数字信号处理(II)
DSP (II)

DSP: Digital Signal Processing

Digital Signal Processor

主讲：杜俊，张结

助教：代宇盛，王景渊

语音及语言信息处理国家工程研究中心智能语音信息处理方向

第0章　绪　　论

1.基本概念

2.DSP(I)基本内容回顾

3.DSP研究动态-Deep Learning

4.现代数字信号处理涉及的范围和**DSP II**的安排

1.基本概念

1)信号

2)信号处理

3)数字信号处理系统

4)DP(Data Processing) VS. DSP

5) Why DSP ?

1.基本概念

1)信号:信息的载体 电信号--》信号

Examples:

• A radio signal carries modulated music and speech.

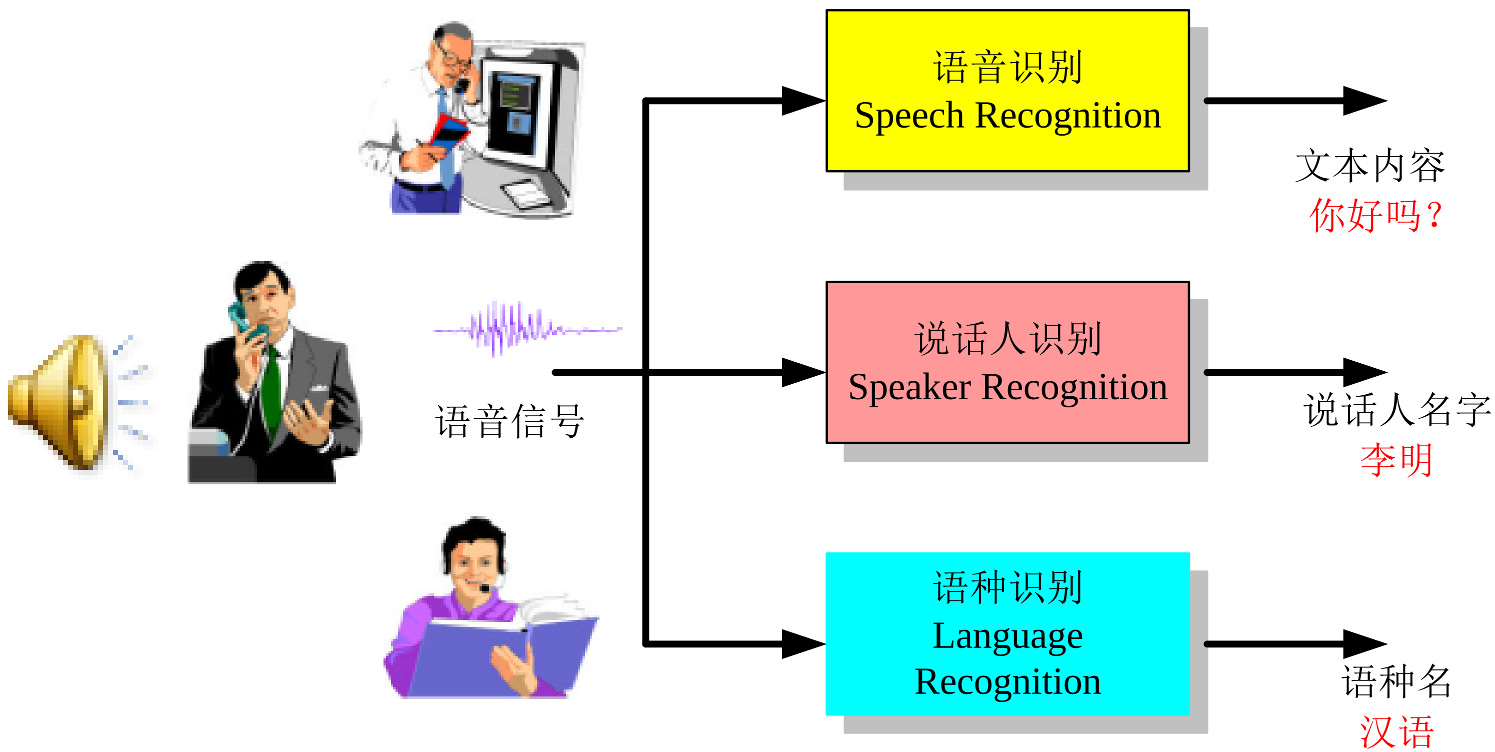
• A heartbeat signal (ECG) contains information about the health of a person’s heart.

• Speech is an acoustic signal that humans use to transmit information to each other.

• A digitized, coded and modulated speech signal carries speech signals.(PCM,Pulse Code Modulation)

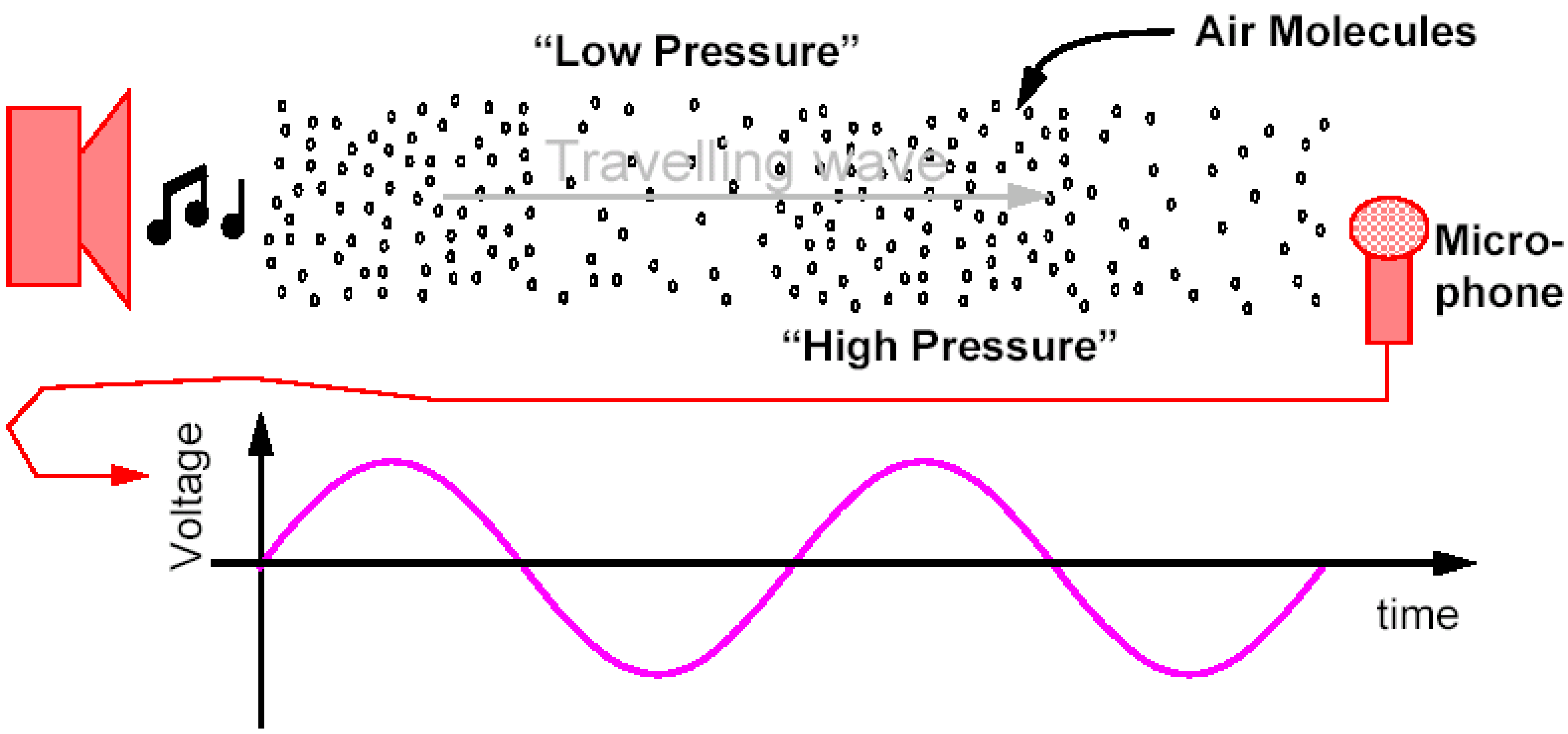
----信号的信息表达的相对性

----信号中包含的信息的多样性：

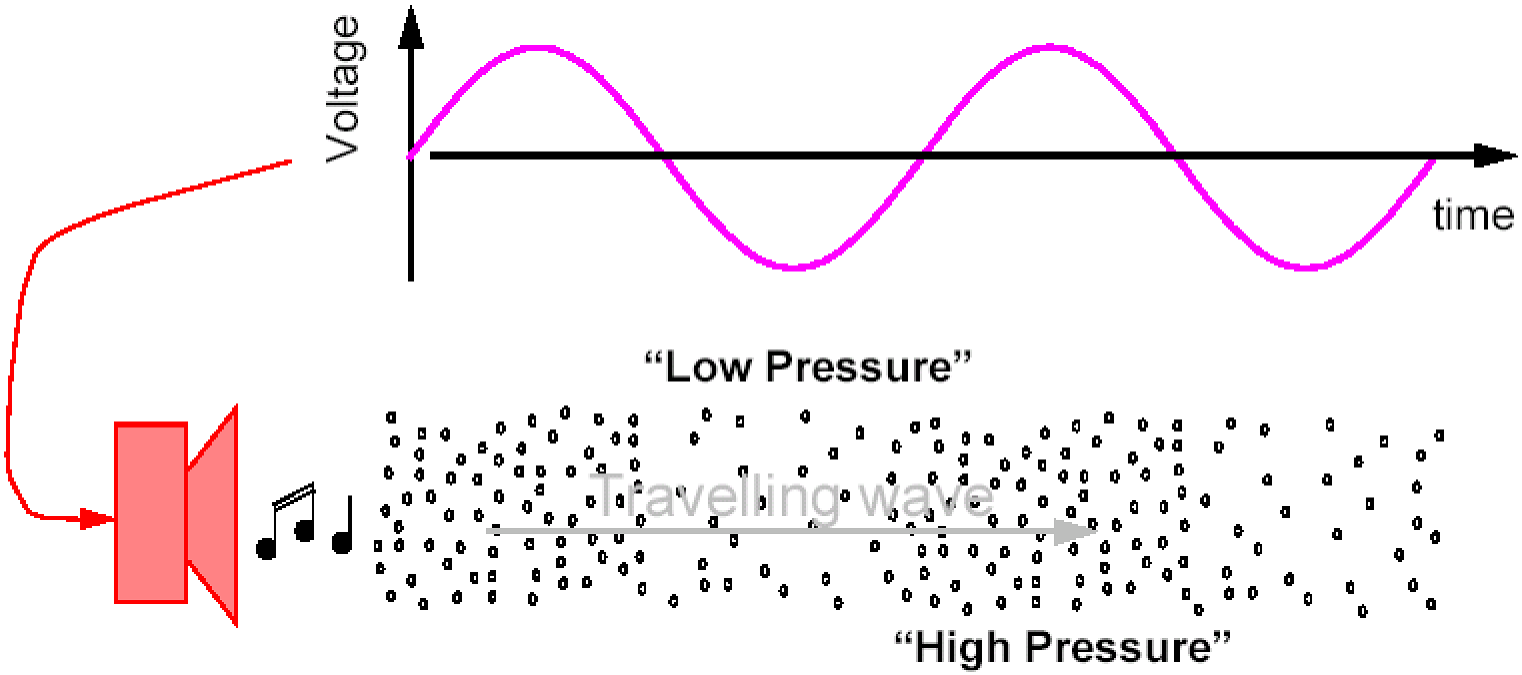


自动语音识别分类图

----电信号与其它形式的信号



----电信号与其它形式的信号



信号分类：取值形式；变化规律；能量特征

- **取值形式—时间与幅度**

模拟信号：时间与幅度均连续

连续时间信号：时间连续，幅度连续或离散

离散时间信号：时间离散，幅度连续或离散

数字信号：时间与幅度均离散

信号分类(继续):

- 变化规律—确定信号

  —随机信号
- 能量特征—能量信号

  能量有限

  —功率信号

  平均功率有限，能量无限

2)信号处理:以一定目的将信号从一种形式变换为另一种形式的过程.

目的:提取, 传输, 存储等

数字信号处理:以一定目的通过数字运算的方式将数字信号从一种形式变换为另一种形式的过程

数字信号处理(I):数字滤波和数字谱分析**理论和算法**---(确定信号)

数字信号处理(II):自适应数字滤波和功率谱估计**理论和算法**----(非确定信号)

数字信号处理

系统设计：

- ●算法设计

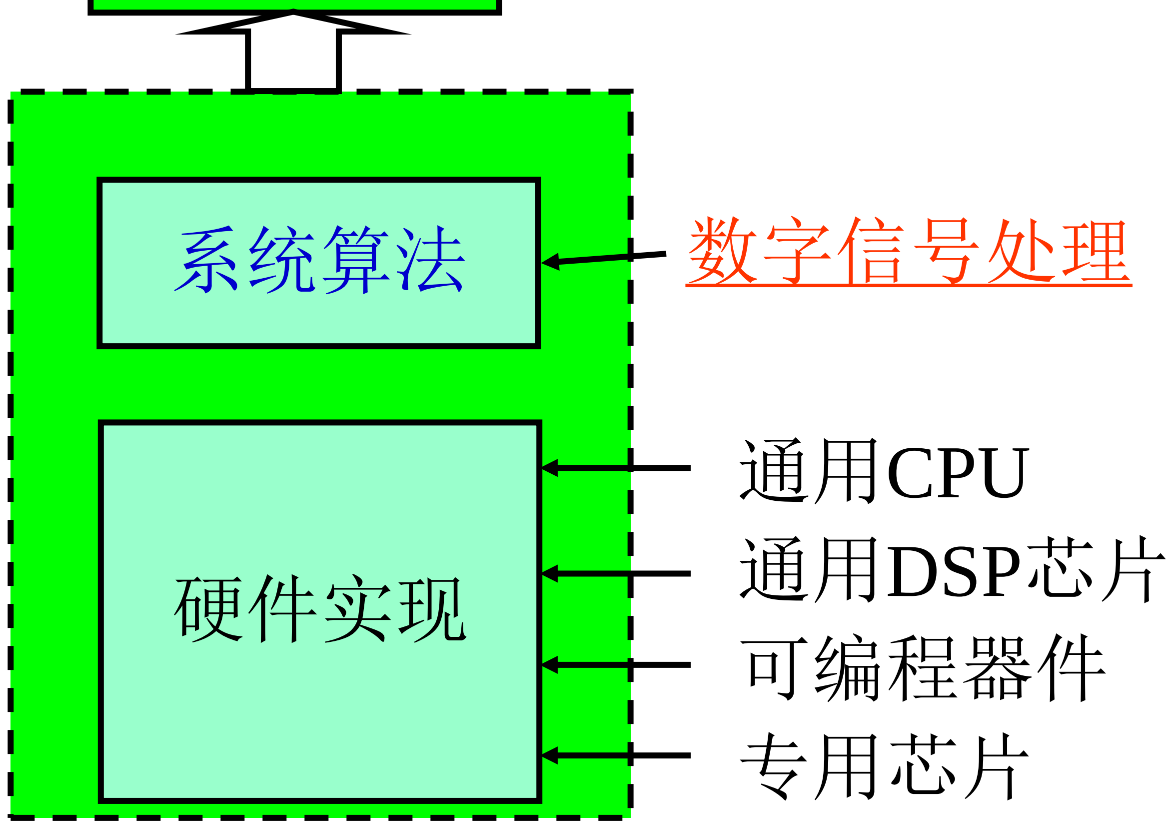
  基本理论，基本方法，协议规范

- ●算法实现

  结构，基本方法，实现技巧

- ●硬件设计

  结构，模块，计算单元



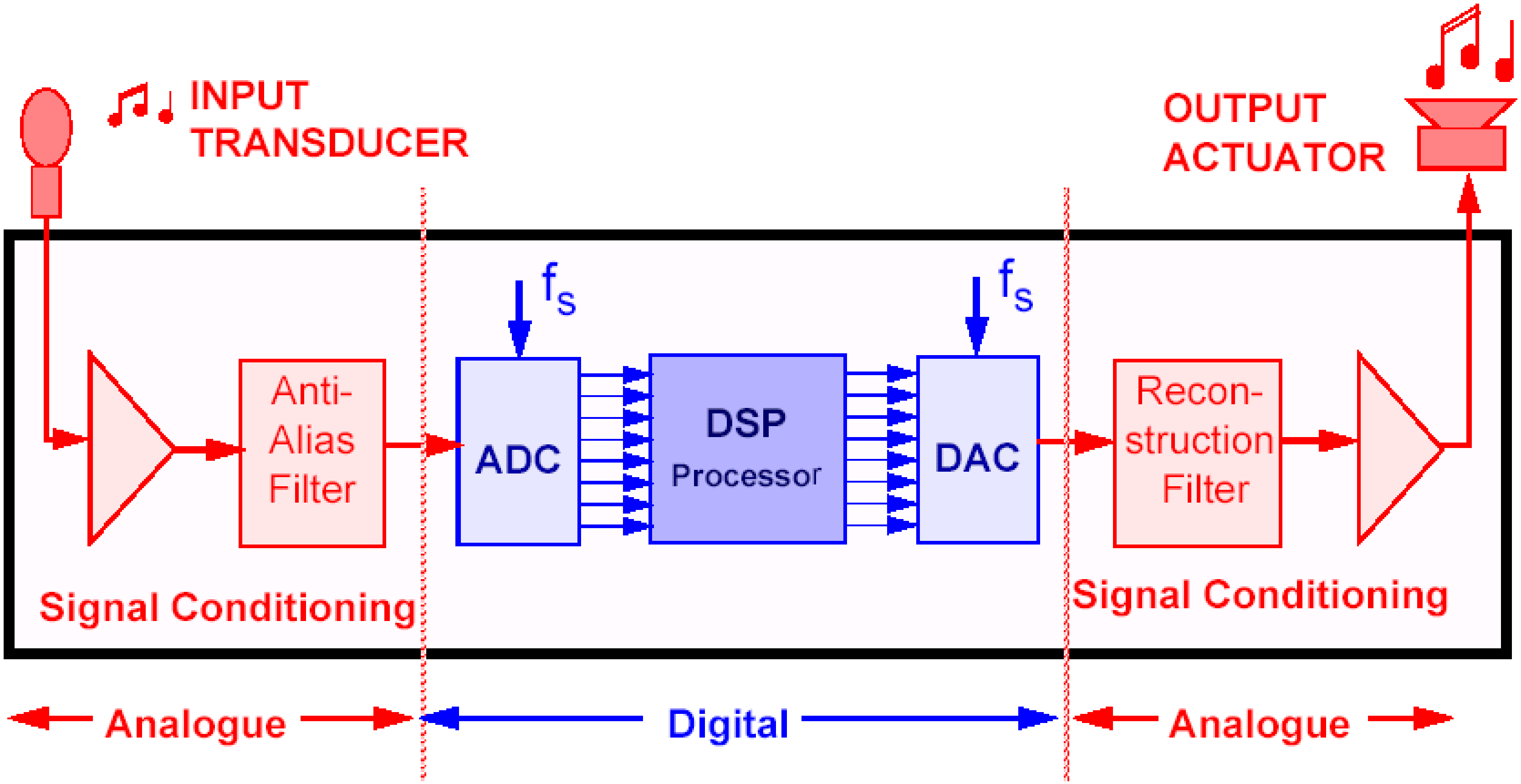
算法

FFT,FIR,IIR

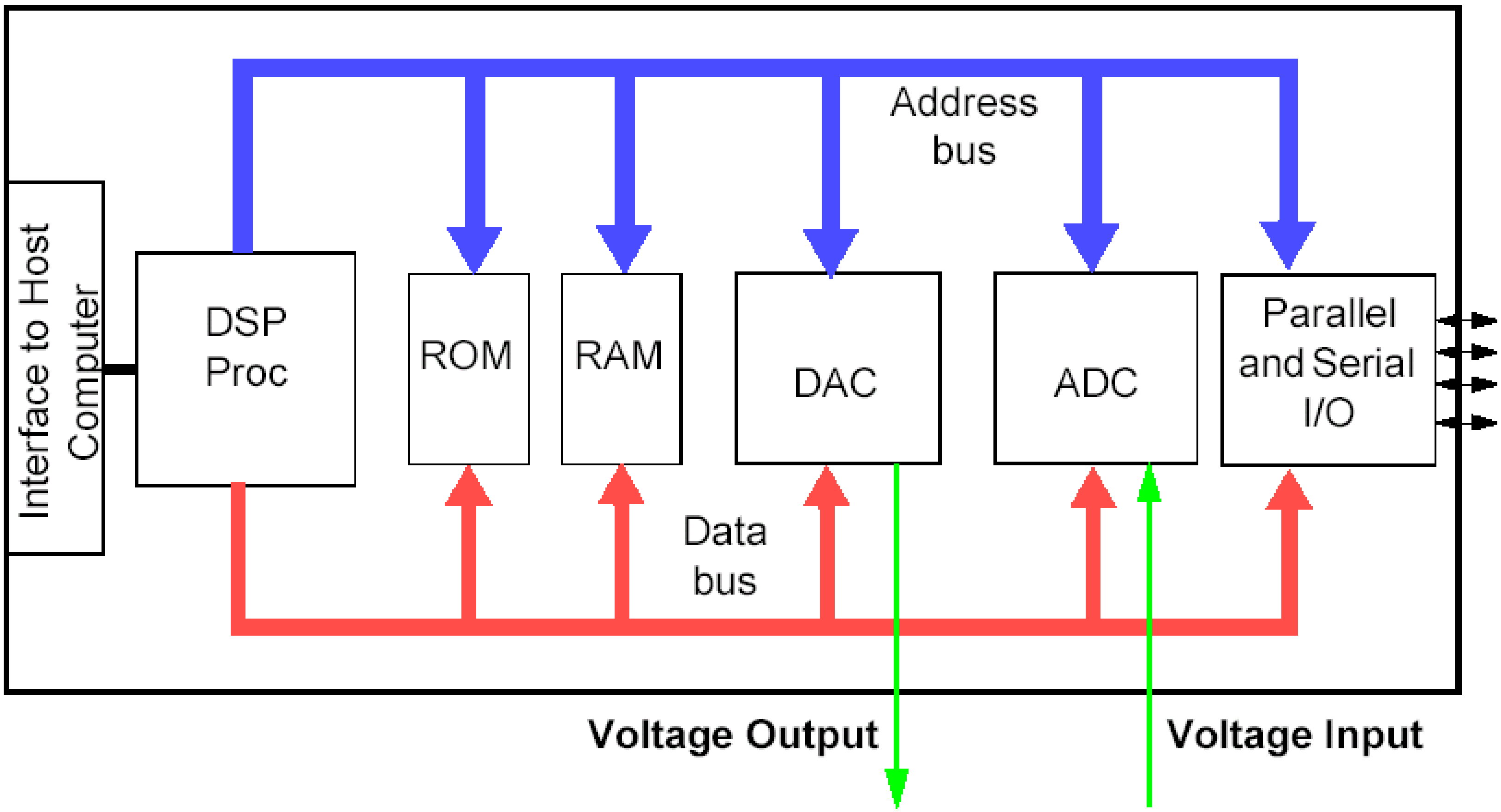
DSP算法特点

*y=a*x+b---MAC,Multiply with ACcumulation* *占所有算法的运算量的70%*

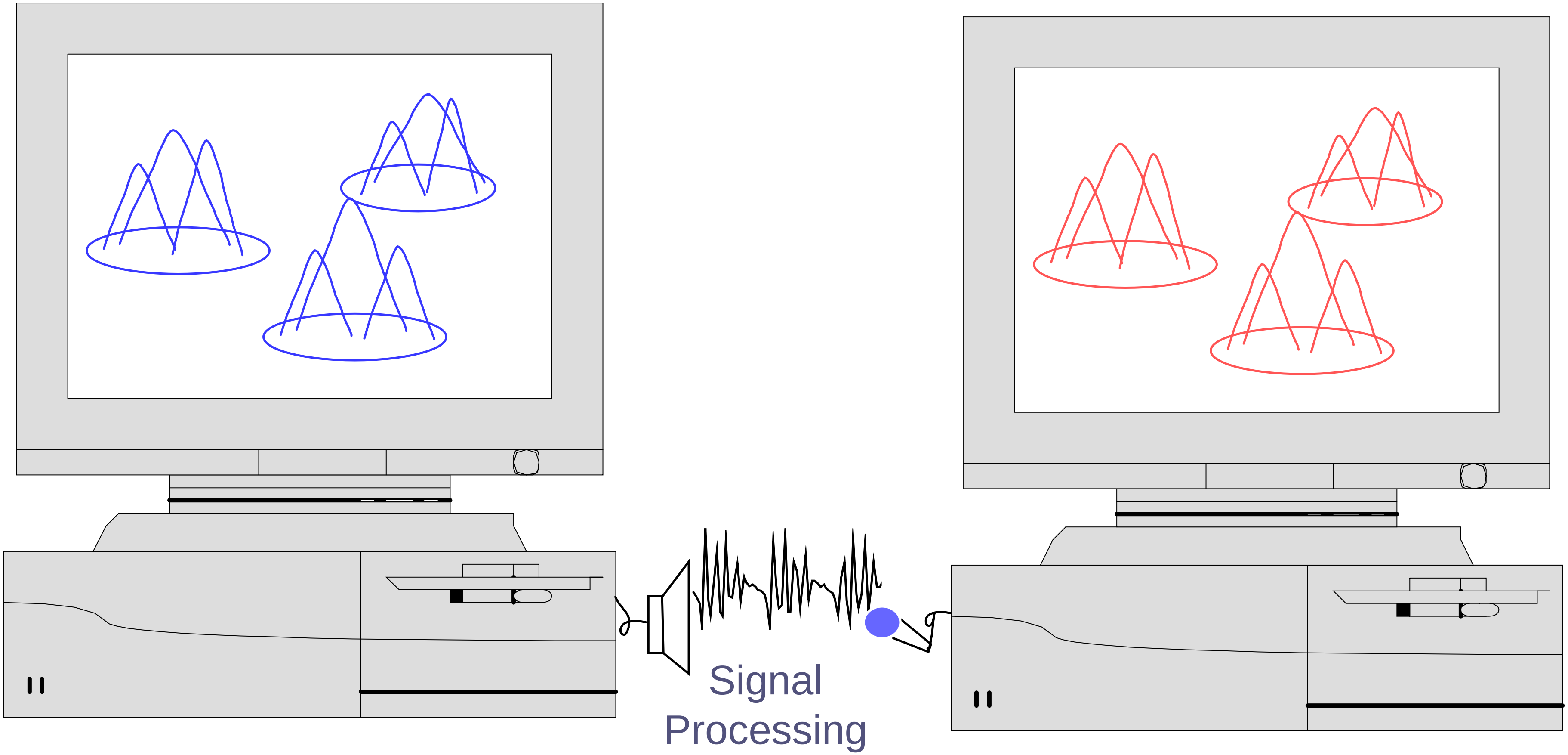
1.基本概念


INPUT
TRANSDUCER
OUTPUT
ACTUATOR
f_s
f_s
Anti-
Alias
Filter
ADC
DSP
Processor
DAC
Recon-
struction
Filter
Signal Conditioning
Signal Conditioning
Analogue
Digital
Analogue

DSP Board


Address
bus
Interface to Host
Computer
DSP
Proc
ROM
RAM
DAC
ADC
Parallel
and Serial
I/O
Data
bus
Voltage Output
Voltage Input

Speech communication in human and in machine



4)DP(Data Processing) VS. DSP

DP is the arithmetic processing of stored integer numerical quantities (accounts, salary spread sheets and so on). Fast processing of data is desirable but not essential.

DSP is concerned with the arithmetic processing of numerical representations of real world analogue quantities. Real time performance is necessary, such that processed outputs are produced as fast as input data is available.

The key difference is :

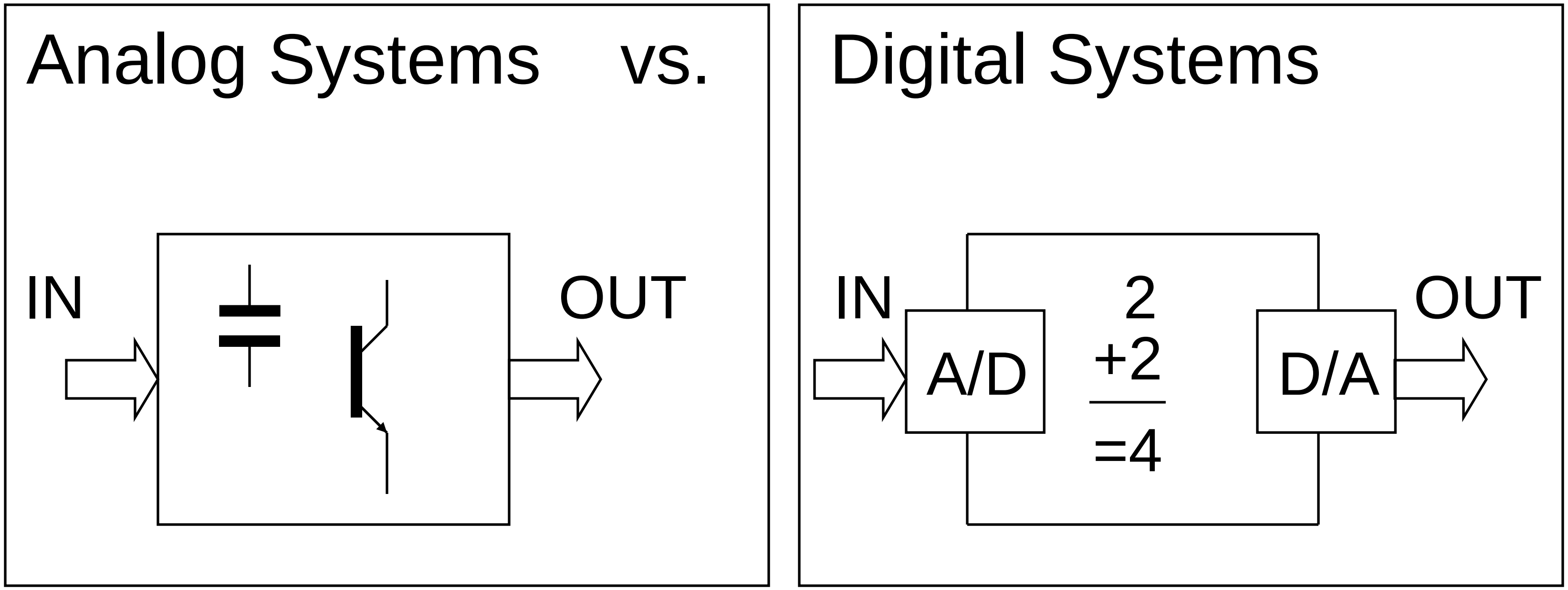
- DSP - REAL TIME ARITHMETIC
- DP - NON REAL TIME ARITHMETIC

1.基本概念

	Data Manipulation	Math Calculation
Typical Applications	Word processing, database management, spread sheets, operating sytems, etc.	Digital Signal Processing, motion control, scientific and engineering simulations, etc.
Main Operations	data movement ($A \rightarrow B$) value testing (*If* $A=B$ *then* ...)	addition ($A+B=C$) multiplication ($A \times B=C$)

All microprocessors can perform both tasks; however, it is difficult (expensive) to make a device that is *optimized* for both. Traditional microprocessors, such as the Pentium®, primarily directed at data manipulation. Similarly, DSPs are designed to perform the mathematical calculations needed in Digital Signal Processing.

5) Why DSP ?



- translate analog (e.g. filter) design into digital
- expand functionality/flexibility/…
  (e.g. analog speech recognition? analog….?)

DSP in present-day systems?

- Example: Telephone Line Modems

voice-band modems : up to 56kbits/sec in 0..4kHz band

ADSL modems : up to 8Mbits/sec in 30kHz…1MHz band

(3.5…5km)

VDSL modems : up to 52Mbits/sec in …10MHz band

X 1000

(0.3…1.5km)

xDSL communication impairments:

channel attenuation/distortion, echo, cross-talk,...

Enabling Technology is

ASP

DSP-I

DSP-II

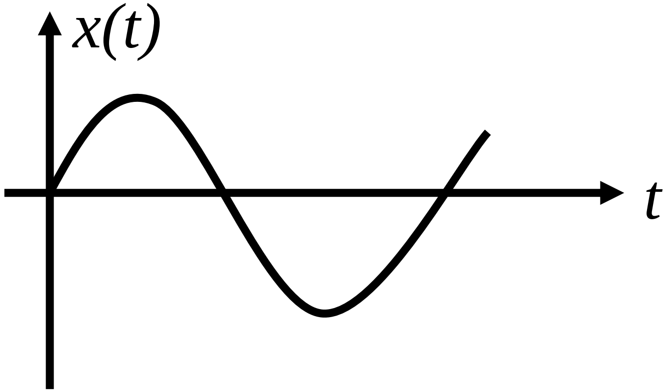
- Signal Processing
  - **1G-SP: analog filters**
  - **2G-SP: digital filters, FFT's, etc.**
  - **3G-SP: full of mathematics, linear algebra, statistics, etc...**
- VLSI
- etc...

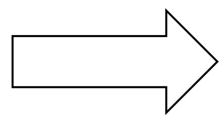
2.DSP(I)基本内容简介

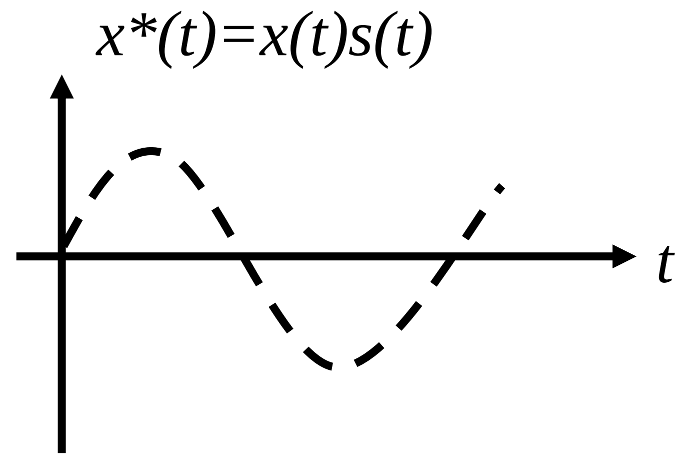
- 连续时间信号的离散化
- 离散时间信号与离散时间线性非时变系统
- 快速傅立叶变换（FFT）
- 数字滤波器及其实现结构
- IIR数字滤波器设计
- FIR数字滤波器设计

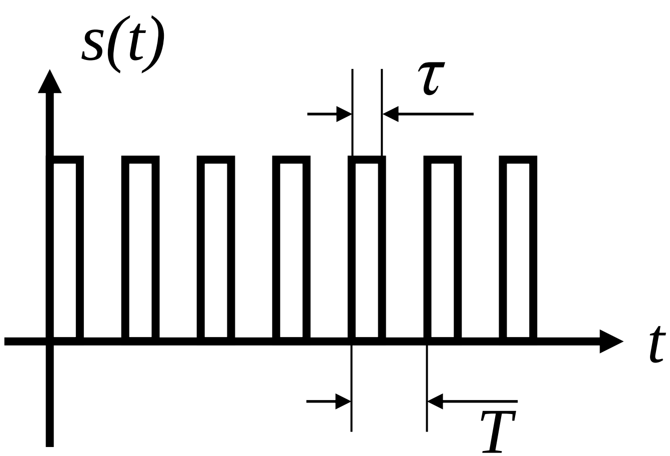
2.DSP(I)基本内容简介

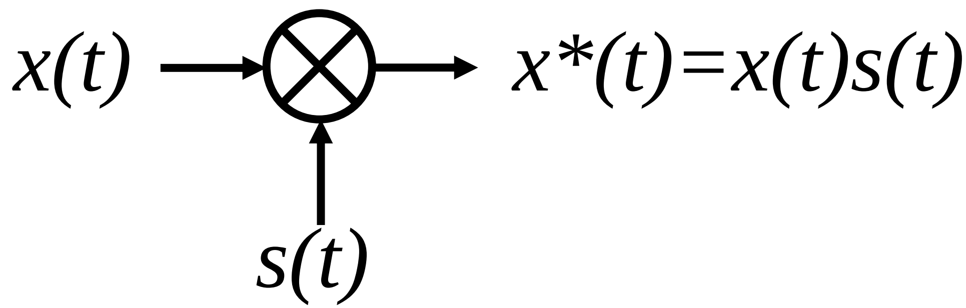
- 连续时间信号的离散化



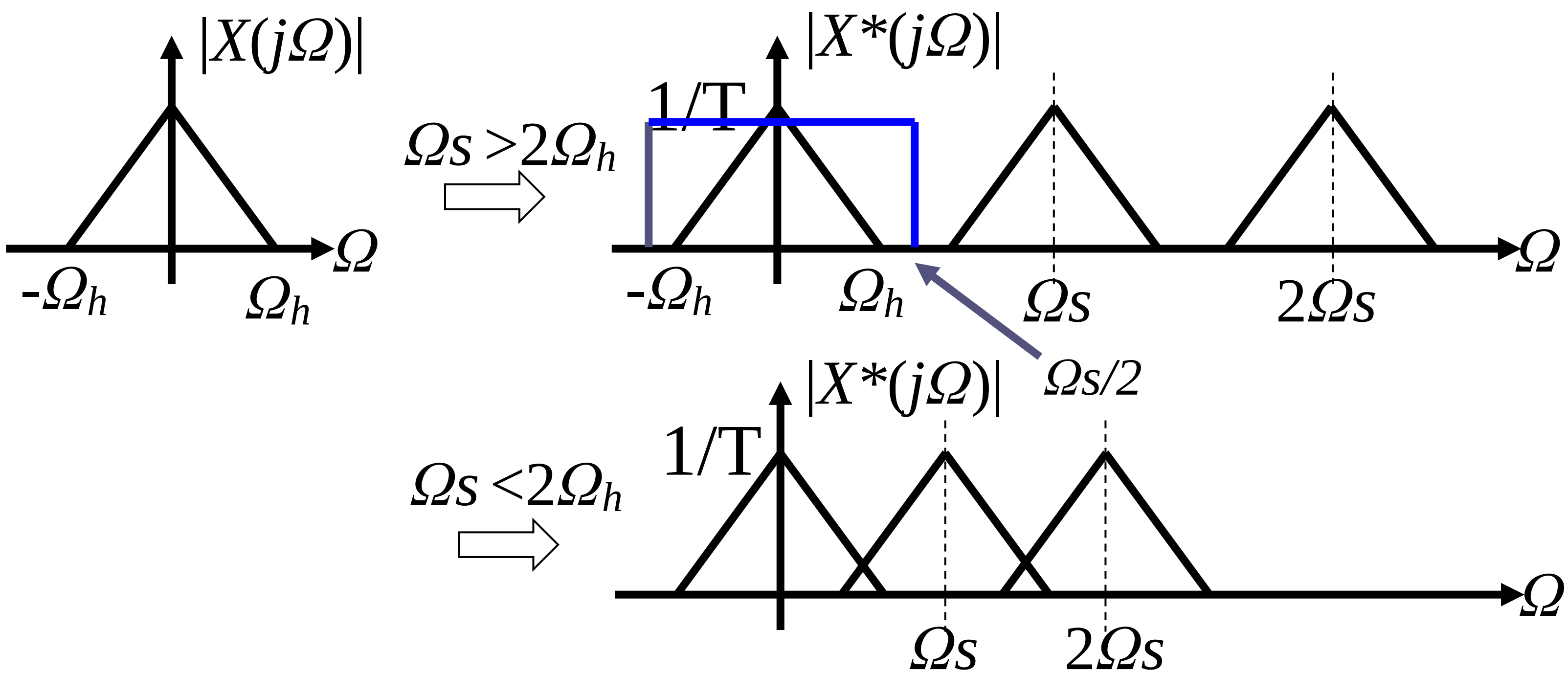








$$X^*(j\Omega)=\frac{1}{T}\sum_{n=-\infty}^{\infty}X[j(\Omega-n\Omega s)]$$



结论：经过取样，原信号的频谱被周期性地扩展，当$\Omega s>=2\Omega_h$时，无频谱混迭;当$\Omega s<2\Omega_h$时，发生频谱混迭。

- 离散时间信号与离散时间线性非时变系统
  - ❑**离散时间信号**:数字域频率的定义和意义
  - ❑离散时间线性非时变系统(1)概念;(2)单位取样响应,线性卷积及其性质;(3)系统的稳定性,因果性,因果序列等概念; (4)频率响应
  - ❑离散时间序列的傅氏变换（DTFT）定义, 意义, 性质
  - ❑Z变换的定义;序列的时间特性和Z变换的收敛域的关系;Z反变换;
  - ❑Z变换的性质;Z变换与拉氏变换的关系;离散线性时不变系统的系统函数.
  - ❑离散傅立叶变换(DFT)定义和性质

采样间隔 $\Omega_0=\dfrac{2\pi}{NT}$,用数字域频率表示 $\omega_0==\dfrac{2\pi}{N}$

引入记号$W_N=e^{-j\frac{2\pi}{N}}$ (指数因子,旋转因子,加权因子)

则

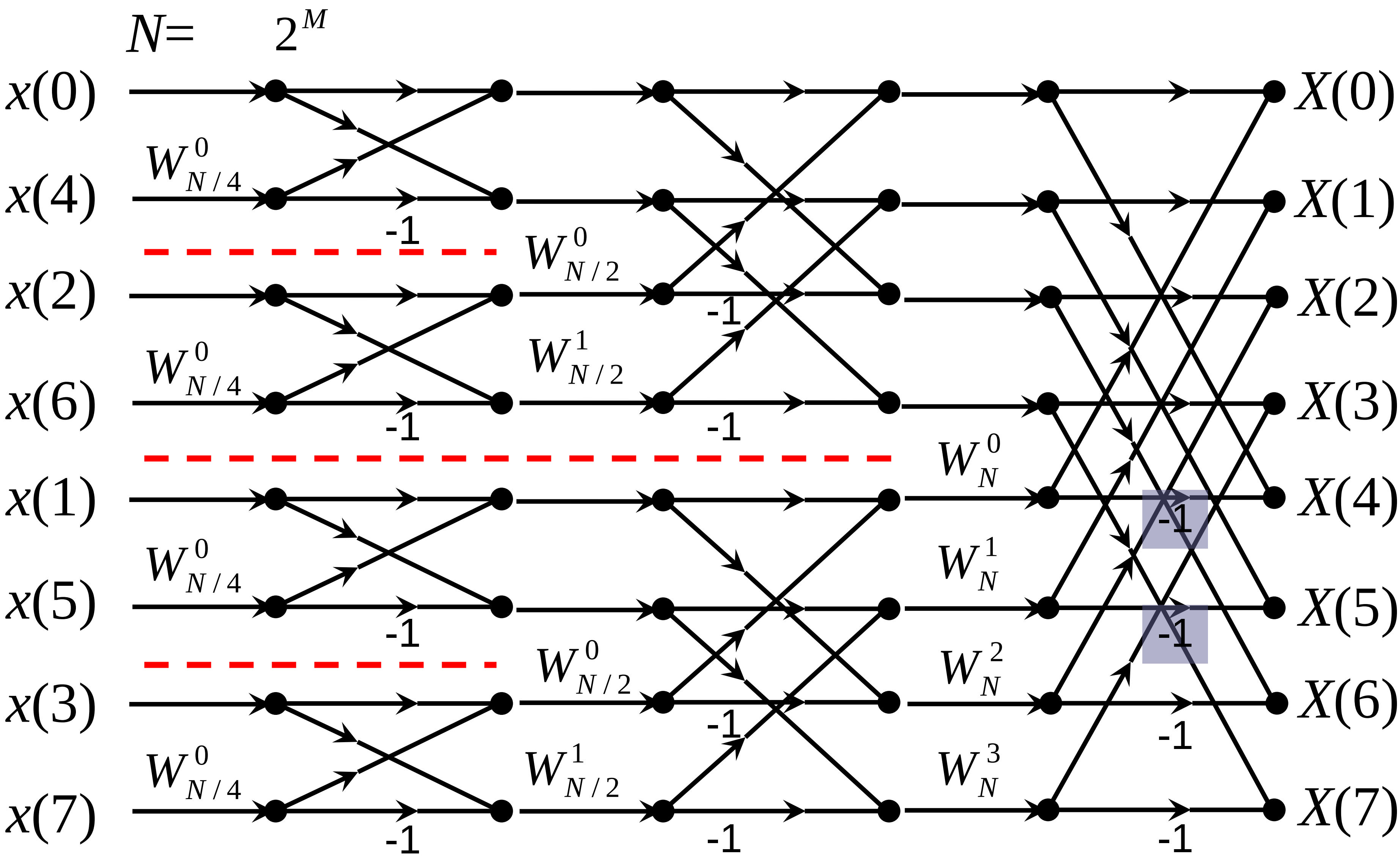
$$
\begin{cases}
\tilde{X}(k)=\sum\limits_{k=0}^{N-1}\tilde{x}(n)W_N^{nk} \\
\tilde{x}(n)=\dfrac{1}{N}\sum\limits_{k=0}^{N-1}\tilde{X}(k)W_N^{-kn}
\end{cases}
$$

时域：离散，周期；**频域**：离散，周期

- 快速傅立叶变换（FFT）

  - 基2的DIT-FFT(按时间抽取的FFT) Decimation In Time
  - 基2的DIF-FFT(按频率抽取的FFT) Decimation In Frequency
  - 利用FFT计算时域卷积

2.DSP(I)基本内容简介

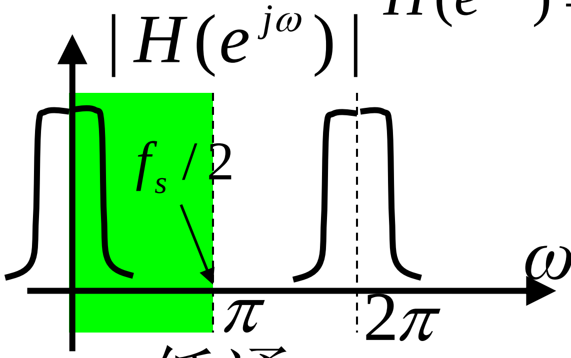


- 数字滤波器及其实现结构

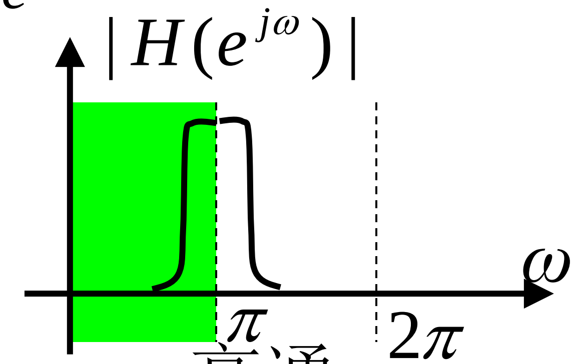
$$|H(e^{j\omega})| = |H(e^{-j\omega})|$$

$$|H(e^{j\omega})| = |H(e^{j(\omega+2\pi)})|$$

$$H(e^{j\omega}) = \sum_{n=0}^{\infty} h(n)e^{-j\omega n}$$

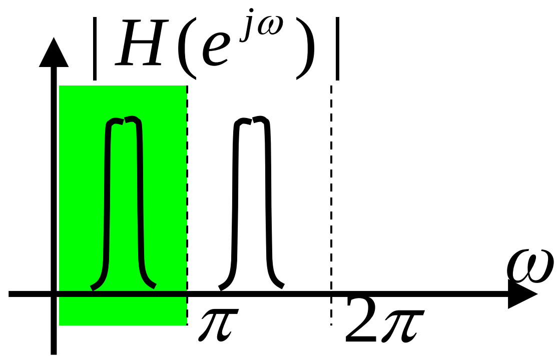


低通

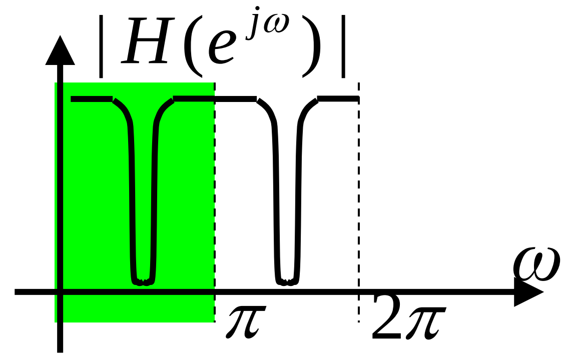


高通

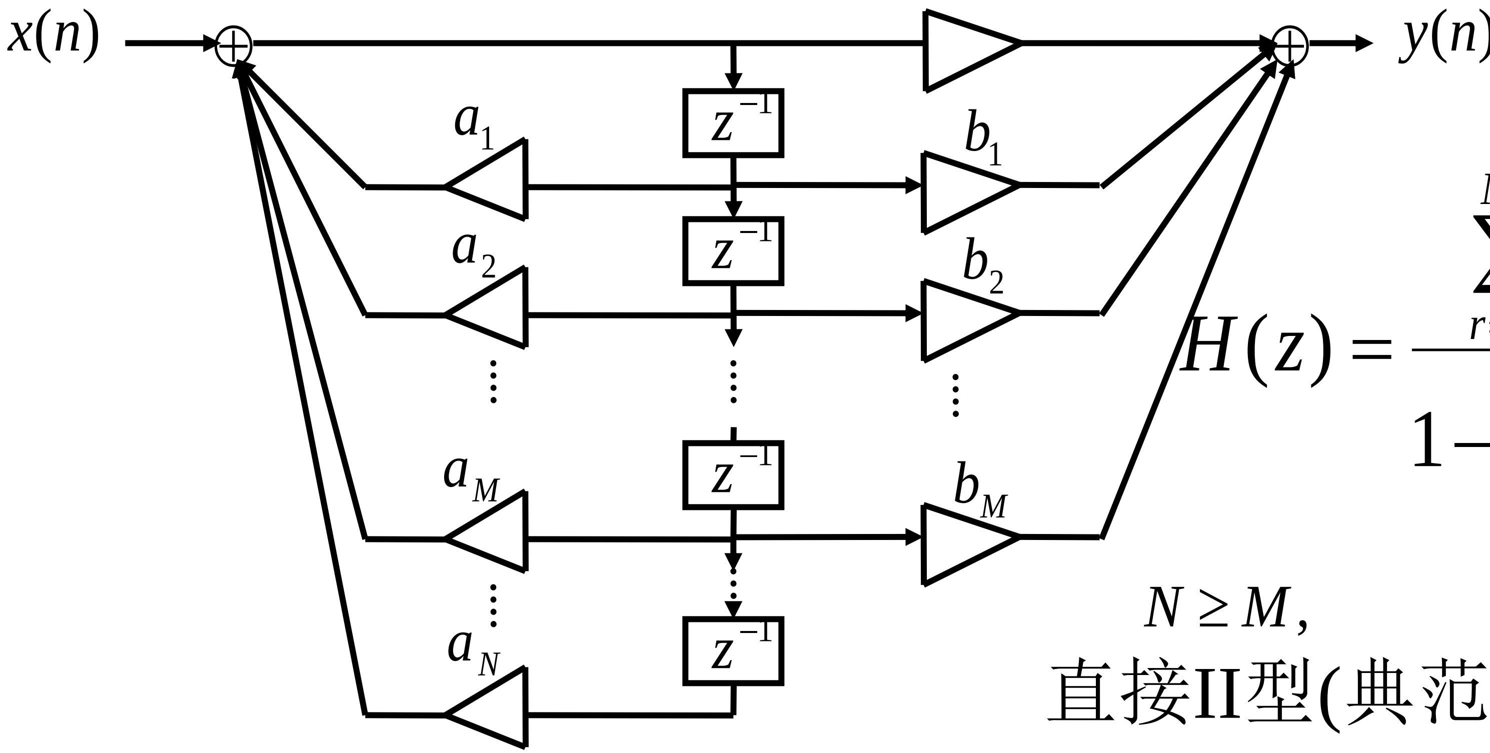
$$\boxed{\omega = \Omega T = 2\pi f / f_s}$$



带通



带阻



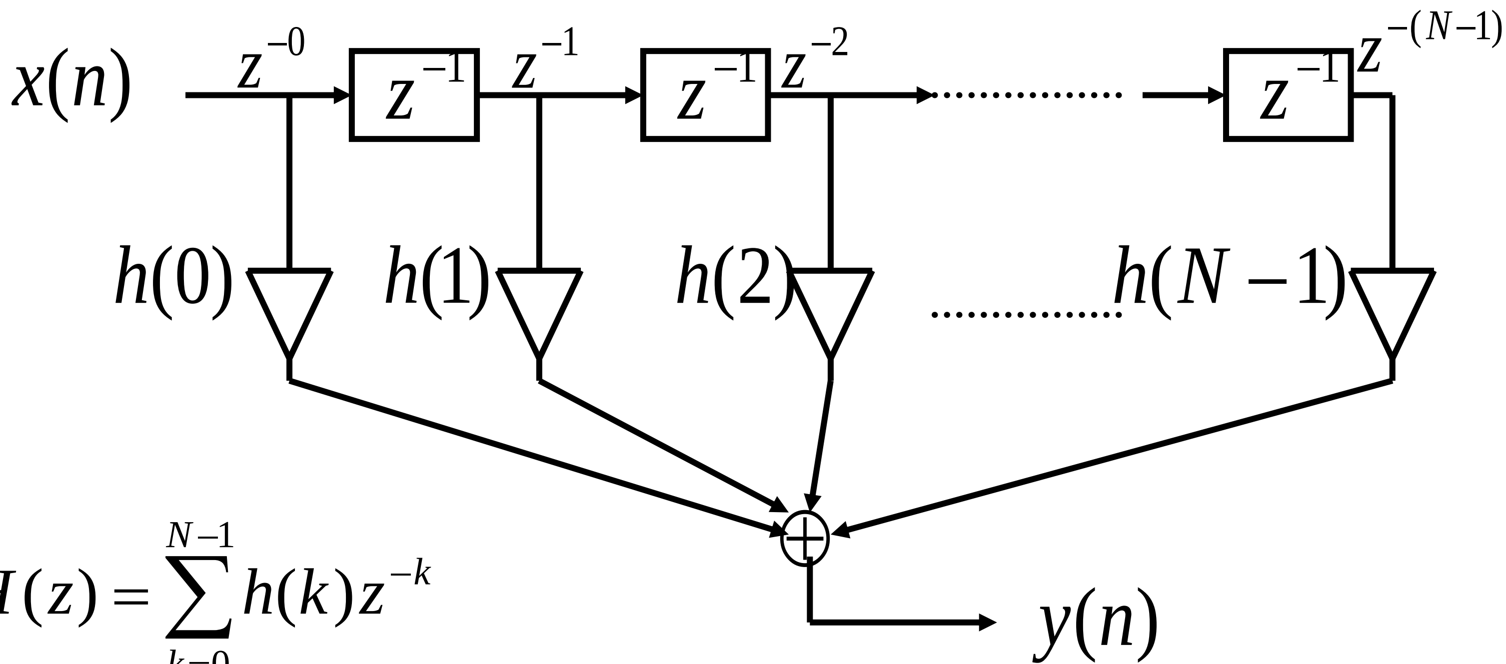
$$H(z)=\frac{\sum_{r=0}^{M} b_r z^{-r}}{1-\sum_{k=1}^{N} a_k z^{-k}}$$

$N \geq M$,

直接II型(典范型)

直接形式

$$y(n)=\sum_{k=0}^{N-1}h(k)x(n-k)$$



$$H(z)=\sum_{k=0}^{N-1}h(k)z^{-k}$$

N抽头延迟线滤波器，横向滤波器，卷积滤波器

2.DSP(I)基本内容简介

- IIR数字滤波器设计

- FIR数字滤波器设计

3. DSP研究动态-Deep Learning

深度语音信号与信息处理

深度学习-基本概念

- ***Definition 1***: A class of machine learning techniques that exploit many layers of non-linear information processing for supervised or unsupervised feature extraction and transformation, and for pattern analysis and classification.（Li Deng）

- ***Definition 2***: "A sub-field within machine learning that is based on algorithms for learning multiple levels of representation in order to model complex relationships among data. Higher-level features and concepts are thus defined in terms of lower-level ones, and such a hierarchy of features is called a deep architecture. Most of these models are based on unsupervised learning of representations." (Wikipedia on "Deep Learning" around March 2012.)

深度学习-基本概念（续）

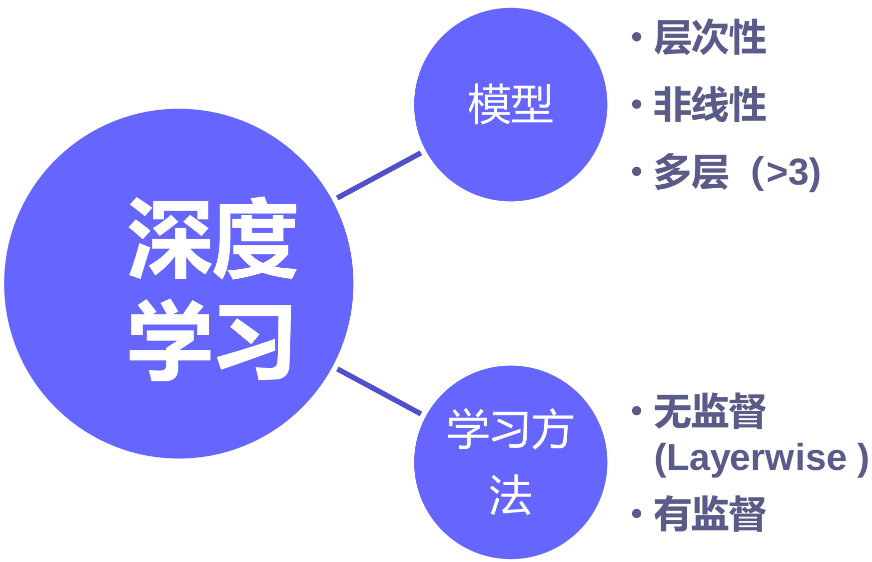
- ***Definition 3***: "A sub-field of machine learning that is based on learning several levels of representations, corresponding to a hierarchy of features or factors or concepts, where higher-level concepts are defined from lower-level ones, and the same lower-level concepts can help to define many higher-level concepts. Deep learning is part of a broader family of machine learning methods based on learning representations. An observation (e.g., an image) can be represented in many ways (e.g., a vector of pixels), but some representations make it easier to learn tasks of interest (e.g., is this the image of a human face?) from examples, and research in this area attempts to define what makes better representations and how to learn them." see Wikipedia on "Deep Learning" as of this writing in February 2013; see http://en.wikipedia.org/wiki/Deep_learning.

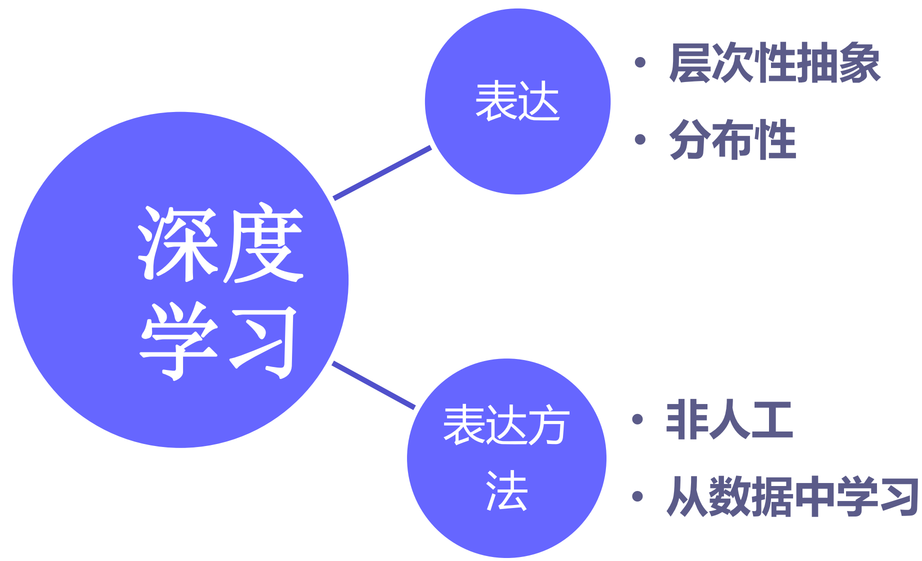
深度学习-基本概念（续）

- ***Definition 4***: "Deep Learning is a new area of Machine Learning research, which has been introduced with the objective of moving Machine Learning closer to one of its original goals: Artificial Intelligence. Deep Learning is about learning multiple levels of representation and abstraction that help to make sense of data such as images, sound, and text." See https://github.com/lisa-lab/DeepLearningTutorials

深度学习-基本概念（续）

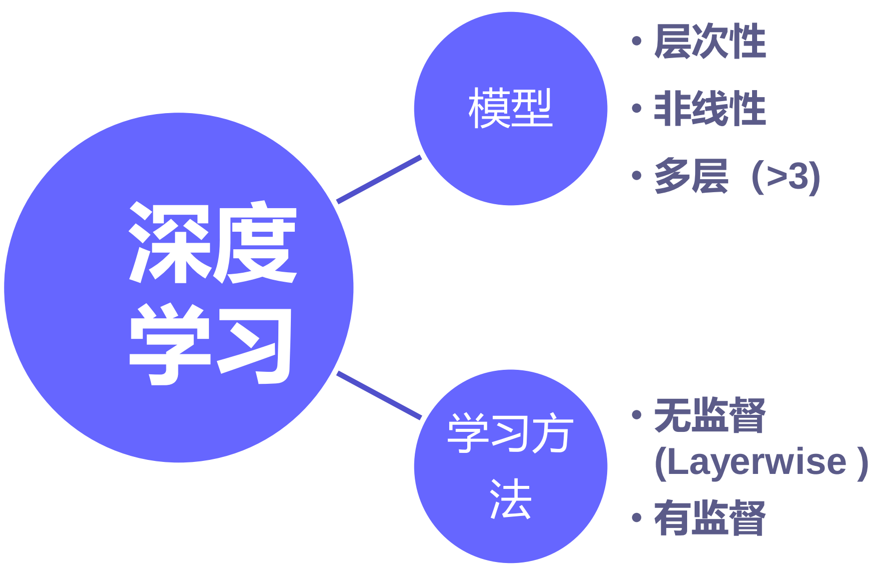
- 从机器学习的基本要素角度
- **从机器学习目的的角度**



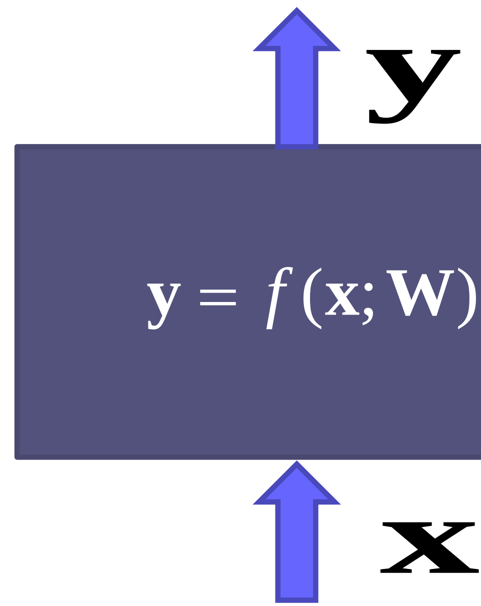


深度学习-基本概念（续）

- 从机器学习的基本要素角度



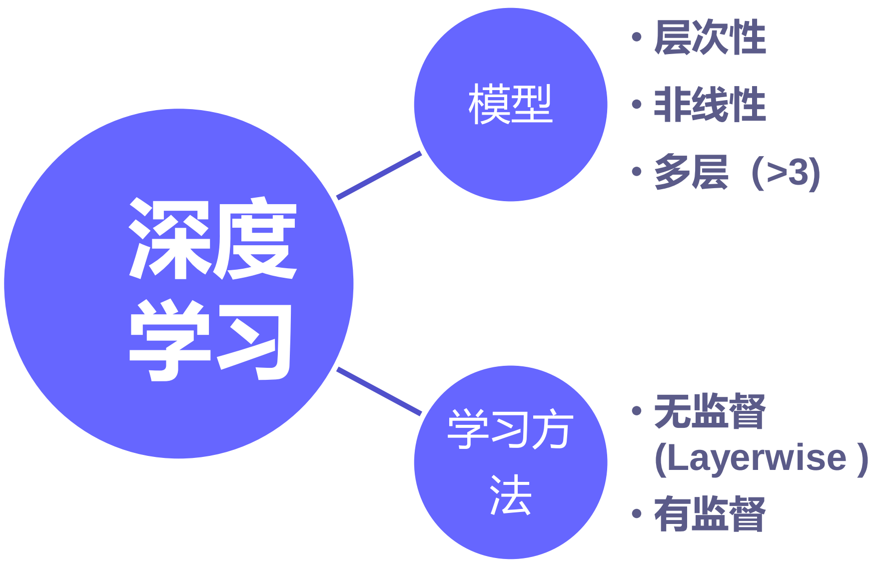
- 一般性模型



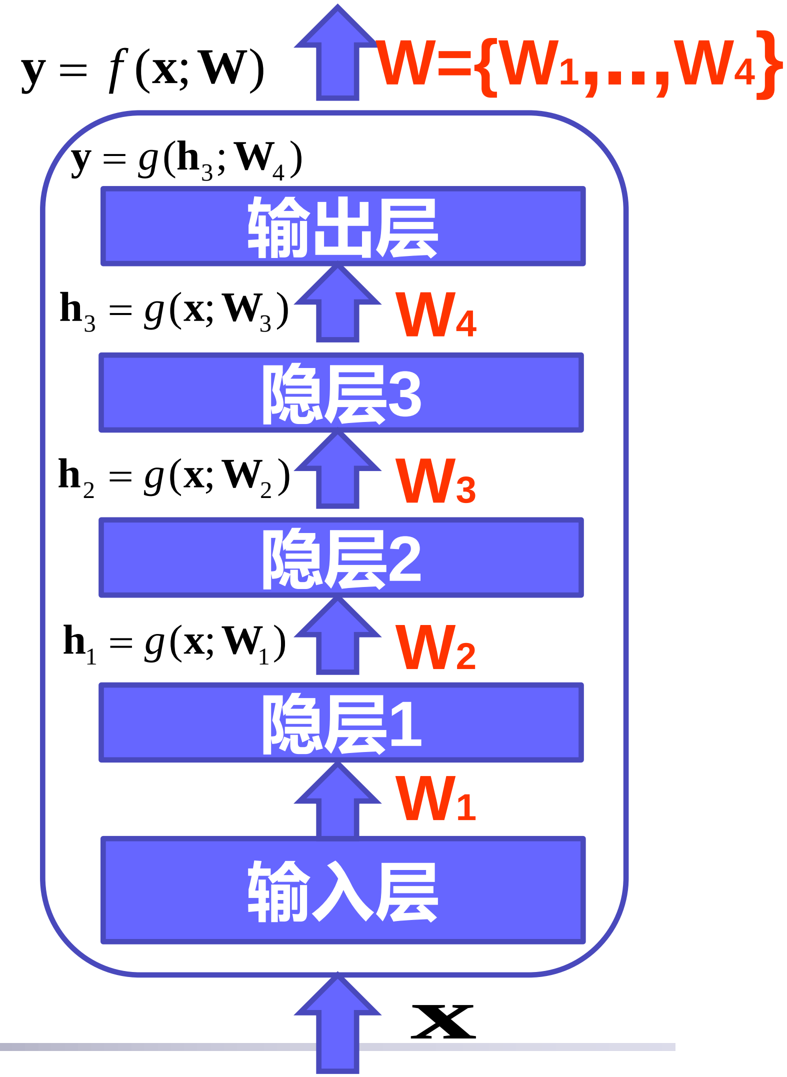
- 模型结构与复杂度：模型学习和表达能力，有效性，推广性
- 模型结构设计与选取非常重要

深度学习-基本概念（续）

- 从机器学习的基本要素角度

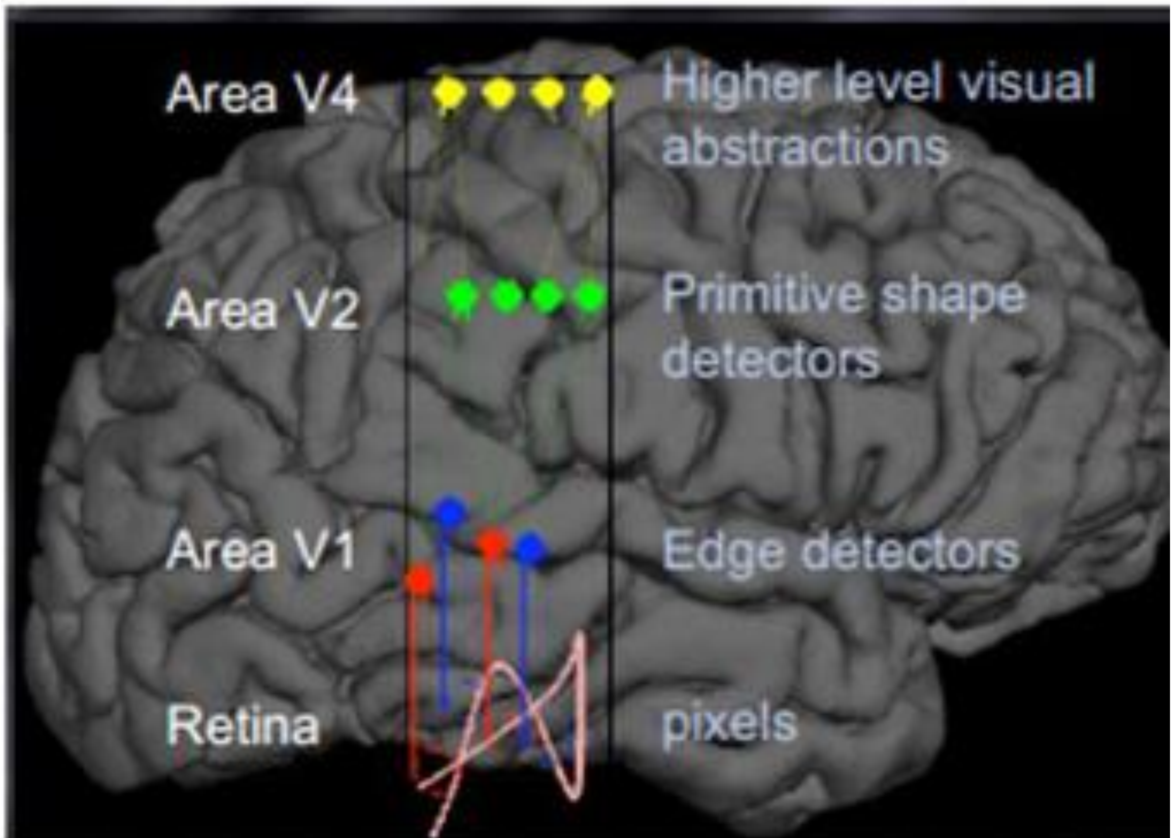


深度学习模型层次化结构



深度学习-基本概念（续）

- 深度学习模型为什么采用层次化结构？



1981 年的诺贝尔医学奖，颁发给了：

David Hubel

Torsten Wiesel

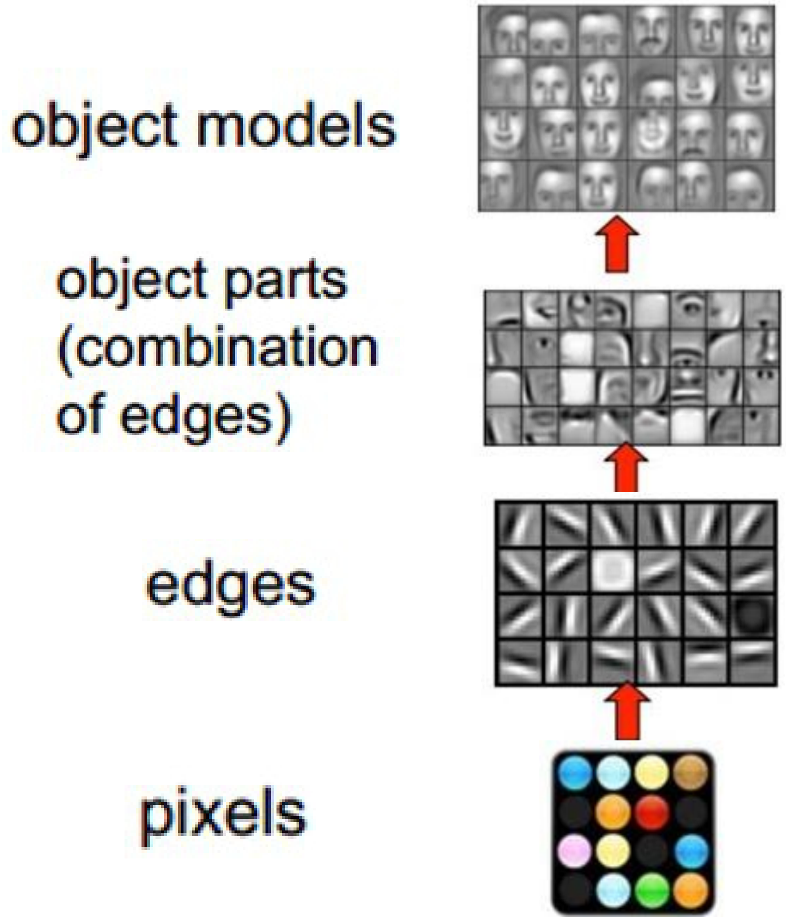
Roger Sperry

前两位的主要贡献，是“发现了视觉系统的信息处理”：

视觉具有层次化处理结构。

深度学习-基本概念（续）

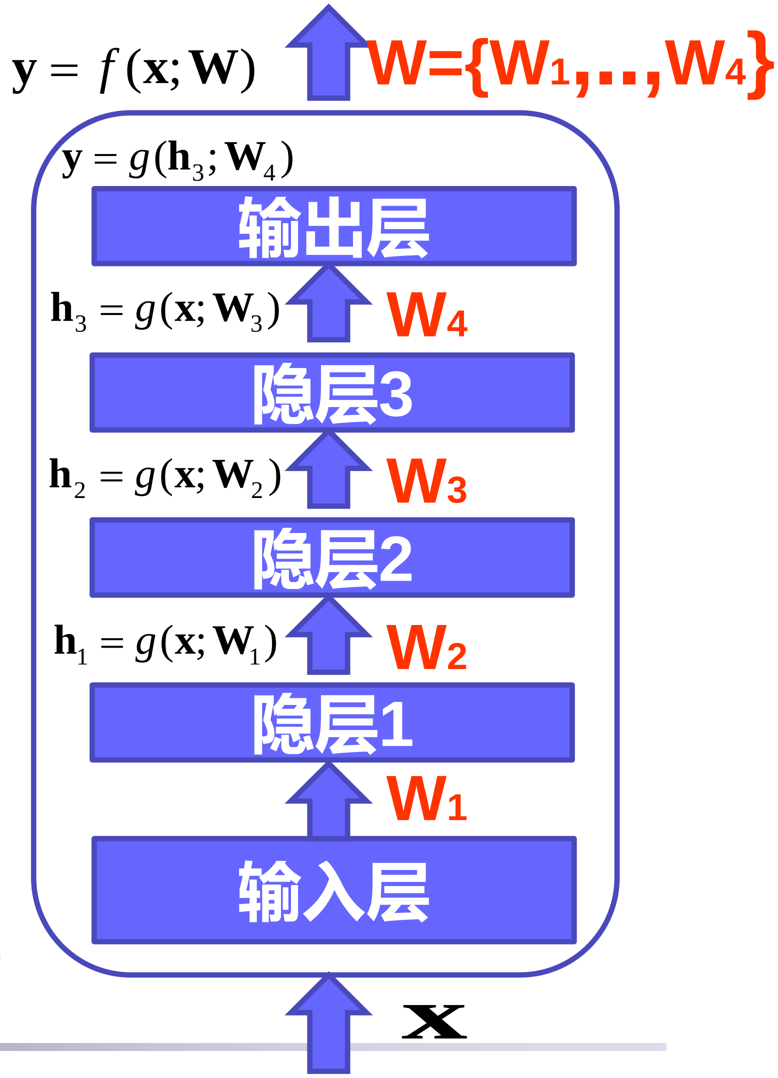
- 优势之一
- 层次化结构模型具有学习递增抽象层次化表达的能力



深度学习-基本概念（续）

- **优势之二**
- **复杂非线性模型的构造转换为简单复合的非线性模型的构造**

$$
\begin{aligned}
\mathbf{y} &= f(\mathbf{x};\mathbf{W}) \\
&= g(g(g(g(\mathbf{x},\mathbf{W}_1),\mathbf{W}_2),\mathbf{W}_3),\mathbf{W}_4)
\end{aligned}
$$

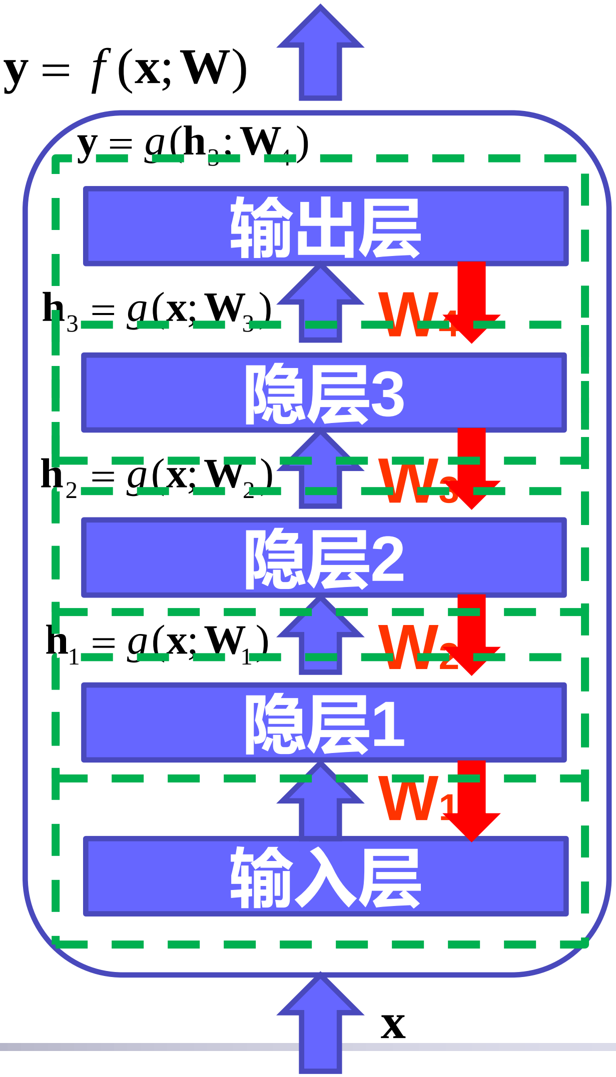


深度学习-基本概念（续）

- **优势之三**
- **高效的无监督模型学习成为可能：RBM（Restricted Boltzmann Machines)；Auto-Encoder**

●基本思路：作为原始数据的表达，应能产生原始数据

●逐层式无监督学习，(Layerwise)预训练(Preraining)



深度学习=无监督预训练(初始化) + 有监督训练

Pre-Training + Fine-Tuning

深度学习-基本概念（续）

- 上世纪80年代人们对深度学习的必要性已有一定的认识;
- 2006年Hinton等人的工作—重大突破

  无监督训练新方法

  （RBM,Autoencoder,CD算法等）
- Changes in computing technology favor Deep learning，eg.GPU
- Changes in data scale

标记性事件：语音识别

- 2009: DNN for small-scale ASR *(Mohamed, et al. 2009, NIP22)*
  - TIMIT core test set, PER=23.0%

- 2011: DNN for large-scale ASR
  - Over 30% rel. gain in Switchboard (Seide et al., 2011)

深度学习-基本概念（续）

- ILSVCR-2012竞赛-图像识别：ImageNet分类

- 20万张高分辨率训练图片，1000个分类

深度学习-基本概念（续）

●ILSVCR-2012竞赛中的误判率

- Krizhevsky et. al. • 16.4%

much bigger gap than for acoustic models

37%

- University of Tokyo • 26.1%
- Oxford University Vision Group • 26.9%
- INRIA + XRCE • 27.0%
- University of Amsterdam • 29.5%

深度学习-基本概念（续）

MIT Technology Review

10 BREAKTHROUGH TECHNOLOGIES 2013

Introduction   The 10 Technologies   Past Years

Deep Learning

With massive amounts of computational power, machines can now recognize objects and translate speech in real time. Artificial intelligence is finally getting smart. →

Temporary Social Media

Messages that quickly self-destruct could enhance the privacy of online communications and make people freer to be spontaneous. →

Prenatal DNA Sequencing

Reading the DNA of fetuses will be the next frontier of the genomic revolution. But do you really want to know about the genetic problems or musical aptitude of your unborn child? →

Additive Manufacturing

Skeptical about 3-D printing? GE, the world's largest manufacturer, is on the verge of using the technology to make jet parts. →

Baxter: The Blue-Collar Robot

Rodney Brooks's newest creation is easy to interact with, but the complex innovations behind the robot show just how hard it is to get along with people. →

Memory Implants

A maverick neuroscientist believes he has deciphered the code by which the brain forms long-term memories. Next: testing a prosthetic implant for people suffering from long-term memory loss. →

Smart Watches

The designers of the Pebble watch realized that a mobile phone is more useful if you don't have to take it out of your pocket. →

Ultra-Efficient Solar Power

Doubling the efficiency of a solar cell would completely change the economics of renewable energy. Nanotechnology just might make it possible. →

Big Data from Cheap Phones

Collecting and analyzing information from simple cell phones can provide surprising insights into how people move about and behave – and even help us understand the spread of diseases. →

Supergrids

A new high-power circuit breaker could finally make highly efficient DC power grids practical. →

深度学习-基本概念（续）

- Geoffrey E Hinton
- 多伦多大学

- Yann LeCun
- 纽约大学

- Yoshua Bengio
- 蒙特利尔大学

- Andrew Ng
- 斯坦福大学

深度学习-基本概念（续）

facebook

Baidu百度

- Yoshua Bengio
- 蒙特利尔大学

深度学习-展望

- 进一步向人脑学习信号与信息的处理模型、方法和算法
  - 对于自然信号(如语音和图像等）的处理及NLP，人脑目前仍远胜于计算机

具体表现：处理能力和鲁棒性及容错性方面人脑更强大

能耗小几个数量级：“Watson”8.5万；人脑20瓦

无需编程

深度学习-展望

- 如何向人脑学习信号与信息的处理模型、方法和算法?
  - 脑图谱：脑网络数据分析与重构
  - 类脑神经网络计算模型
  - 类脑智能信息处理:类脑视觉计算模型与方法;类脑语音语言计算模型与方法
  - 类脑计算芯片与智能系统

4.现代数字信号处理的涉及范围和DSP II的安排

❑现代数字信号处理的主要涉及范围

1)自适应滤波,Adaptive Filtering

2)短时傅里叶分析与小波变换

Short Time Fourier Transform,Wavelet Transform

3)现代谱估计

Modern Spectrum Estimation

4)多速率数字信号处理

Multi-rate Processing of Digital Signal

5)非高斯信号处理(高阶谱分析)

Non-Gaussian Signal Processing

6)以分类,识别为目的的信号处理与建模

Classification and Recognition

(VQ,Neural network,HMM,…)

❑DSP II 课程安排

1)自适应数字滤波(Weiner Filtering, Kalman Filtering, LMS Adaptive Filtering,RLS Adaptive Filtering,Linear Predictive Error Filtering)

2)现代谱估计（参数模型法谱估计, 最大熵谱估计）

3)时频分析（短时傅立叶分析与综合）

4)同态信号处理（乘积, 卷积同态信号处理, 倒谱定义, 计算与性质）

4.现代数字信号处理的涉及范围和DSP II的安排

参考书目：

- A. Oppenheim & R. Schafer DSP-I
  ***`Digital Signal Processing'* (Prentice Hall, 1977)**
- 姚天任，孙洪，《现代数字信号处理》，华中科技大学出版社，1999。
- 张贤达著，《现代信号处理》，清华大学出版社，1995。
- Simon Haykin DSP-II
  ***`Adaptive Filter Theory'* (Prentice Hall, 2002)**
- **Ali H. Sayed**
  Fundamentals of Adptive Filtering
  (IEEE Press,2003)

学习中注意的问题

1)课堂听讲与课堂笔记

2)作业

3)参考资料的使用

考核方式：

- 平时作业
- 闭卷考试

联系方式：jundu@ustc.edu.cn

jzhang6@ustc.edu.cn

课程主页：https://dsp2ustc.github.io/

课程QQ群：873662107