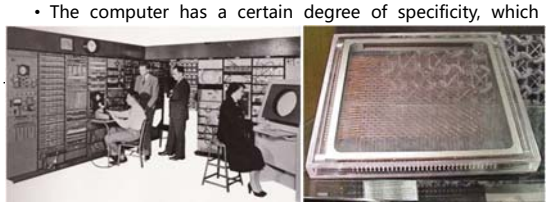
- **The "Embeddable" Development Process of Computers**
  - **Embedded " 1.0 " : Calculation Function Embedded**
    - The computer has a certain degree of specificity, which



computer Whirlwind for controlling flight simulator and its magnetic core memory

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- **Embedded "3.0" : Polymorphous Networked**
  - Various lightweight network protocol stacks suitable for embedded applications have been developed. Hardware, operating systems provide network interfaces and services, and more and more applications are connected to the network.
- **Embedded "4.0" : Deep Integration of Information (Systems) with Physics (the World)**
  - The computing device can interact autonomously with the physical world in a certain degree through sensors and actuators, showing the complex computing characteristics of intelligent function, information system and physical world.

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Distinction of several concepts

- **Classical Embedded System VS Cyber-Physical System (CPS)**
  - **环境感知能力、计算能力、环境交互能力、服务能力、预测能力不断丰富和增强；**
  - **早期的数传控制、移动电话（前者）；**
  - **正在出现的智能驾驶、智能电话（后者）。**


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- **ES VS IoT**
  - 前者赋予物件“生命”，是前提；
  - 后者是网络化嵌入式系统互联形成的大应用系统。

- **ES VS Intelligent Systems**
  - 前者让物件数字化，是前提；
  - 后者融合综合感知、AI、大数据、云计算等技术，实现自主的行为、服务能力。

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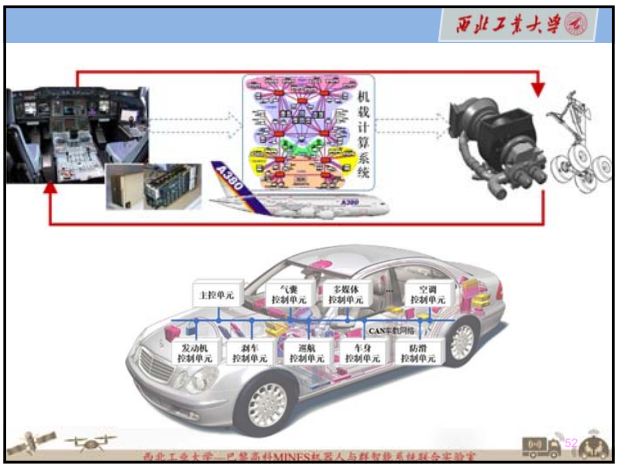


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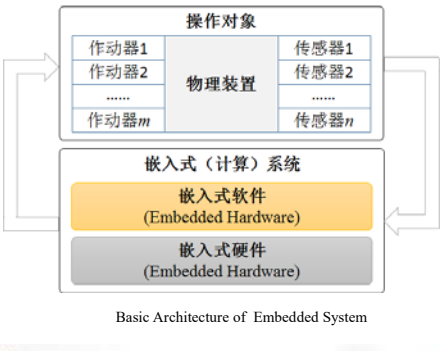


Basic Architecture of Embedded System

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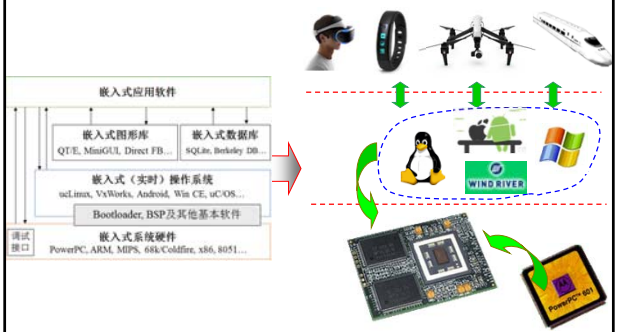


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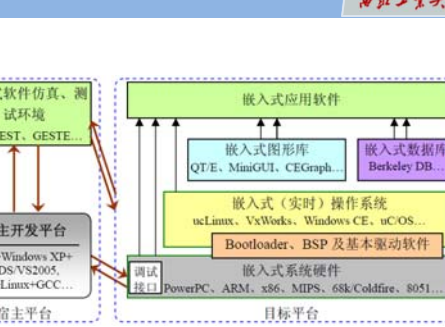


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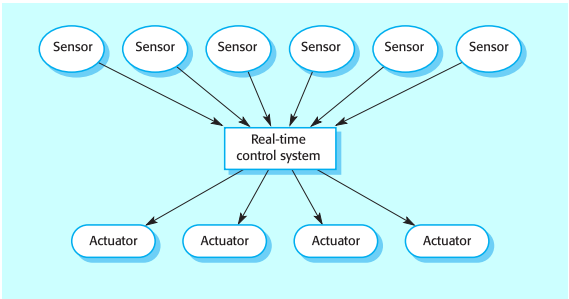
## Real - Time System Model

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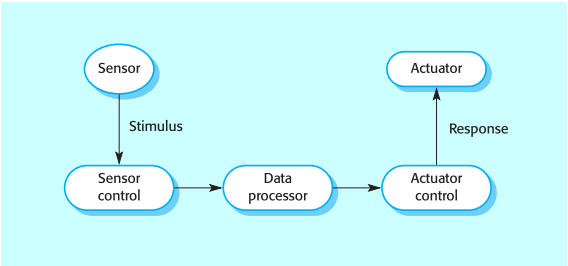
## Sensor/Actuator Processes

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## About Model

- **What is a Model? List several models**


– Fitting special physical phenomena of object

- British statistician, George E. P. Box:
  "All models are wrong, but some are useful."
  **The world should be creative!**
  Werner Karl Heisenberg: *The uncertainty principle*
  **"The world is uncertain!"**

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## Understanding "Real-Time" from the aspect of EOS

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## The Connotation of "Real-Time"

- **The Sinking of The Titanic**
- **Missile Interception Failed**
- **Mars Polar Lander Crashed**

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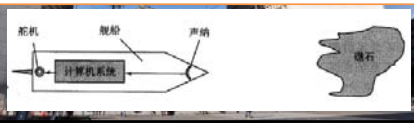
– **When people use computers to solve problems, they focus mainly on the correctness of the calculations and do not mind the time;**
– **In a considerable number of applications, the correctness of the results is closely related to the computation time, and even time is more**

The calculation of the system must produce the correct result, called **Logical or Functional Correctness**;
The calculation of the system must be completed within a predetermined time, called **Timing Correctness.**

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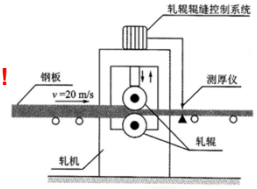
- The rolled steel plate passed at the speed of 20m / s, and the gauge does not meet the requirement of thickness. Then the adjustment instruction is issued to the control system. If the control device needs 100ms to control the machine to meet the requirements, is it timely?
- If the total length of the steel plate is 100 m, approximately 2 m of waste will be produced during the adjustment period;
  Require rejection rate not more than 3%, in time;
  The requirement of the reject rate becomes less than 1.5%, not in time.

**Real-time is also relative!**

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– **What is a real-time system?**
  - A very fast computing system?
  - A system with very small cloc
  - Single tasking or multitasking?

作业要求你多快处理，你就能多快处理的系统。

特点：如果逻辑和时序出现偏差将会引起严重后果
分类：软实时系统和硬实时系统
软实时系统的宗旨是使各个任务运行的越快越好
硬实时系统各个任务不仅要执行无误而且要做到准时
大多数实时系统是两者的结合，且多数实时系统又是嵌入式的

就是处理时间要求非常严格的系统。以嵌入式操作系统居多。

银行，机场，重要的环境监测，等等都用到了实时系统

实时系统就是CPU执行任务时总是一个个的执行，只有等在执行的问题完成了之后，才交出CPU，这种方式的速度很快，但是去不怎么好用，DOS就是这种工作方式；
与这种工作方式相对的就是分时系统，WINDOWS就是分时系统工作方式，CPU被分成很多个芯片，同时执行多个任务，当然，这中间占用芯片的大小我就不懂了：）我没有深研过操作系统

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– **The definition of POSIX 1003.b**
  - Refers to a system that provides the required level of service within a defined response time

– **The definition proposed by Donald Gillies**
  - A real-time system means that the correctness of the calculation depends not only on the logical correctness of the program , but also on the time it takes for the result. If the time constraints of the system are not met, a system error will occur.

– **A computer application system that can respond to external random events in a timely manner and complete the pro-cessing of events at a sufficiently fast speed (within a given time) .**

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– **Basic Characteristics**
  - Time constraints: hard real-time, soft real-time
  - Predictability
  - Reliability
  - The interaction of the external environment: control, CPS

– **New Features**
  - 多任务类型: periodic, nonperiodic, occasional, anytime;
  - The complexity of constraints: time constraints, resource constraints, execution sequence constraints, and performance constraints;
  - Have the characteristic of 短暂超载： Caused by component aging , dynamic variations of environment and the overloading of application scale.

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- **Time Attributes of One Task**
  – Release time（释放时间） , the time when the task is ready; If all tasks are ready when the system is started, the release time is 0;
  – Deadline（截止期）, the time when the task must be completed; If the deadline is infinite, it means that the deadline does not exist;
  – Relative deadline（相对截止期）, the event interval between the release time and the deadline, and the task should be completed within that time period;
  – Response time（响应时间）, the time interval between the completion and completion of the task, equal to the completion time release time";
  – Tardiness（延迟时间）,If the completion time does not exceed the deadline, the time value is 0, otherwise it is equal to the completion time minus the deadline;
  – Lateness（滞后时间）, which is equal to the completion time minus the deadline, and the value can be positive or negative.

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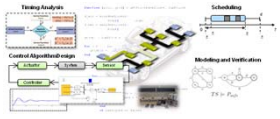
- **Task Scheduling Characteristics**
  – Feasible schedule （可行的调度）,For each task with a deadline requirement, it can be completed before the deadline as long as it is activated at (or after) the release time ;
  – Schedulable（可调度性）, For a scheduling algorithm, a group of tasks always have a feasible scheduling scheme; if all the tasks in a system are schedulable, it can be said that the system is real-time;
  – Optimal Schedule（调度优化）, As long as it exists, the scheduling algorithm can always find this feasible scheduling sequence;
  – Miss rate（错失率）, The proportion of tasks that have been executed but completed beyond the deadline;
  – Loss rate（丢失率）, The proportion of discarded tasks;
  – Invalid rate（失效率）, which is equal to "miss rate + loss rate".

67

67

## Hard Real-Time

- **The deadline must be met**
  – The deadline for a task must be met→ **Hard Real-Time Task**;
  – If any deadline is wrong, it will cause a system error;
  – Therefore, it is necessary to verify whether the deadline for each task can be met.
- **Hard Real-Time System**
  – All tasks with deadlines , their deadlines must be satisfied , that is to say all real-time tasks are hard real-time tasks→ **Hard Real-Time System;**
  – **For example: flight control , nuclear power plant control**




68

68

## Soft Real-Time System

- **Soft deadlines are allowed to be missed**
  - When a task's deadline is missed, it does not cause serious consequences → **Soft Real-Time Task;**
  - The longer the completion time exceeds the deadline (the longer the lateness), the worse the credibility of the logical result is→ Statistical Thinking;
- **Soft Real-Time System**
  - There are some tasks that are soft real-time tasks for the system → **Soft Real-Time System;**
  - **For example, multimedia applications etc.**

69

- **Concept Differentiation: which are correct?**
  - Embedded operating systems are not necessarily real-time oper-ating systems, such as μCLinux , Windows XP/E;
  - A real-time operating system is not necessarily an embedded oper-ating system , such as Linux+RT-Linux , Windows+RTX;
  - A real-time system cannot be constructed based on time-sharing operating systems;
  - A system built on a real-time operating system is not necessarily a real-time system, unless the real-time service mechanism is used and the schedulability of the time constraints is guaranteed;
  - Generalized real-time systems are not necessarily embedded systems , for example, real-time systems can be built on PC;
  - Embedded systems are not necessarily real-time systems, such as mobile phones, routers / switches, medical devices, etc..

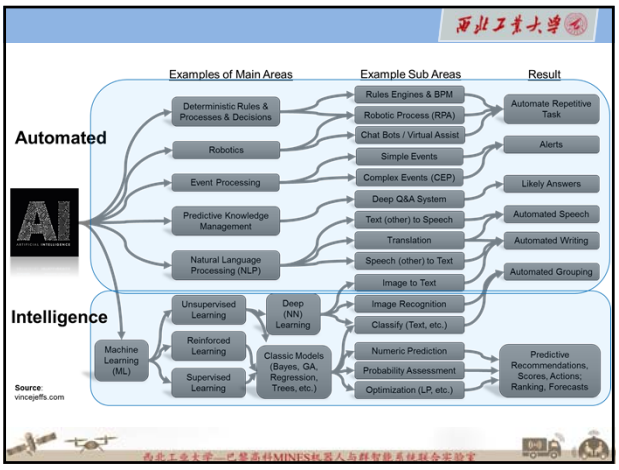
70

# Part IV: About Intelligence

71

- **The process from sensation to memory to thought is called "wisdom" . The result of wisdom produces behavior and language, and the process of expressing actions and language is called "ability", the combination of them is called intelligence;**
- **Intelligence is a process of combining the smart and the ability;**
- **Information domains: Self-Adaption, Autonomy, Intelligence, Evolution …**

72

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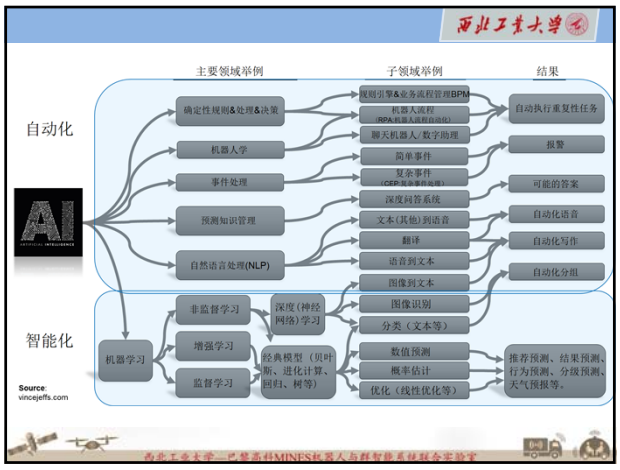
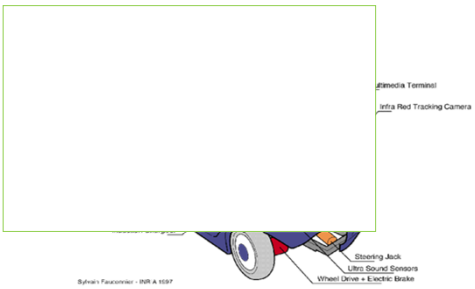



74

## What is an intelligent embedded system?



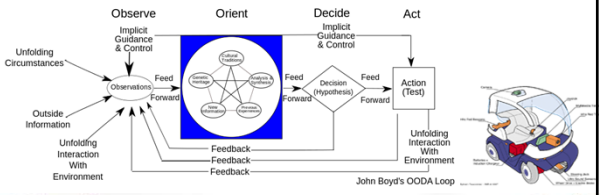

75

## • What is an intelligent embedded system?

- It is a new embedded application system with the autonomous ability, and it is the advanced form of embedded system development;
- Connotation: On the basis of embedded system technology, through the deployment of **intelligent hardware** and **software**, the computing system can "more" complete the device running environment awareness, judgment, decision-making and adaptive control;
- Embedded software is the soul of intelligence!
- Different field applications have different "intelligent" features, and the corresponding theories and techniques are different.

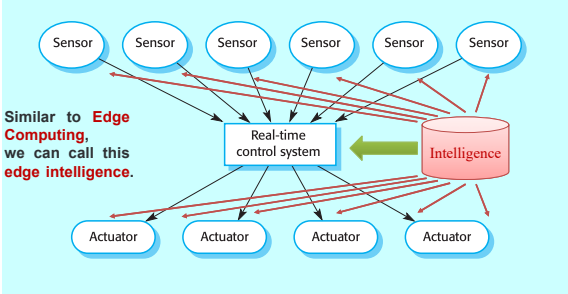
76

- The realization of intelligent ability, relying on the embedded computing system, often using closed-loop intelligent process **"perception – judgment – decision-making – actuate "** →The early stage was mainly "Applied Intelligence" technology ;
  - For example: the OODA Loop (包以德循环): observe (观察) 、orient (调整) 、decide (决策) 和act (行动)



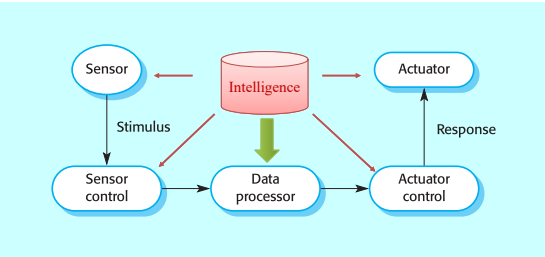

77

## Real - Time Intelligent System Model




78

## Sensor/Actuator Processes

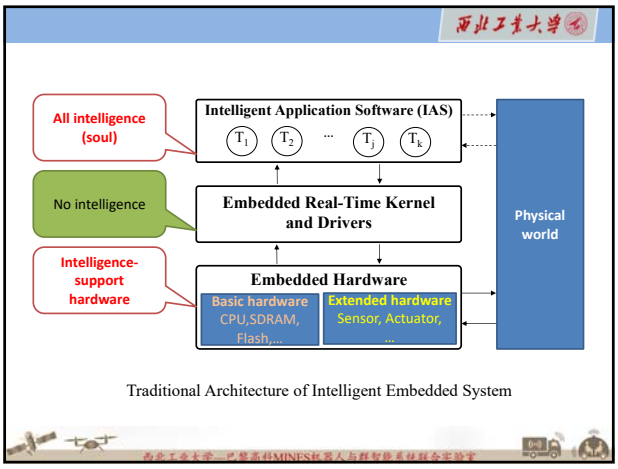



79

## • Application Intelligence

- **Objective**: Providing some kind of automation and intelligence for a specific application.
- **Related techniques**
  - Integrated sensing technology;
  - High performance embedded computing technology;
  - Pattern extraction and recognition;
  - Real-time intelligent processing and control method;
  - Communication and networking technology;
  - Optical Electromechanical Integration ,Micro-Electro-Mechanical System(MEMS) technology, etc.
  - Biotechnology …

80

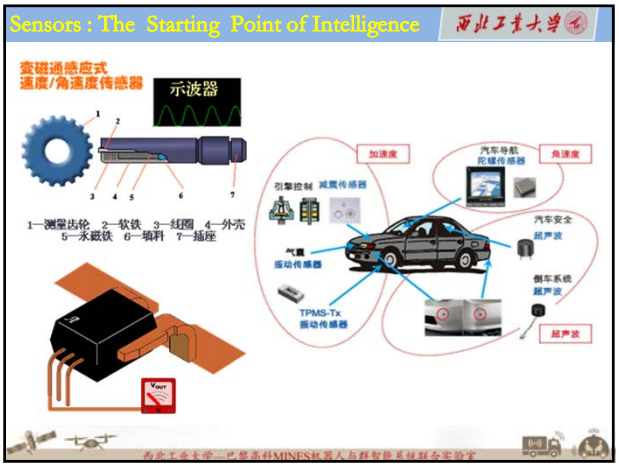



Traditional Architecture of Intelligent Embedded System

81

- **Computation intelligence**
  - Architecture
  - Evolvable Hardware
  - Polymorphic Hardware
  - Polymorphic Adaptive Software
  - Service Middleware
  - Collaborative Computing…

82

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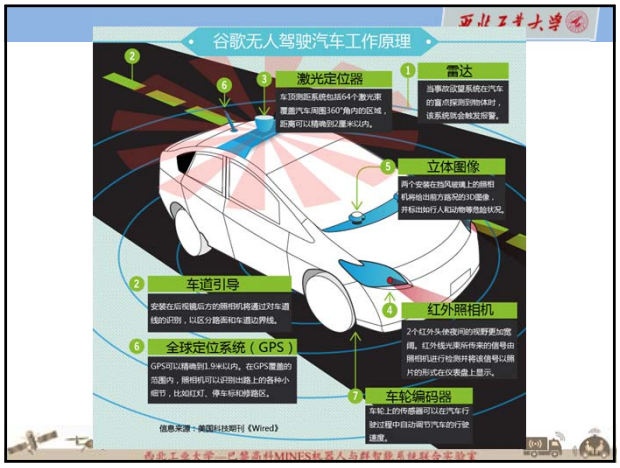


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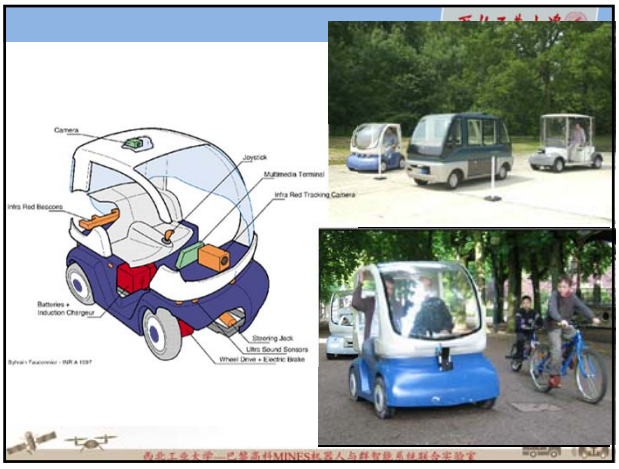


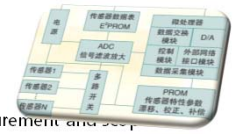

85

- Intelligent Sensor(**智能传感器**)


86

– **Function**
  - Information storage and transmissior
  - Self compensation and calculation fu
  - Self checking, self calibration and self function
  - Compound sensing functions
  - Integration of intelligent sensors

– **Characteristic**
  - Improve accuracy
  - Improve reliability
  - Improve cost performance
  - Adaptive capabilities for measurement and application



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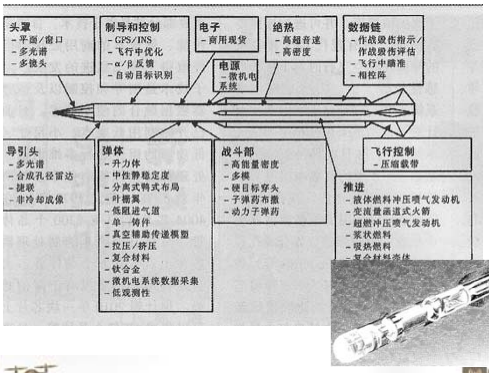
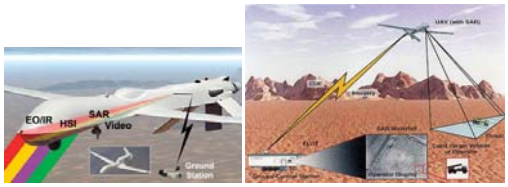


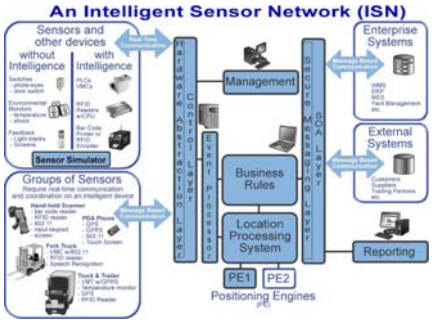

88

– **Multi-Sensor Data Fusion**
  - A large scale HPEC 6000 signal processing system with dozens of PowerPC 8640D/8641D processors based on RapidIO technology, can meet the data processing and data fusion of large UAVSAR, radar, photoelectricity, infrared, hyperspectral imaging and ground multi-target detection.



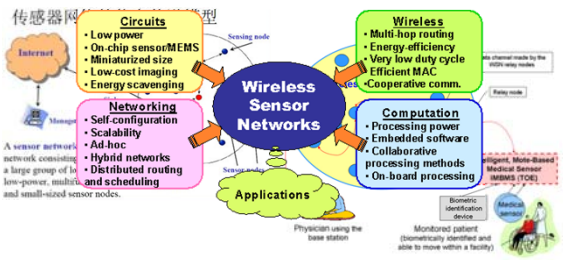

89

– **Intelligent Sensor Network(ISN,智能传感器网络)**




90

– **Wireless Sensor Networks(WSN,无线传感器网络)**

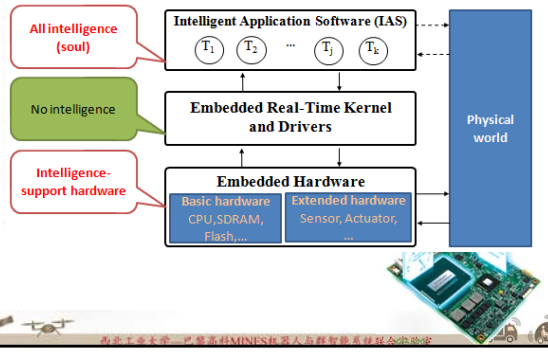



91

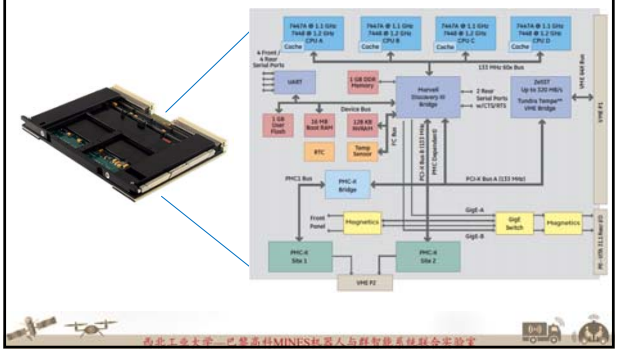
Hardware: The Foundation of Intelligence

92

- **Design with embedded microprocessor(MPU、MCU、DSP、FPGA、SOC etc.) as the core;**




93



94

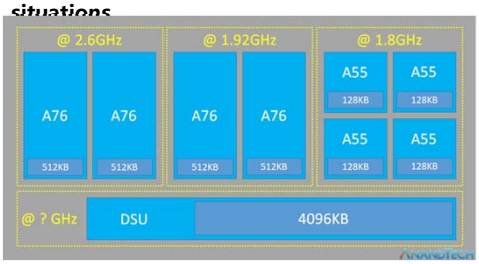
- **The new demand for computing platform of "intelligent application"**
  - The application of the intelligent capabilities need to be achieved through the embedded computing system;
    - **High performance**: PowerPC, Cortex-A76...
    - **AI capability**: NPU (Huawei, Apple, Qualcomm)
    - **Hybrid**: in the Kirin 980, there are CPU、GPU、NPU etc.
    - **Adaptive organization** of resources.

95

The Kirin 980 Features ARM's Mali G76MP10 GPU, A New ISP, And A Dual NPU That Promises A 134% Improvement In AI Performance


96

- **Big-Little Cores**
  - **Different GHz, Different types, Different numbers of active Cores, for different situations**

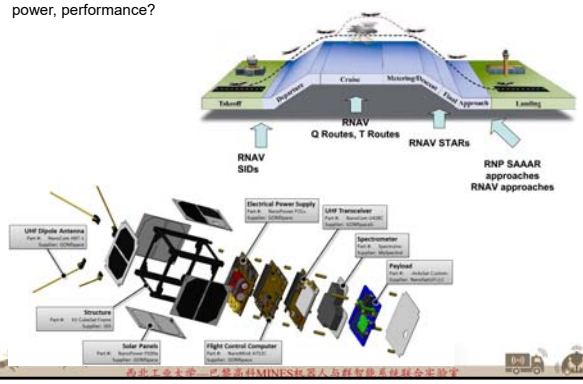



97

- **Current Research Methods and Trends**
  - The mechanism of adaptive control, evolutionary computation and intelligent decision are deployed in the system platform, which provides the platform resource construction and processing for the ability of self- management and match the current computing hotspot;
  - The internal state of the platform + The state of the physical world→ the **Universal environment**.

98

If at different stage, different situation, only require different functions or performance, how to weigh the balance between resource supply and the weight, power, performance?




99

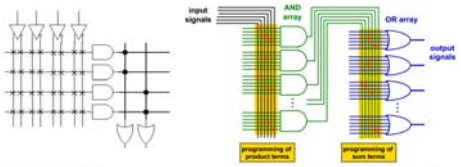
## Colorful Hardware

**----that changes during run-time**

Further complexity arises from the introduction of ***heterogeneous processing units*** that feature more than one type of processing resource. Not only the borders between CPUs, DSPs and (recently) GPUs are blurring, but also the arrival of **reconfigurable computing units** (FPGAs, reconfigurable processors) in the embedded domain has increased the need for effective and efficient design, analysis and verification methods. Whilst many advances have been made in the area of compilers/synthesizers of individual processing resources (e.g., auto-vectorization on CPUs, inference of target-specific components on FPGAs), there is still a lack of support for heterogeneous design flows, especially in the real-time domain.

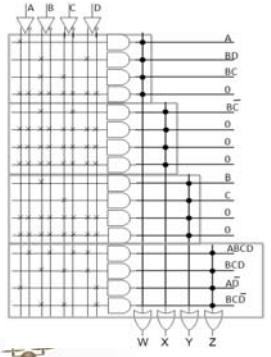
100

- **Reconfigurable Logic（可重构逻辑）**
  - **PAL (Programmable Array Logic)**
    - A programmable AND array and a fixed OR array, each OR gate of the OR array acquires input from a group of AND gates;
  - **PAL (Programmable Logic Array)**
    - There is not only a programmable AND array, but also a programmable OR array;
    - The AND array is used to implement the product of the SOP (Sum of Product) expression , and the OR array is used to sum the product terms.




101

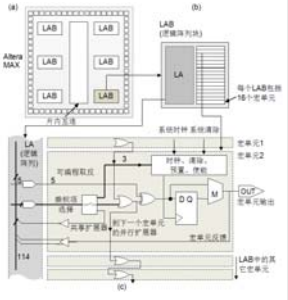
A 4 Bit BCD-Grey Decoder Based on PAL




$$\begin{cases} W = A + BD + BC \\ X = B\overline{C} \\ Y = B + C \\ Z = \overline{A}\,\overline{B}\,\overline{C}D + BCD + A\overline{D} + \overline{B}C\overline{D} \end{cases}$$

102

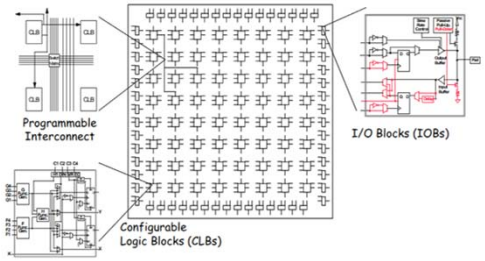
- **CPLD**
  - It is a programmable device with PLD as a macro unit and having a greater number of more complex gate circuits;
  - Within the CPLD, a number of logical block macro cells similar to PAL and PLA are connected through a programmable connectivity and provide an external interface through a configurable I/O control block.




Note: Figure (a) is the chip flatness, Figure (b) is a logical array of blocks (LAB) , Figure (c) is the macro unit internal logic
Figure 3.20 The Architecture of Altera MAX CPLD Series

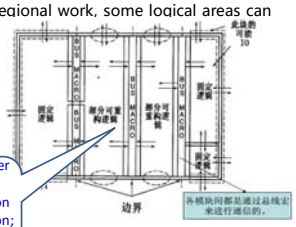
103

- **FPGA（Field Programmable Gate Array）**
  - Xilinx FPGA--Field Programmable Gate Array Based on RAM




104

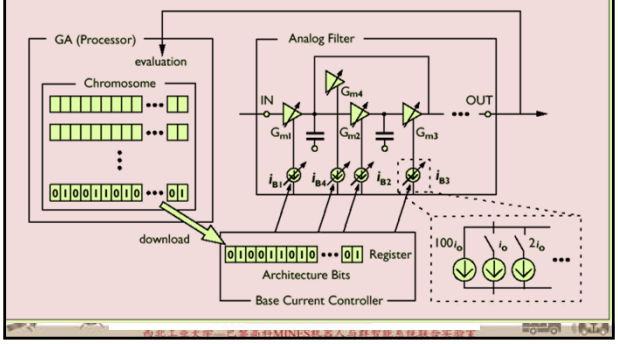
- **Dynamic Partial Reconfigurable Logic(动态局部可重构逻辑)**
  - The on-chip capacity increases, the wiring of the chip is more difficult, and the damage rate of FPGA increases;
  - When logic is complex, it takes more time to reconstruct all of its circuits;
  - In the case of other regional work, some logical areas can be reconstructed;




•Local operations do not affect other logical operations during runtime;
•Reduce the scale of circuit construction and improve the efficiency of construction;
•It can flexibly support the dynamic changes in application requirements.

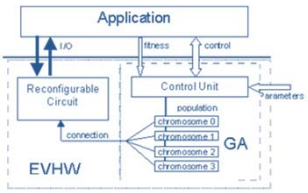
105

- **Evolvable HardWare(EHW) vs. Reconfigurable Logic**
  - Based on the evolutionary algorithm (genetic algorithm, genetic programming and evolutionary strategy) and the development of programmable logic




106

– **Application-Adaptive Logic Evolution**
  - Application requirements are switched with the scene ➔ Circuit logic needs to evolve
  - Function Switching, Migration
  - The Fault-Tolerant of Fault Logic
  - Performance Optimization

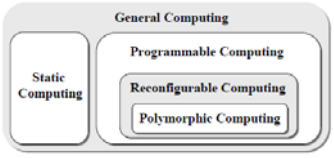



107

- **Polymorphic Computing vs. Reconfigurable Logic**

Improve resource utilization, optimize calculating efficiency, and improve fault-tolerant capability, etc.

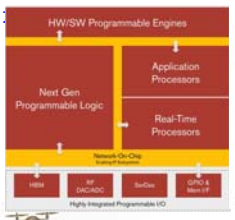
– (*Improve Calculation Performance in Parallel*)

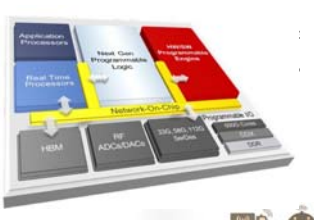



108

## Adaptive Compute Acceleration Platform
## 自适应计算加速平台

- 自适应和智能计算的全球领先企业赛灵思公司（Xilinx, Inc.），2018宣布推出一款**超越 FPGA 功能的突破性新型产品ACAP**（Adaptive Compute Acceleration Platform，自适应计算加速平台）。
- ACAP是一个高度集成的**多核异构计算平台**，能根据各种应用与工作负载的需求从硬件层对其进行灵活修改。可在工作过程中进行动态调节的自适应能力，实现了CPU与 GPU所无法企及及的性能与性能功耗比。
-



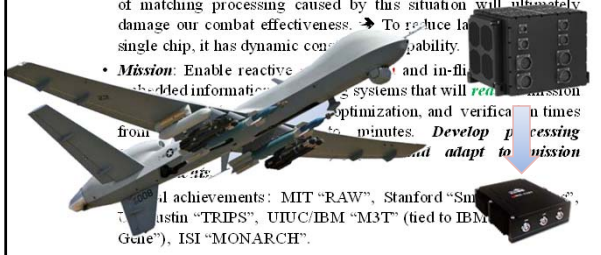



109

– **PCA: Polymorphic Computing Architecture**

DARPA

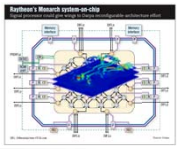
- **U.S. DARPA**: The static method lacks the diversity required for dynamic tasks, the performance degradation or poor performance of matching processing caused by this situation will ultimately damage our combat effectiveness. ➔ To reduce la… single chip, it has dynamic con… pability.
- ***Mission***: Enable reactive … and in-fli…
  …added informati… systems that will *red*… mission …optimization, and verifica… times from … minutes. ***Develop p…cessing … adapt to …mission …ity***



…l achievements: MIT "RAW", Stanford "Sm…", …astin "TRIPS", UIUC/IBM "M3T" (tied to IBM …Gene"), ISI "MONARCH".

110

– Raytheon MONARCH(Morphable Networked Micro-Architecture,形变网络微架构)
  - The world's first adaptive polymorphic computer;
  - Multiple microprocessors form a computer array through a high degree of interconnection;
  - It can simultaneously optimize the foreground signal processing, background control and data processing;
  - High computing power, high data bandwidth, low power consumption, programmable.



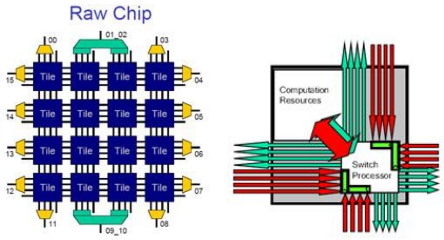


111

– The university of Texas has proposed a ***trillionth computing reliable intelligent adaptive processing system TRIPS***
  - Using grid parallel processing and on-chip sensor system to achieve multi-state system；
  - Each processing core has 16 isomorphic execution nodes and corresponding storage systems . Further more , it has an on-chip sensing system. The hardware can reconstruct itself according to different application software and different load, and realize data level parallelism, instruction level parallelism and thread Level parallel, which is called the polymorphic system;
  - The task of compiling and operating systems is new and complex.

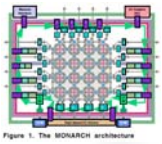
112

– **The RAW Architecture of MIT**
  - A RAW processor consists of 16 programmable Tiles. Each Tile has its own microprocessor, data cache, memory, and interconnected network interfaces that connect to each Tiles;




113

- **High-Performance Polymorphic Embedded Hardware**
  – New Dynamic Local Reconfigurable FPGA Chip , Xilinx V5；
  – UC Berkeley's GARP research program, which aims to integrate reconfigurable computing units with common RISC processors into a single chip to improve processing power;
  – MIT's Professor Ethan *et al.* designed the on-chip reconfigurable structure MATRIX, its on-chip logical interconnect structure can be statically configured or dynamically switched;
  – CMU's Godstei *et al.* carried out the Reconfigurable Computing Research Program PipeRench, the design introduces a pipeline reconstruction technology;



114

– The university of Texas released a multiform microprocessor architecture called Trips(A reliable intelligent adaptive processing system for trillions of calculations per second);
– Nvidia uses the Kepler architecture in the new GPGPU to support the dynamic allocation of the kernel resources and the construction of architecture.

115

- **Many-Core Processor and Parallel Computation Technique**


116

## Software: The Soul of Intelligence

117

- **Functional Attributes**
  - **The Realization of Intelligent Ability**
- **Non-Functional Attributes**
  - **Real-Time Performance Assurance**
  - **Enhancement of Reliability, Safety and Robustness**

118

## （1）Application Software Intelligent Method

- **Field-Oriented and Application-Oriented Intelligent Approach**
  - **Artificial Intelligence Method**
    - Knowledge representation, automatic reasoning and search method, machine learning and knowledge acquisition, knowledge processing systems , natural language understanding, computer vision, intelligent robots, automatic programming and so on.
  - **Knowledge Representation**
    - The basic problems of artificial intelligence, reasoning and search are closely related to the presentation method;
    - **Common method** :logic representation method , production representation method , semantic network representation method , frame representation method , etc.

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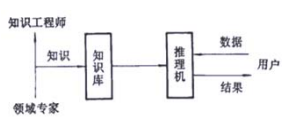
- **Automatic Reasoning and Search Method**
  - Problem solving depends on the knowledge representation method;
  - Based on deductive reasoning of predicate logic, inheritance performance reasoning under structured representation (non - deductive reasoning);
  - The search strategy determines the priority relationship in which knowledge is used in a reasoning step when solving a problem;
    - Blind search without information guidance
    - Heuristic search based on empirical knowledge guidance

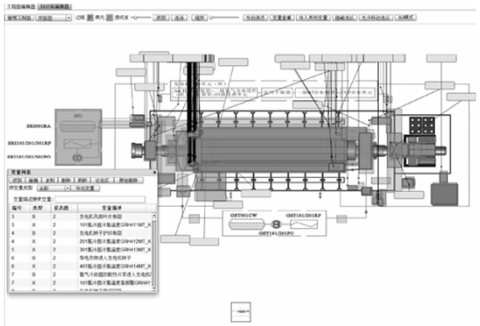
120

- **Knowledge Processing System**
  - It consists of knowledge base and inference engine;
  - If the knowledge base is stored in a domain of expert knowledge (such as medical diagnosis), then called the knowledge system for the **expert system.**
  - To meet the need to solve complex problems, a single expert system develops toward a multi-agent distributed artificial intelligence system, then knowledge sharing, collaboration among between the agent, the emergence and treatment of contradictions will be the key issue.




121

Intelligent Expert System for Nuclear Power Plant--Knowledge Base System of Generator Fault



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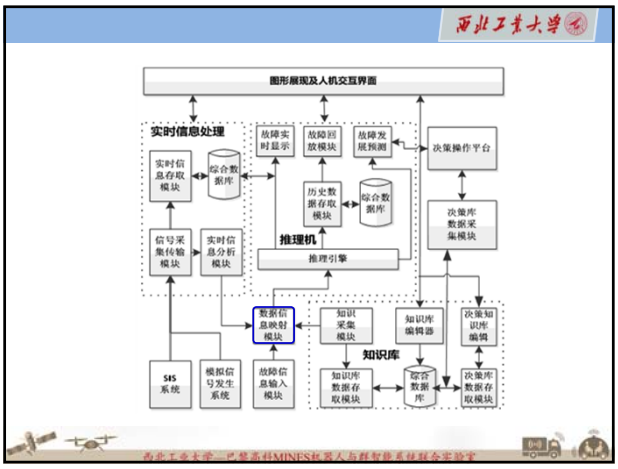
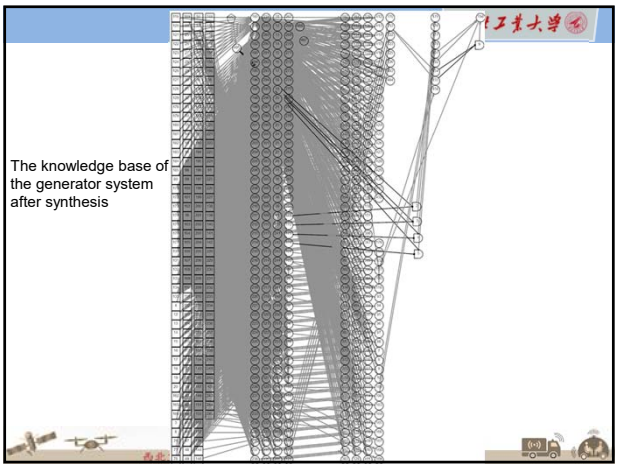



123

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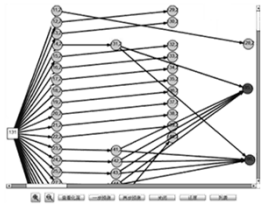
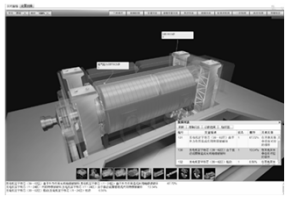


Two-step prediction of the failure development

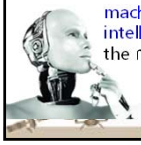


The fault diagnosis results are located in the engineering drawing.

125

– **Machine Learning** Another important subject of artificial intelligence;

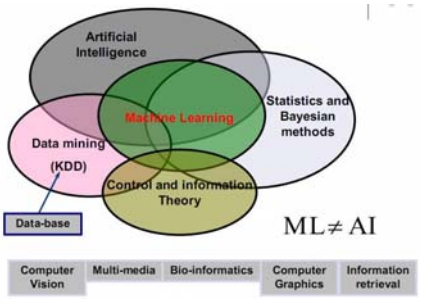
- Machines produce **self-learning** , just as : If you put the child in the car, let him observe the outside world from the window, he will see a variety of vehicles, and no one tell him what these objects are. He is through their own observation to summarize the similar things.
- Alan Turing(艾伦·图灵), the father of computer science, defined the artificial intelligence in 1950 as follows : Suppose you are chatting with some entity via a text chat session. Could you tell, solely from the conduct of the session, whether the other entity was a human or a machine ? If not, then that entity is judged to be intelligent. **The fresh idea of machine learning** is to let the machine think like the human brain.



126

- It refers to the process of acquiring new knowledge under certain knowledge representation, which includes inductive learning, analytical learning, connection mechanism learning and genetic learning according to different learning mechanisms;
- **Deep-learning** is a new field in machine learning research. Its motivation lies in the establishment and simulation of the human brain to analyze and study the neural network, and then imitate the human brain mechanism to explain the data, such as images, sounds and text.

127




128

– **Natural Language Understanding/ Human-machine Conversation**
  - Research can achieve the various theories and methods of effective communication between people and computers in natural language.
  - Since the 1960s, mainly about speech recognition , and by the middle of 70s,there was a breakthrough;

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- Beginning in the 1990s, it is mainly for dealing with large-scale real text, large-scale real corpus development. And large-scale, information-rich dictionary preparation work began to enhance;
- Microsoft Skype Translator ——Simultaneous interpretation

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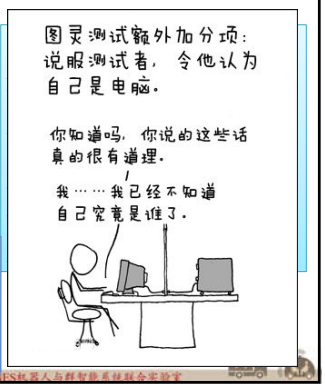
（On June 10, 2014, the computer of the University of Reading passed the "Turing test" for the first time by "posing" as a 13 years old boy.）

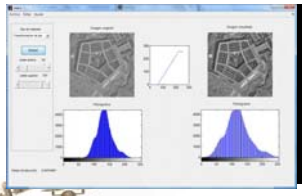
Chatbot "Eugene Gustman""


Q:Do you play chess?
A:Yes.
Q:Do you play chess?
A:Yes , haven't I told you that?
Q:Please answer again. Do you play chess?
A:You are too boring! Why do you always ask the same question?




131

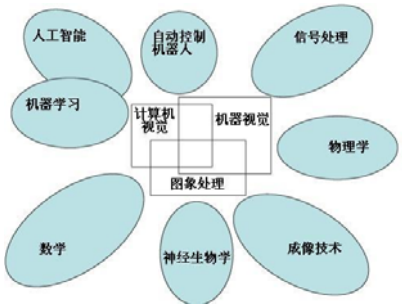
– **Computer Vision**
  - Using machine vision, such as using cameras , computers etc. instead of human eyes to identify, track and measure objects , based on further image processing, using computer processing to make it become an image which is more suitable for human eye observation or make it an image transmitted to an instrument.



132

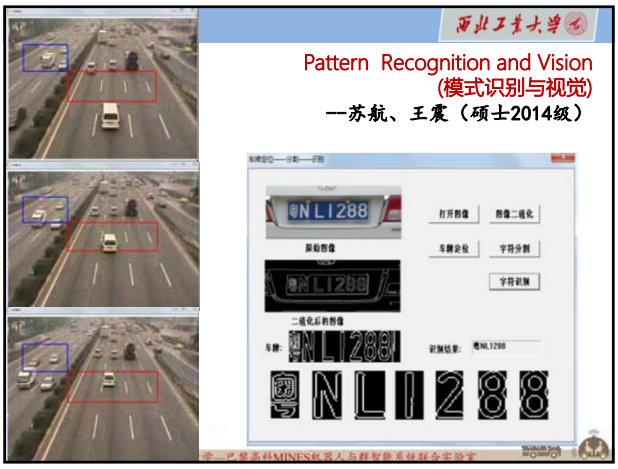
- Researching relevant theories and techniques, and attempting to establish artificial intelligence systems that can obtain "information" for decision - making from images or multidimensional data;
- It is closely related to image processing, machine vision, pattern recognition, image analysis and other techniques , and can be used for 位置/姿态辨识, object recognition, and special content discovery.

133




The relationship between computer vision and other fields

134




135

- **Artificial Intelligence Control**
  - **Neural Computation**
    - Artificial neural network , Knowledge Representation and Reasoning Based on Neural Network
  - **Fuzzy Computation**
    - Fuzzy Sets , Fuzzy Logic and Its Algorithm
    - Fuzzy Logic Inference
    - Fuzzy Judgment Method
  - **Genetic Algorithm**
  - **Artificial Life**
  - **Particle Swarm Optimization**
  - **Ant Colony Algorithm**

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- **Affective Computting(情感计算)**


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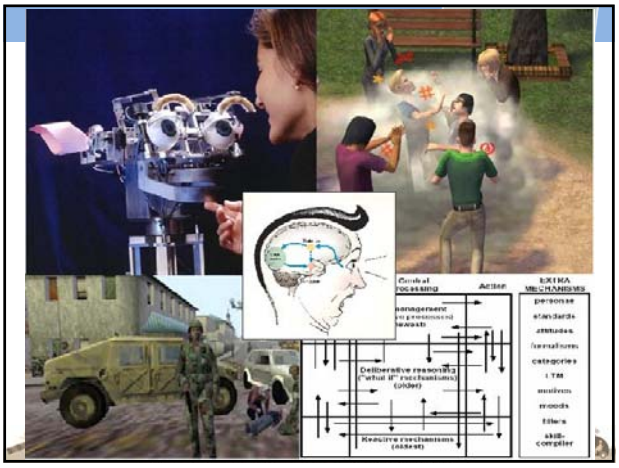

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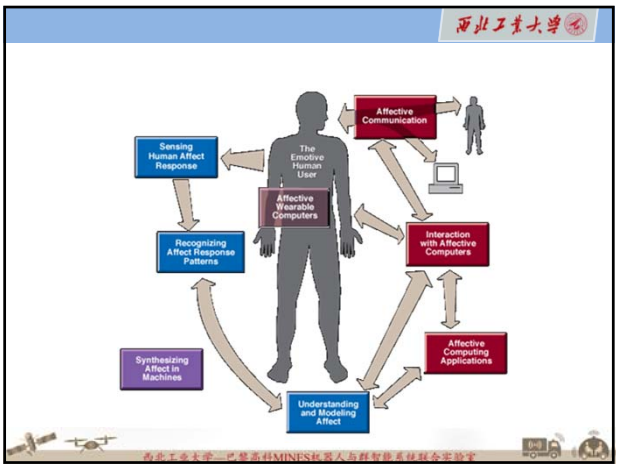


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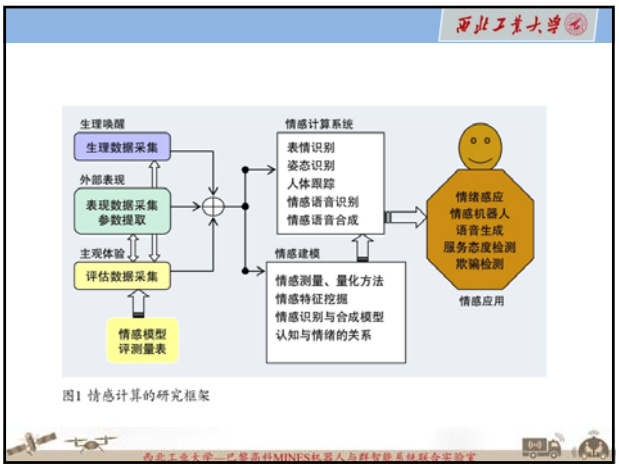
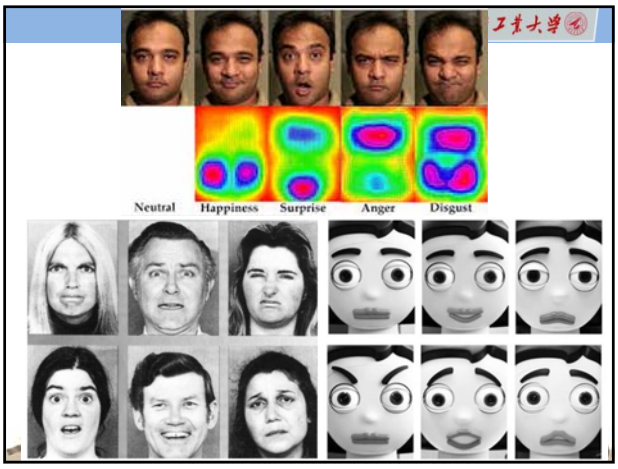



图1 情感计算的研究框架

140

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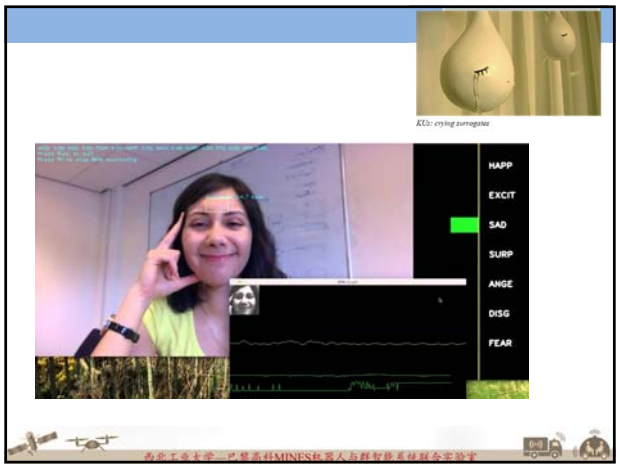


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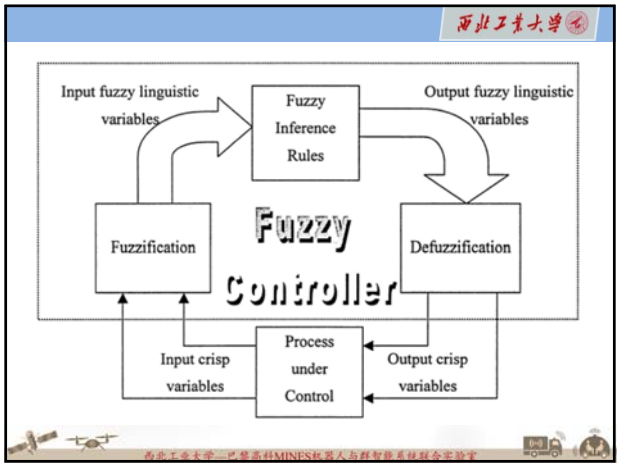


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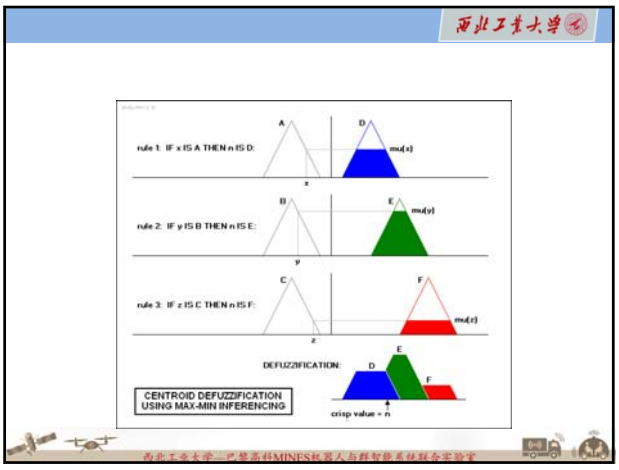
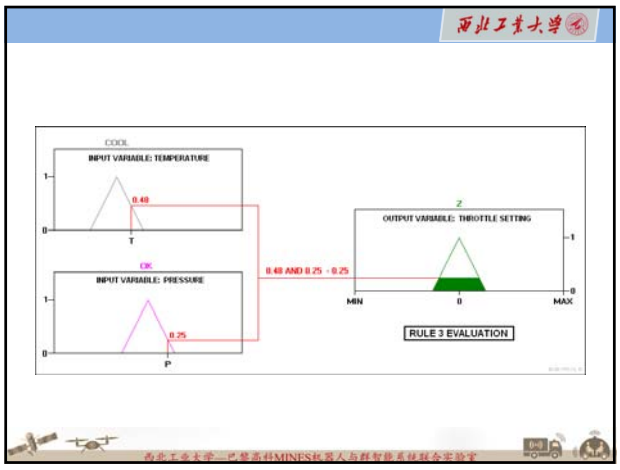
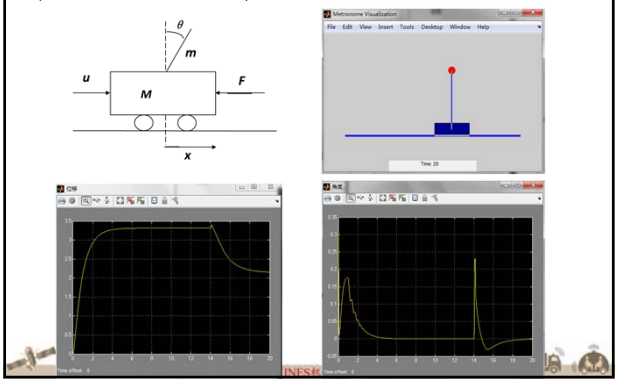



145

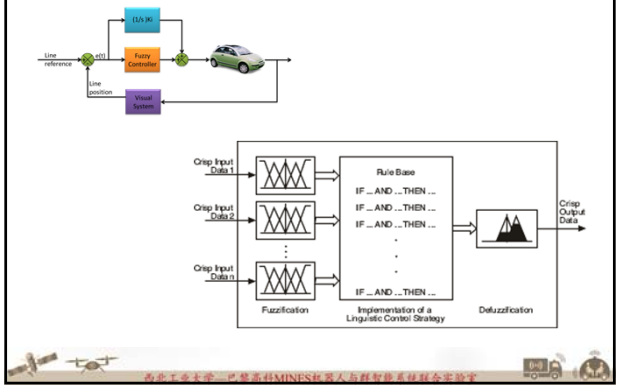



146

Design of Fuzzy Controller for First-Order Inverted Pendulum
(一阶倒立摆模糊控制器设计)——杨安胜、王九州（硕士2014级）




147




148

– **The Evolution of Fuzzy Control**
  - Fuzzy-PID Compound Control
  - Adaptive Fuzzy Control
  - Parameters Self-Tuning Fuzzy Control
  - Expert Fuzzy Controller(专家模糊控制EFC)
  - Human Simulating Intelligent Fuzzy Control
  - Neuro-Fuzzy Control(神经模糊控制)
  - Multivariable Fuzzy Control

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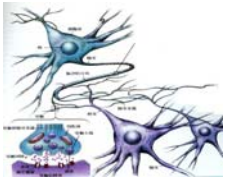
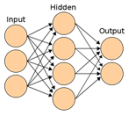
- Artificial Neural Network(ANN,**神经网络** )
  – A mathematical model or a computational model that mimics the structure and function of a biological neural network, a nonlinear statistical data modeling tool, commonly used to model the complex relationships between input and output;






150

– The ANN is formed by the massive nodes (or neuron) and the connection constitution , each node represents a specific output function (activation function) , and the connection between each of the two nodes represents a weighting value for the signal passing through the connection , called the weight, which corresponds to the memory of the artificial neural network.

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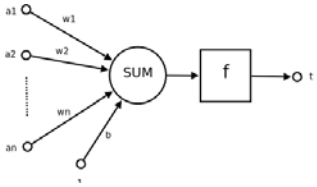


数学表示 $t = f(\vec{W}\vec{A'} + b)$

- $\vec{W}$为权向量
- $\vec{A}$为输入向量，$\vec{A'}$为$\vec{A}$的转置
- $b$为偏置
- $f$为传递函数

•a1~an:the input vectors of various components;
•w1~wn:the weight of each synapse of neurons;
•B:bias;
•F:transfer functions , usually a nonlinear function, generally there are traingd (), tansig (), hardlim ();
• t:the output of neurons

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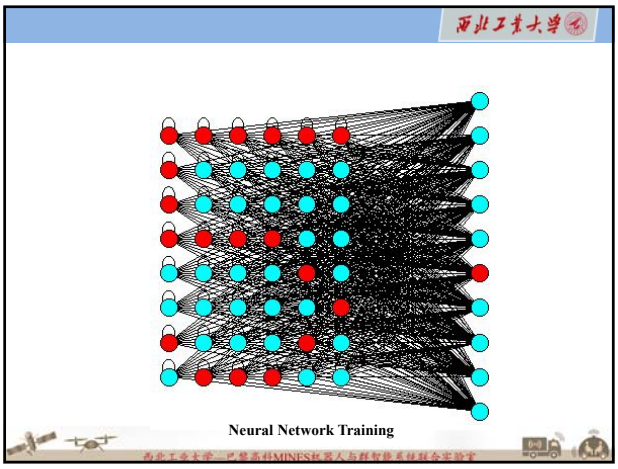
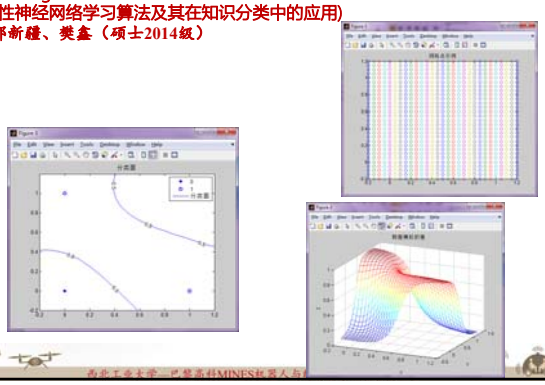



153

Linear Neural Network Learning Algorithm and Its Application in Knowledge Classification
(线性神经网络学习算法及其在知识分类中的应用)
--邢新疆、樊鑫（硕士2014级）



154

- **Evolutionary Computation**
  - It covers successive optimization, combinatorial optimization and so on. It is a global optimization method;
  - It is a general term of genetic algorithm , evolutionary strategies and evolutionary programming;
  - Mainly used in engineering control, machine learning, function optimization and other fields;

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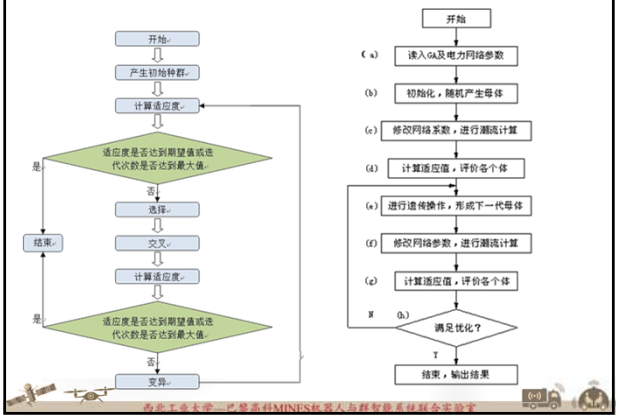
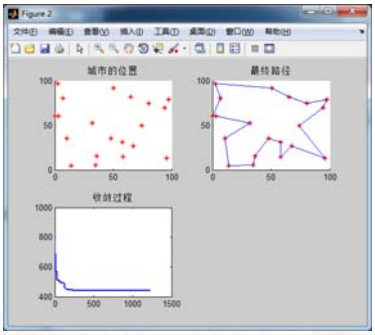



156

Genetic Algorithm for Solving TSP Problem
(遗传算法求解TSP问题)
--常乐、仇建龙（硕士2014级）

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- **Markov Chain and Its Model**
  - **When given the current state, it is conditionally independent of the past state (i.e the historical path of the process), then the stochastic process has Markov property.**
  - **The Markov process with a discrete state is usually called the Markov Chain.**
  - Markov chain describes a state sequence whose every state value depends on the previous finite state. The statistical model is used to describe a Markov process with implied unknown parameters;
  - In the case of a given current knowledge or information , the historical state of the past is irrelevant to predict the future (i.e. the future state after the present period);
  - It is often used to model queuing theory and statistical modeling, and can also be used as signal models for entropy coding techniques, such as algorithmic coding.

$$P(X_{n+1} = x | X_1 = x_1, X_2 = x_2, \ldots, X_n = x_n) = P(X_{n+1} = x | X_n = x_n).$$

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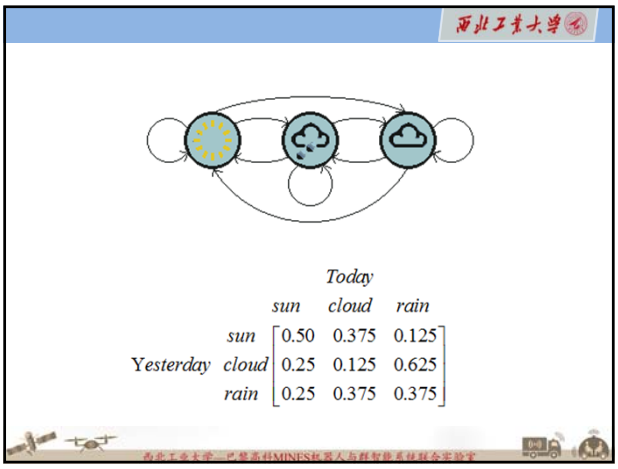
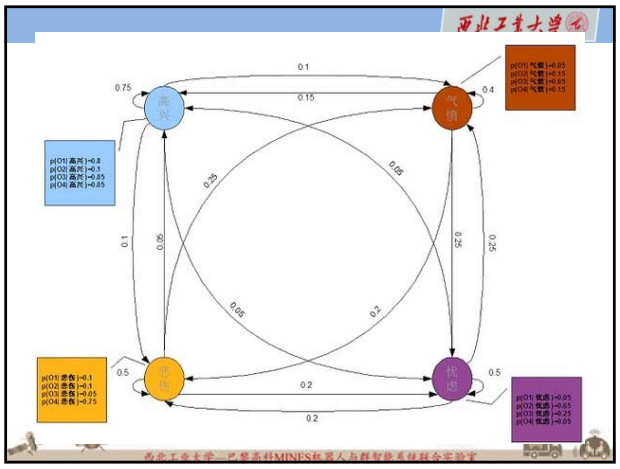


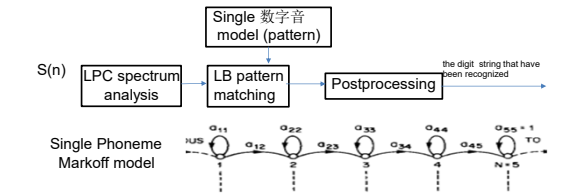
| | | Today | | |
|---|---|---|---|---|
| | | *sun* | *cloud* | *rain* |
| *Yesterday* | *sun* | 0.50 | 0.375 | 0.125 |
| | *cloud* | 0.25 | 0.125 | 0.625 |
| | *rain* | 0.25 | 0.375 | 0.375 |

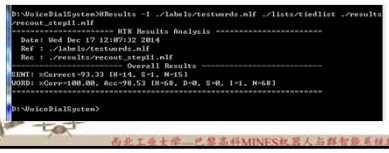
159




160

## Markov Model and Speech Recognition
## (马尔可夫模型及语音识别)
**--周策、曹望（硕士2014级）**



the recognition correct rate of words：100%
identification precision：98.53%
deletion error：0
substitution error ：0
insertion error ：1

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## Typical Methods of Intelligent Embedded System

| Method | Characteristics | Typical Applications |
|---|---|---|
| ANN(人工神经网络) | Unsupervised or supervised (trained) learning ,black-box data processing structure; | Signal calibration , pattern recognition , classification; |
| AFS(模糊神经系统) | Integration of Fuzzy inference rules with neural networks; | Intelligent control, embedded expert system |
| MAS(多智能体系统) | Abstract for multi-agent network, different aspects of cooperation methods are studied according to the application ; | Multi-agent system collaboration , Such as multi - robot, unmanned vehicles, intelligent production line; |
| PCA(多形态计算) | Flexible dynamic architecture and resource management mechanism, dynamic matching of resources and computing hotspots; | Construction of a high-performance adaptive embedded computing system for new complex intelligent systems; |

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| Method | Characteristics | Typical Applications |
|---|---|---|
| GA(遗传计算) | Optimization method especially for large and unstructured search space; | Real-time scheduling , program timing analysis; |
| MC(模型验证) | Automatic attribute verification method for complex systems; | Analysis and verification of system function and non function attribute; |

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Wilfried Elmenreich--INTELLIGENT METHODS FOR EMBEDDED SYSTEMS

| Method | Characteristics | Sample embedded applications |
|---|---|---|
| Artificial Neural Networks | unsupervised or supervised (trained) learning, black-box data processing structure | signal calibration [5], pattern recognition [26], classification [7] |
| Genetic Algorithms | optimization method especially for large and unstructured search space | real-time scheduling [27], program timing analysis [8] |
| Model Checking | automated method for verifying finite state concurrent systems | verifying properties of distributed systems [25] |
| Multi-Agent Systems | distributed system of self-acting programs acting in a network | flexible automated manufacturing [14] |
| Neural Fuzzy Systems | integration of Fuzzy inference rules with neural networks | intelligent control [28], embedded expert systems [29] |

Table 1: Overview on presented methods

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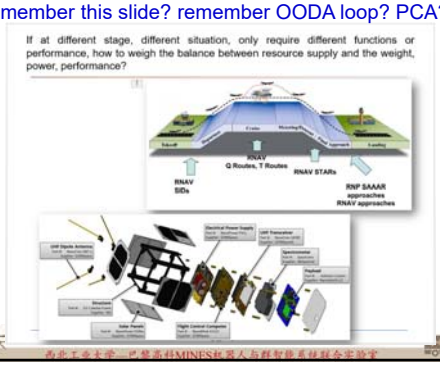
## （2）Intelligent Methods for *System Software*

You remember this slide? remember OODA loop? PCA?...

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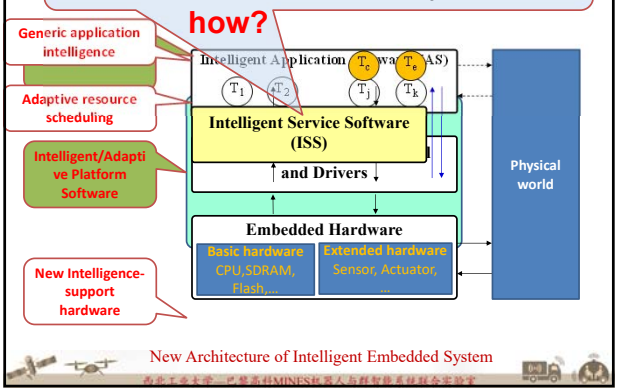
**What should be such intelligent services?**

Adaptive resource scheduling/management, event management, data-distribution, communication, fault-tolerant, load-balancing, …




New Architecture of Intelligent Embedded System

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## An Evaluation of User Satisfaction Driven Scheduling in a Polymorphic Embedded System

A polymorphic system consists of heterogeneous cores such as CPU, GPU, FPGA, and ASIC cores. **A polymorphic thread** is compiled for multiple morphisms afforded by these diverse cores. The resulting polymorphic computing system can solve two problems - **(1) Polymorphic threads enable more complex, dynamic trade-offs between delay and power consumption**. A piecewise cobbling of multiple morphism energy-delay profiles of individual thread morphisms offers a richer energy-delay profile for the entire application. **(2) The OS scheduler not only picks a thread to run, it also chooses the thread's morphism.**

In this work, we propose a scheduler to optimize a class of User Satisfaction Index (USI) functions. We develop a model for a mobile polymorphic embedded system computing platform. We integrate a polymorphic scheduler in this model to assess the application design space offered by polymorphic computing... We further discuss the feasibility of USI-based polymorphic scheduler by identifying its strengths and weaknesses in relation to the application design space based on the simulation results.

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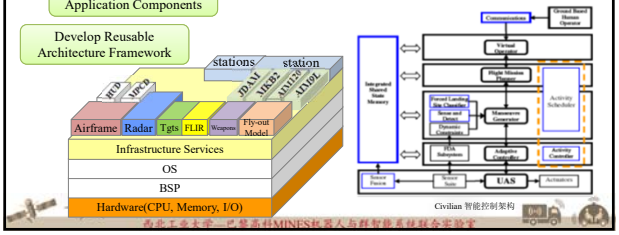
- **Structure of A New Dynamic Computing System**
  - DARPA 's OCP/SEC , DARPA's polymorphic computing architecture (PCA) , Sweden's WITAS , the university of Queensland's Civilian intelligent control architecture and the MOLEN research program at Delft University of Technology in the Netherlands.

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SEC DARPA & AFRL

DARPA

- **OCP: Open Control Platform**
  - **Software Enabled Control Project(SEC) for Intelligent UAV**
  - OCP provides an open, middleware-based software framework and a development platform. And provides the runtime methods, software, and simulation capabilities of multiprocessors and aircraft.
  - Based on the real-time CORBA middleware, it makes the application have nothing to do with the hardware, provides the control of the executing component, the communication between components, and the distribution and deployment of application components in the form of services;
  - The ultimate goal is to create a common environment that can be used for large-scale control system problems.

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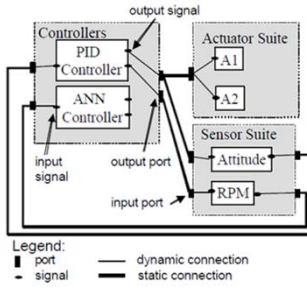


**Figure 3. An Example OCP Component Configuration with Ports and Signals**

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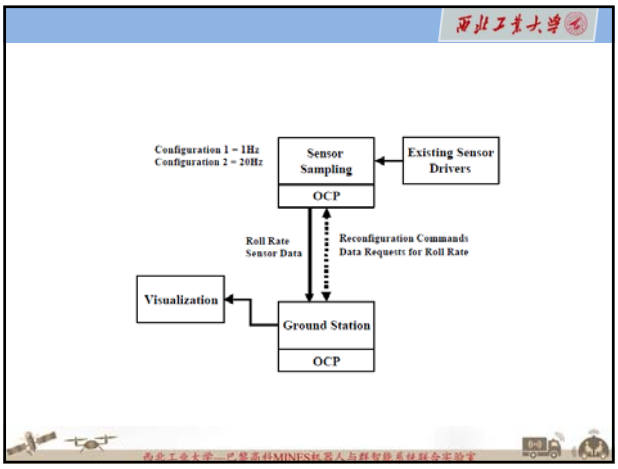


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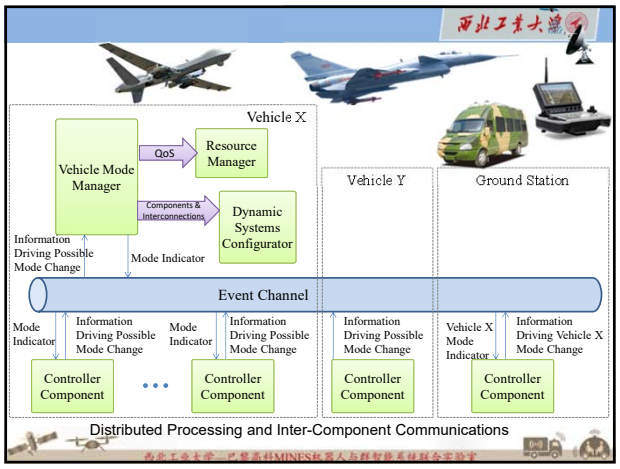


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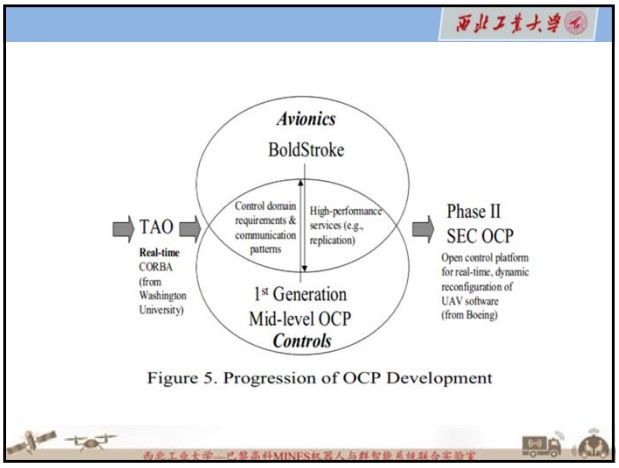


Figure 5. Progression of OCP Development

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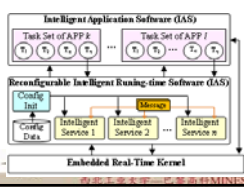
- **Intelligent platform Software Technology**
  - The project SEC, PCA of DARPA , etc. , Service Middle-ware;
  - Polymorphic software model and design, polymorphism decision, environment adaptive task scheduling, resource adaptive management and construction, polymorphism cosntruction;



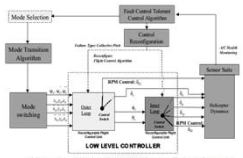




Figure 3. Flight Control Reconfiguration

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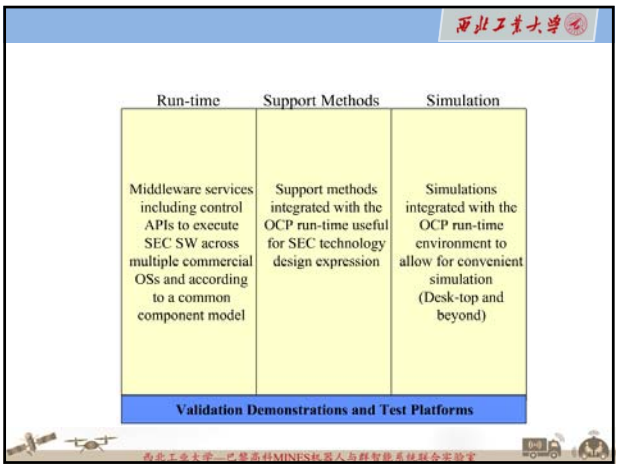


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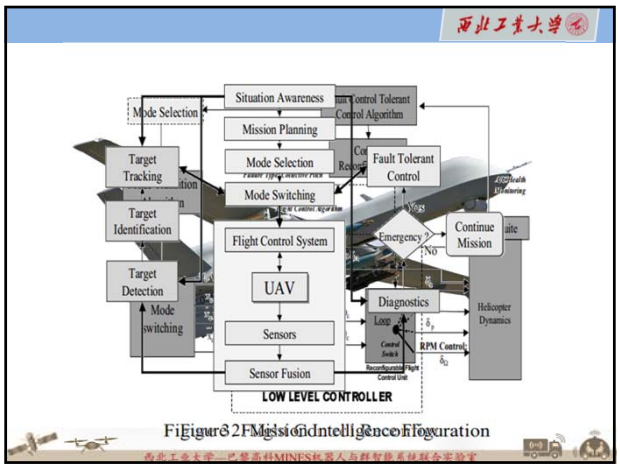


Figure 2 Mission Intelligence Flow

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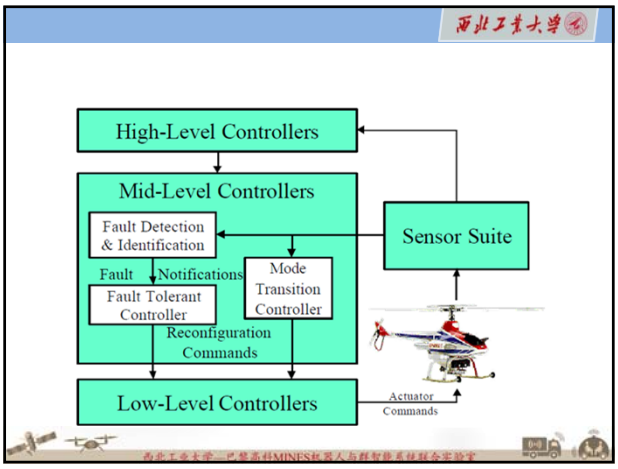


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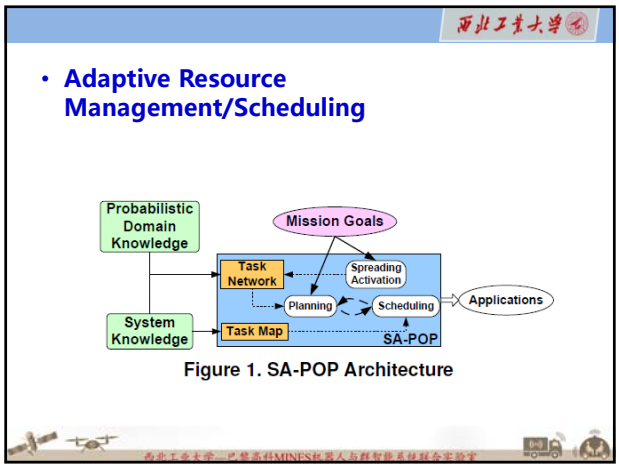


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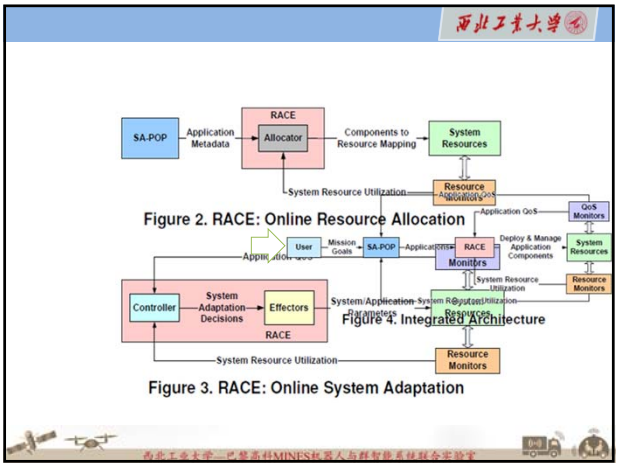


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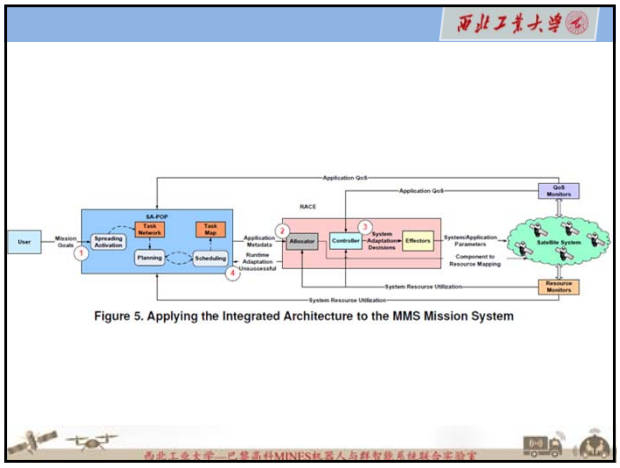


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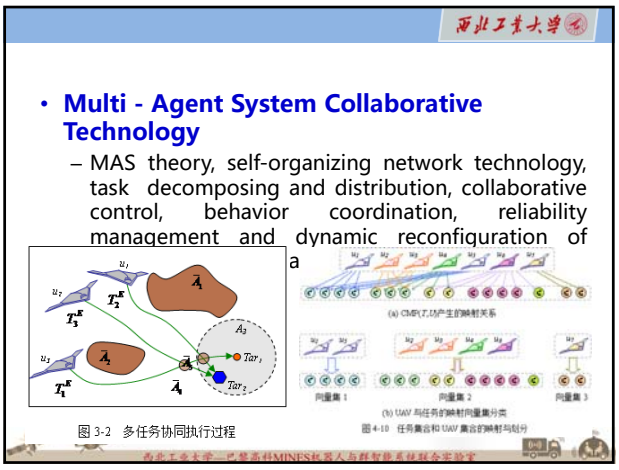


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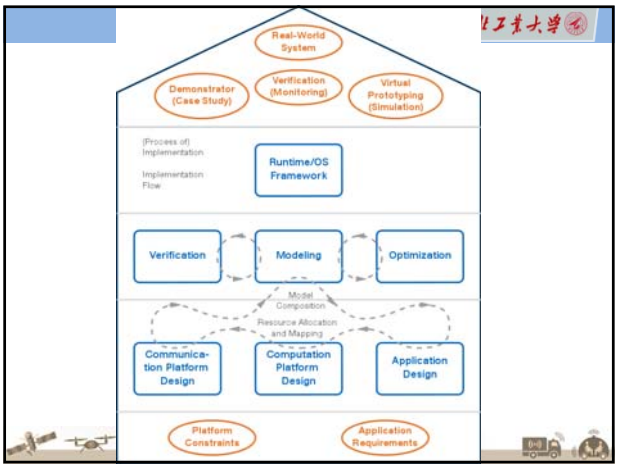


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- ***Synchronous programming languages***

- STATEMATE, **Rhapsody** (ilogix)
- **Rose RT** (Rational)
- **SCADE**, Esterel Studio (Esterel Technologies)
- Stateflow and Simulink (Mathworks)
- **Timed Automata**
- **UPPAAL** Verification Tool
- POLIS (Berkeley), Cierto VCC (Cadence)
- SpecCharts (Irvine)

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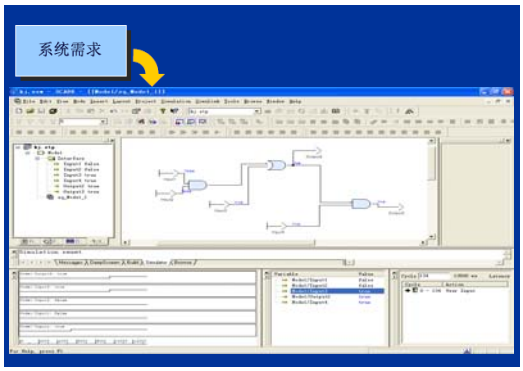


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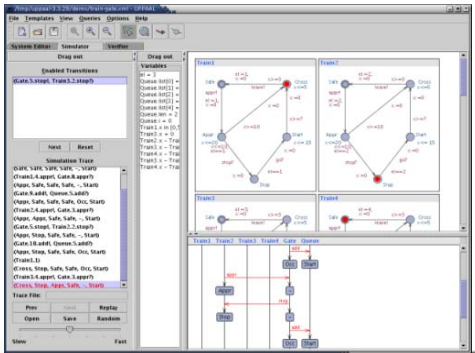

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– **System Design and Verification Method**

- Model system design theory, methods and tools;
- Real-time UML extension —MARTE profile ,the UML Gaspard profile of Inria and university of Burgundy , which is modeling for reconfigurable system, Real-time UML profile of TUT university in Finland;
- The Lockheed Martin Company studies the methods of verification and validation of PCA and verifies it on avionics. The authentication environment READAPT has been developed at present.


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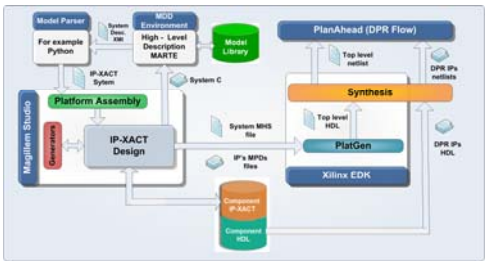


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Simulation: Verification of Intelligence

BUT HOW?

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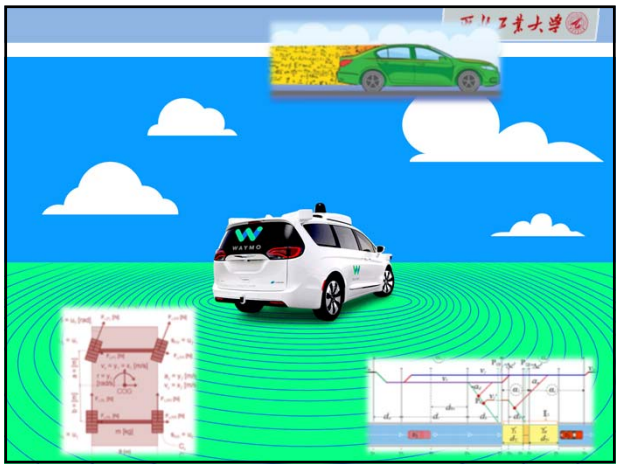

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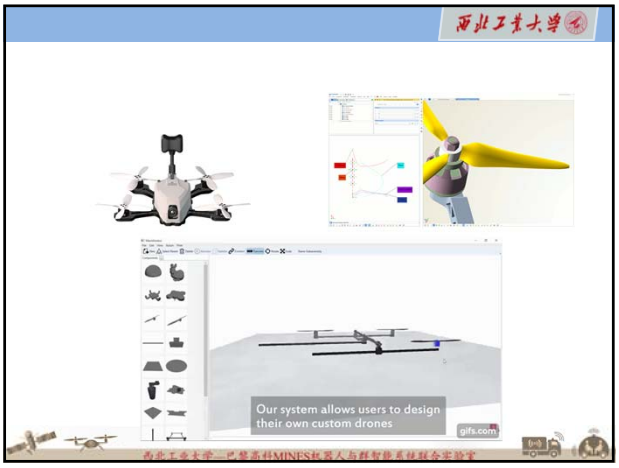


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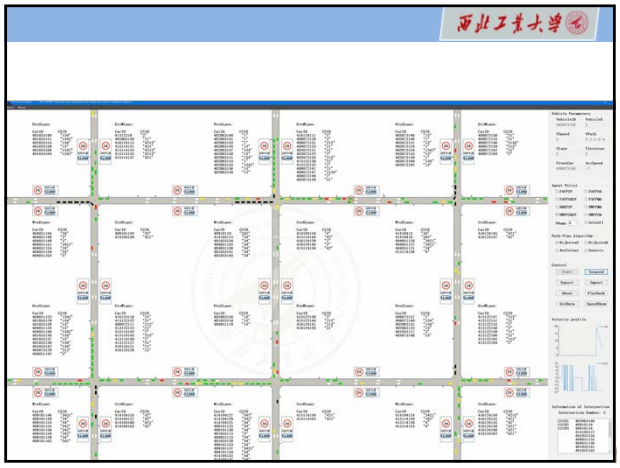

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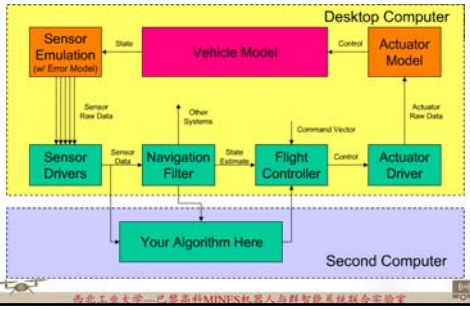
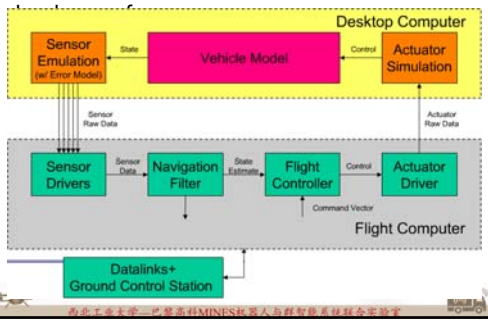
- **Hardware in the loop--second computer**
  - Another form of the previous




193

- **Hardware in the loop**
  - "models + environment simulator" + core

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## How to TEST & TRAIN intelligent vehicles?

**The fact:**

**in the last 9 years,**
**Waymo has been tested in virtual environment, 5 billions miles!**

Test and train in physical world!
Google's Waymo has traveled more than 8 millions miles.
If problems? & how?

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## How to TEST & TRAIN intelligent vehicles?

- **Virtual environment** and **Big data** based test and training is one vital way to verify and train intelligent vehicles!
- **Typical tools**
  - DRIVE PX
  - Dominik Dörr
  - Roberto De Vecchi
  - Pro-SiVIC
  - Pr...
  - ...

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## How to TEST & TRAIN intelligent vehicles?

- **Virtual environment** and **Big data** based test and training is one vital way to verify and train intelligent vehicles!

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## Typical example：UAV + Simulated environment

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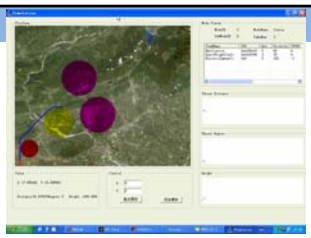

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## Self-Developed Embedded Software and Systems

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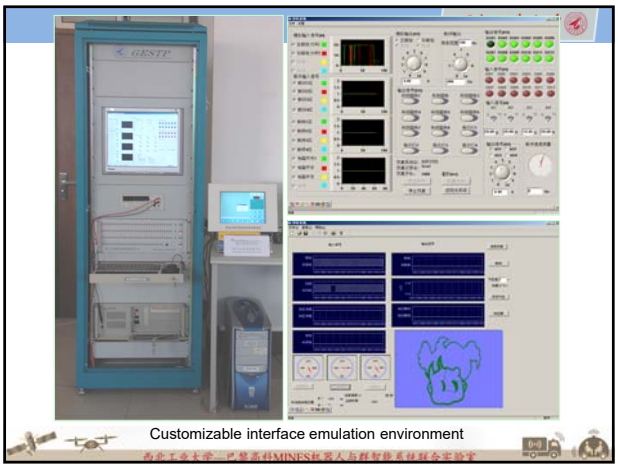


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