1. Introduction to Smart Cities
第1课：智慧城市简介

金力 Li Jin
li.jin@sjtu.edu.cn
上海交通大学密西根学院
Shanghai Jiao Tong University UM Joint Institute

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Course information

- Schedule
  - MW(F)
  - 24 lectures, 4 recitations
- Optional references (free online):
  - Friedland, B. (2012). Control system design: An introduction to state-space methods. Courier Corporation. Available through SJTU online library.
  - Boyd, S., Boyd, S. P., & Vandenberghe, L. (2004). Convex optimization. Cambridge university press. https://web.stanford.edu/~boyd/cvxbook/bv_cvxbook.pdf
  - Hastie, T., Tibshirani, R., and Friedman, J., The Elements of Statistical Learning: Data Mining, Inference and Prediction, Springer, 2nd ed., 2009. https://web.stanford.edu/~hastie/ElemStatLearn/printings/ESLII_print12.pdf

Grading

- 5 homework (HW) sets: 25%
  - Focus on concepts, modeling and formulation
  - Individual work
  - Late submissions will be docked by 80%
- 3 Mini projects (MP): 15%
  - Simulation/computation of problems discussed in class
- 2 quizzes: 40%.
  - 75-min in class
  - Open-book
- Final project: 20%.
  - Groups of 3 or 4 (based on session size). Flexible topic.
  - Simulation and exploration of a non-trivial problem in smart cities. Peer-evaluated.
  - 15-min presentation + 5-page report

Schedule

- Lectures 1--10: Control
  - HW 1 & 2, MP 1
- Quiz 1: 2022.6.8 in class
- Lectures 11--20: Optimization
  - HW 3 & 4, MP 2
- Quiz 2: 2022.7.11 in class
- Lectures 21—24: Learning
  - HW 5, MP 3
- Presentations: 2022.7.27-29

TAs

- Yumeng Bai
  - ym.Bai@sjtu.edu.cn
  - Responsible for Part 1: control
- Yanwei Sun
  - yanweisun@sjtu.edu.cn
  - Responsible for Part 2: optimization
- Office hours upon request

Project topics

- Option 1: learning-based adaptive cruise control
- Option 2: rebalancing shared bikes on campus
- Option 3: whatever topic you are interested in
- Expectation: simulation, computation, and exploration
- Beyond expectation: theoretical analysis
- *If you are indeed interested in theory, do a PhD with us*
- ***We are recruiting PhD and Master students!***

What you can expect from this course

- Task 1: introduce key smart city applications.
  - Most importantly, autonomous driving, intelligent transportation, and smart grids.
  - What are the technological bases?
  - What are the decisions to be made?
- Task 2: introduce decision-making problems
  - Control, automation
  - Optimization, operations research
  - Learning, statistics

What are beyond the scope of this course

- Details of specific smart city technologies such as
  - Computer vision, Lidar, ...
  - Wireless communication, edge computing,...
  - Wind turbines, solar panels,...
- Theories of control, optimization, or learning such as
  - How to determine whether a dynamical system is stable? [Take a control course]
  - How to prove the optimality of a given solution? [Take an optimization course]
  - How fast does a learning algorithm converge? [Take a machine learning course]

Questions you should be able to answer...

- What is a smart city?
- What is a connected and autonomous vehicle?
- What is an intelligent transportation system?
- What is a smart grid?
- What is control?
- What is optimization?
- What is learning?

Outline for this lecture

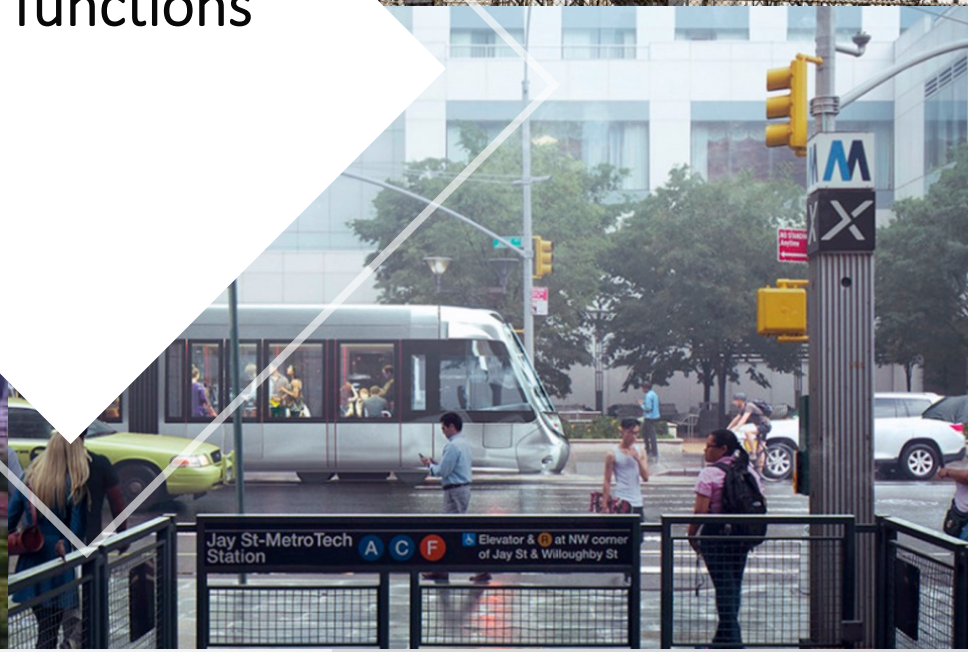
- Keywords
- Applications: Smart cities/cars/grid/living…
- Tools: learning/control/optimization

Cities

New York 上海

أبو ظبي

Basic city functions



What makes a city smart?

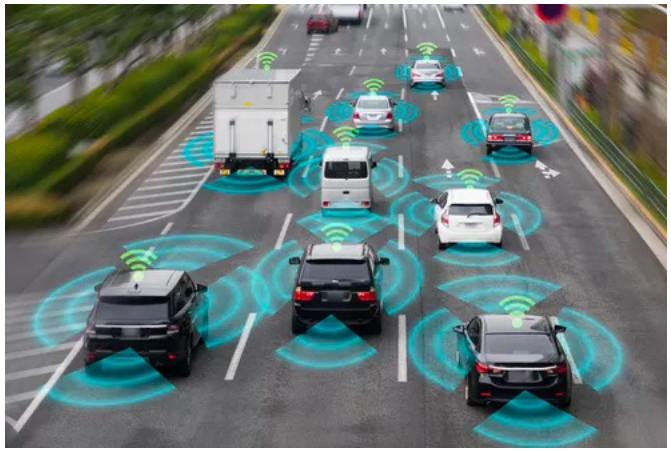
- Road traffic: autonomous vehicles, smart intersections
- Public transit: autonomous trains
- Power systems: smart grid
- Buildings: smart buildings
- Governance: smart policy making
- What is smart? -> Replacing human tasks with automatic algorithms.
- Artificial intelligence: basically the same idea.

Automated自动 vs. smart智能

- Automated: follow pre-programmed procedure, do pre-programmed task
- Examples:
  - Washing machine
  - Elevator
  - Automatic transmission car
- Smart: can make decisions in response to real environment; less/no human intervention needed
- Examples:
  - A washing machine that automatically selects the best cycle
  - An elevator that automatically selects floor for you
  - A car that drives on its own

Autonomous vehicles

- 自动驾驶汽车、无人车、自主汽车……
- Replacing human tasks with automatic algorithms.
- Human decisions (lower-level)
  - Steer
  - Throttle/brake
  - Turn on/off light
  - Windscreen wiper
- Human decisions (higher-level)
  - Change lane
  - Overtake
  - Turn left/right
  - Determine destination & route



Autonomous vehicles

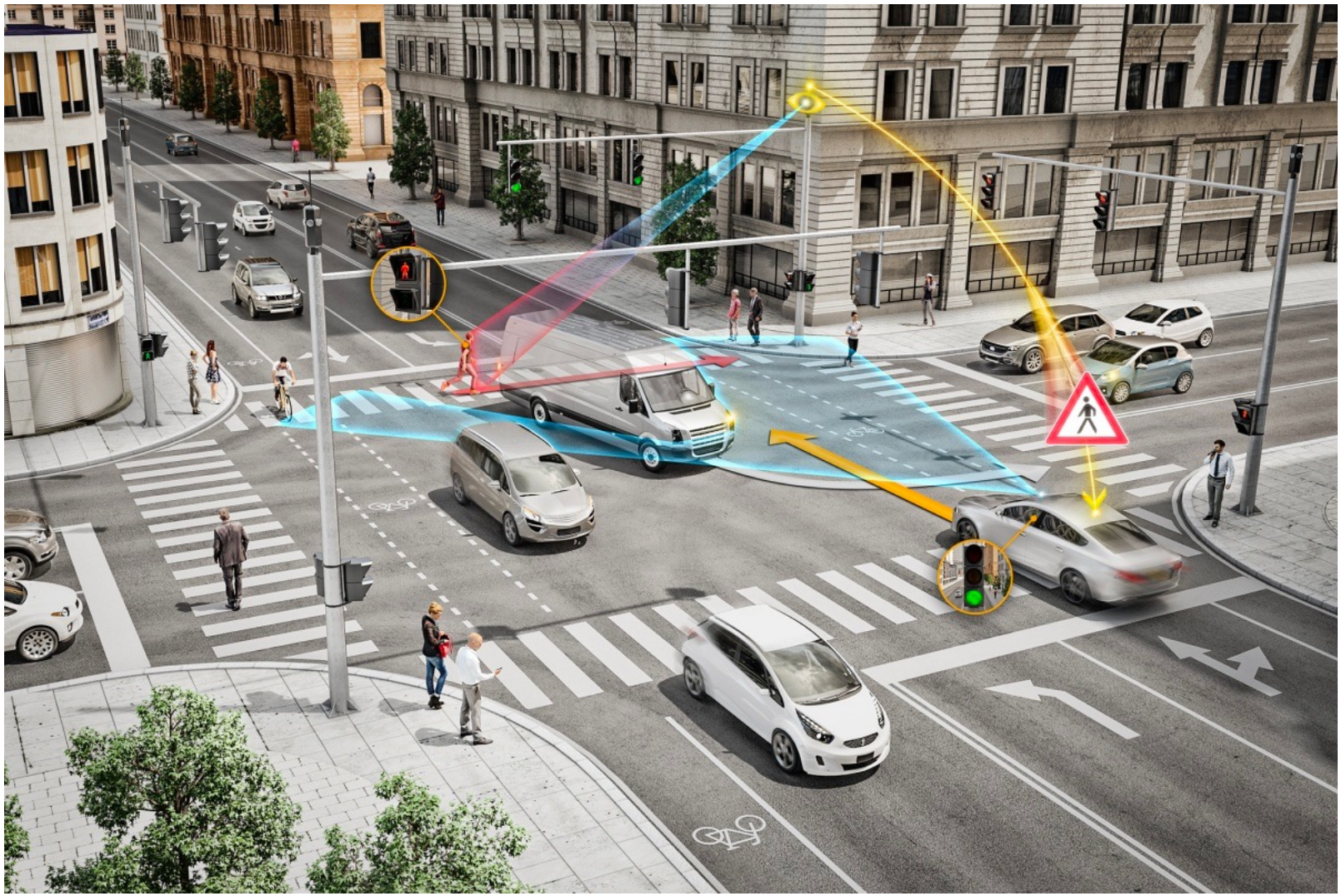
How does a human driver make decisions when driving?

- When to steer?
  - Need to make a turn
  - Need to adjust direction along the lane
  - Need to change lane
- Based on what does the driver make these decisions?
  - Make a turn: routing, intersection ahead
  - Adjust direction: geometry of markings
  - Change lane: movement of nearby vehicles (e.g. overtaking)
- How does a human driver obtain this information?
  - Eye: see marking, nearby vehicles, intersections
  - Ear: hear sounds

Why is a human driver smart?

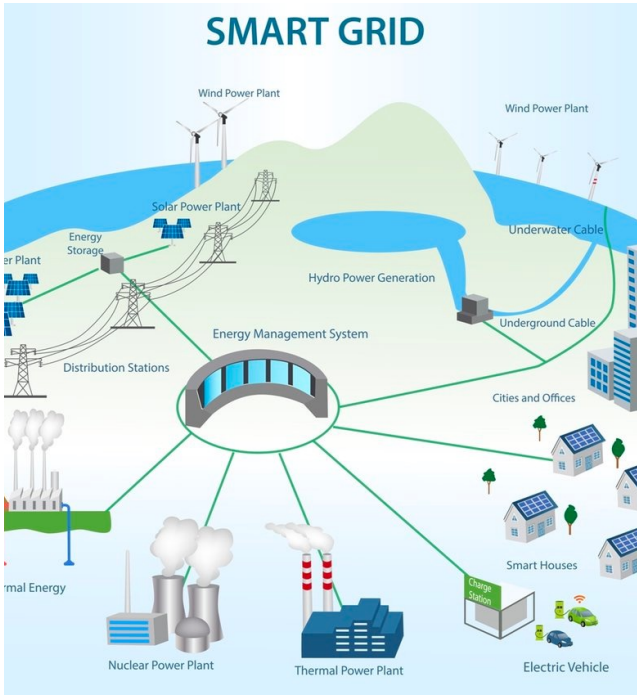
- A human driver can make decisions according to information collected from senses.
- If a car can do these on its own, then the car is smart.
- Smart = information -> decisions
- Indeed, automatic transmission cars can make decisions: they sense the speed and the throttle a human driver applies and change gears
- However, such decisions are mechanical and sort of trivial to human: it is like looking up a table
- For such automation that looks trivial to humans, we don’t call them smart

Smart intersection 智能路口



Smart intersection

- A non-smart intersection has a fixed green-red cycle
- This can be highly inefficient: compliant drivers may have to wait even if no vehicles are traveling in the other direction
- A smart intersection can perceive the movement of vehicles in multiple directions and allocate the green times in an intelligent manner
  - Essentially more green time to the more congested directions.
- But actual traffic condition is very complex and very uncertain; looking up a simple table does not work
- Need to construct a sophisticated table -> smart intersection!



Smart grid 智能电网

Smart grid

Fundamental challenges:

- Prediction
  - How many households will use electricity? (decisive factors?)
  - If electricity price is increased by 1%, how will the demand change?
- Planning
  - How many generators to activate over the next day? (why is this a non-trivial question?)
  - Where to install the smart meters?
- Resilience
  - What will happen if my prediction turns out to be terribly wrong?
  - What if a generator is suddenly down?
  - What if demand suddenly increases 20% in 30 minutes?

Smart living
智慧生活

Replacing your everyday decisions with computer decisions

- Managing finance
- Planning and preparing meals
- Family health care
- Education
- Household maintenance
- Generating income and recreation
- Social life maintenance

Smart waste management
智慧废物管理

- Based on geographic information systems (GIS)
- IoT-based measurement of waste volume
- Dynamically allocate storage & processing resources

Smart economy 智慧经济

- Knowledge economy driven by innovation & technologies
- Supported by academia, industry, and people
- Wise management of natural & human resources
- *Planned economy（计划经济）2.0?*

Smart governance
智慧治理

- Enhanced information collection
- Improved transparency
- Optimized public resource allocation
- Privacy & security

Smart agriculture
智慧农业*

- Using computers to make decisions: irrigation, fertilization, breeding…
- Computers can take over tedious monitoring & decision-making tasks
- Computers can handle datasets beyond human comprehension

What does smart mean?

- The term “smart” is a rather vague notion in engineering.
- Roughly speaking, it refers to computer-driven devices/facilities that can integrate external information and make non-trivial decision.
- The term “non-trivial” is really up to common sense.
- So, automatic transmission is not smart, but self-driving is: self-driving looks much more complex than looking up a table.
- Actually, self-driving is essentially looking up a table, BUT the table is so extensive and so sophisticated that human brain cannot process or even understand it

Cyber-physical systems

- Smart city is essentially a collection of cyber-physical systems (CPS)
- CPS = cyber part + physical part

System	Cyber part	Physical part
Autonomous vehicle	?	?
Smart roads		
Smart grid		
Smart buildings		
Smart agriculture		

Where do engineers stand?

- Conventional engineering: build vehicles, build bridges, build power plants…
- Conventional engineers: draw structural plots, calculate mechanics, select materials and components…
- Modern or future engineering: replace mechanical human work with computers

Where do engineers stand?

- Future engineering: replace human decisions with computer decisions
- NOT a trivial problem!
- Computers need to first understand human decisions; already hard
- Then computers attempt to outperform human; even harder

Three core notions of this course

- Control 控制
  - Feedback control 反馈控制
  - Adaptive control 自适应控制
  - Robust control 鲁棒控制
  - Learning-based control 学习控制
- Optimization 优化
  - Stochastic optimization 随机优化
  - Robust optimization 鲁棒优化
  - *Game theory 博弈论*
- Learning 学习
  - Machine learning 机器学习
  - Statistical learning 统计学习
  - Reinforcement learning 强化学习

Control 控制

- Typically refers to decision making in real time.
- Using automatic algorithms to instruct the behavior of hardware.

The scope of control is much broader than playing with machines…

Control 控制

Control

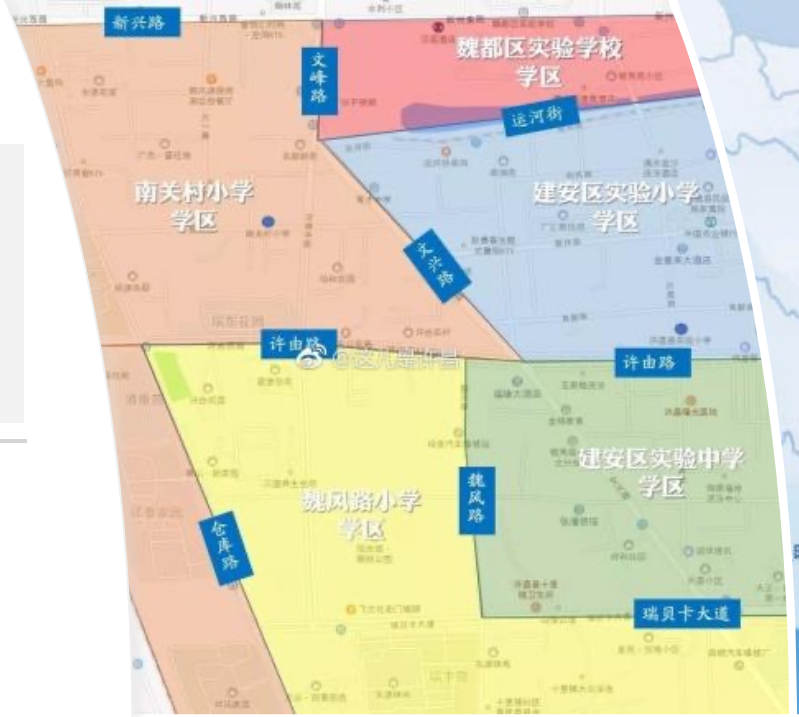
- Essential concepts in control
- State 状态: information that you need to predict the evolution of a system
- Observation 观测: capability of collecting information about the behavior of a system
- Actuation 制动: send a command to the system to influence the evolution thereof
- Controller/control policy/control law 控制器/控制策略/控制法则: the logic according to which the actuation command is generated

Control

- Open-loop control 开环控制
- Closed-loop/feedback control 闭环/反馈控制
- Stochastic control 随机控制
- Robust control 鲁棒控制
- Optimal control 最优控制
- Fault-tolerant control 容错控制
- Adaptive control 自适应控制
- Learning-based control 学习控制
- Secure control 安全控制

Optimization
优化

- Typically refers to decision-making at one time.
- That is, once the decision is made, it cannot be changed soon.
- Search the best action or sequence of actions to minimize some cost or maximize some reward.
- Here are examples of one-time actions.



Optimization

- Here are examples of a sequence of actions.

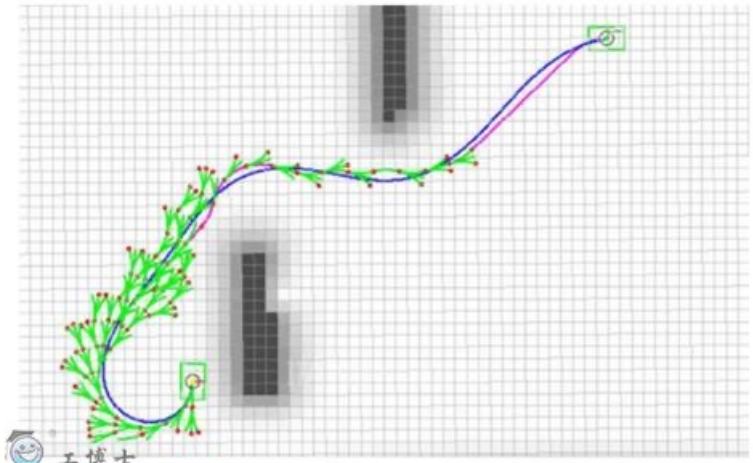


图2 启发式搜索到最优路径

Optimization

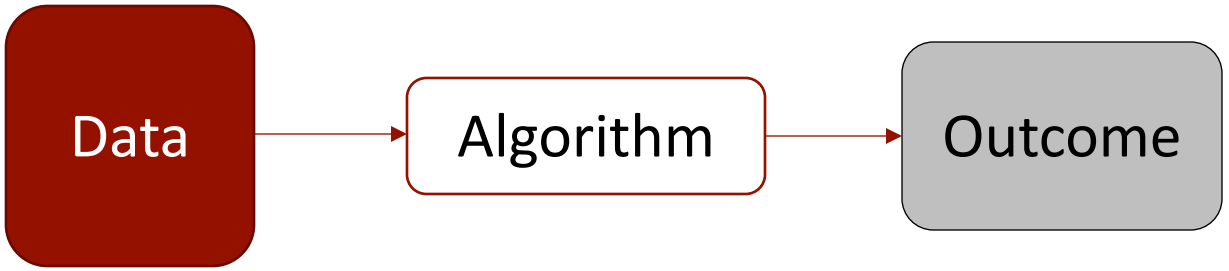
- Architecture of optimization problems
- Data 数据
  - Prior information that defines the environment in which you make decisions
- Decision variables 决策变量
  - Quantities that you need to specify/select
- Constraints 约束条件
  - Conditions that the decision variable must satisfy
- Objective function 目标函数
  - Criterion you use to evaluate decisions

Optimization

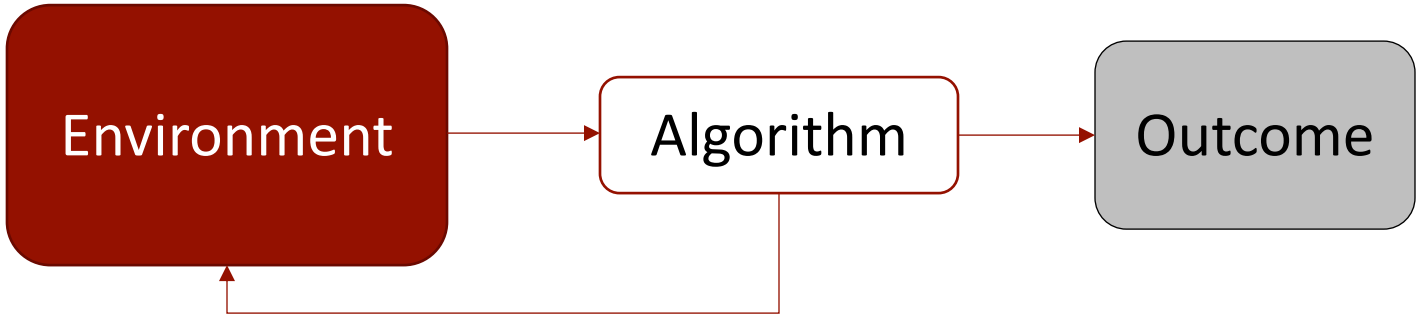
- Linear programming 线性规划
- Quadratic programming 二次规划
- Integer programming 整数规划
- Convex optimization 凸优化
- Stochastic optimization 随机优化
- Robust optimization 鲁棒优化
- *Game theory 博弈论*
- Analytical solutions 解析解
- Heuristic algorithms 搜索算法
- Learning-based approaches 学习方法

Machine learning

- Statistical learning (this course):



- Reinforcement learning (VE558):



Statistical learning

Statistical learning plays a key role in many areas of science, finance and industry. Here are some examples of learning problems:

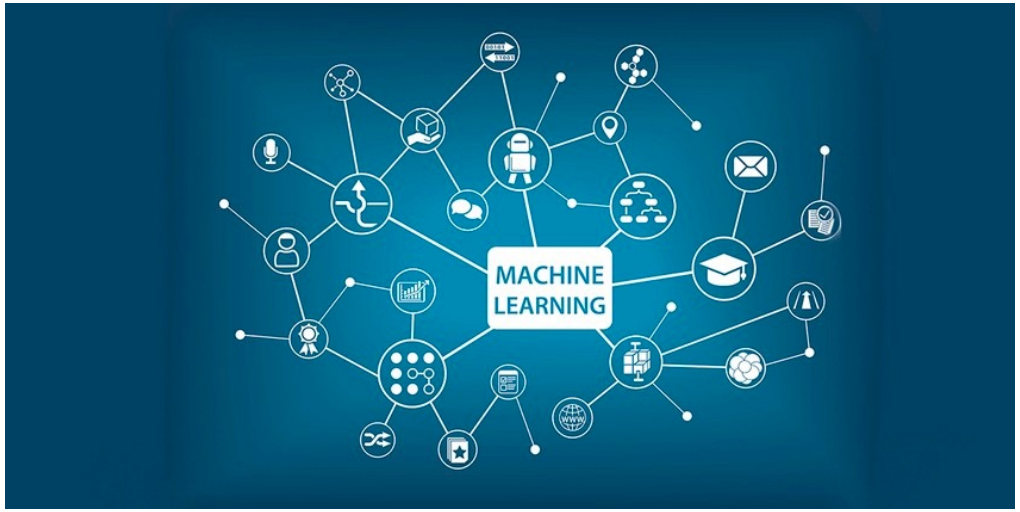
- Predict whether a patient, hospitalized due to a heart attack, will have a second heart attack. The prediction is to be based on demographic, diet and clinical measurements for that patient.
- Predict the price of a stock in 6 months from now, based on company performance measures and economic data.
- Identify the numbers in a handwritten ZIP code, from a digitized image.
- Estimate the amount of glucose in the blood of a diabetic person, from the infrared absorption spectrum of that person's blood.
- Identify the risk factors for prostate cancer, based on clinical and demographic variables.

Typical scenario

- In a typical scenario, we have an outcome measurement, usually quantitative (such as a stock price) or categorical (such as heart attack/no heart attack), that we wish to predict based on a set of features (such as diet and clinical measurements).
- We have a training set of data, in which we observe the outcome and feature measurements for a set of objects (such as people).
- Using this data we build a prediction model, or learner, which will enable us to predict the outcome for new unseen objects.
- A good learner is one that accurately predicts such an outcome.

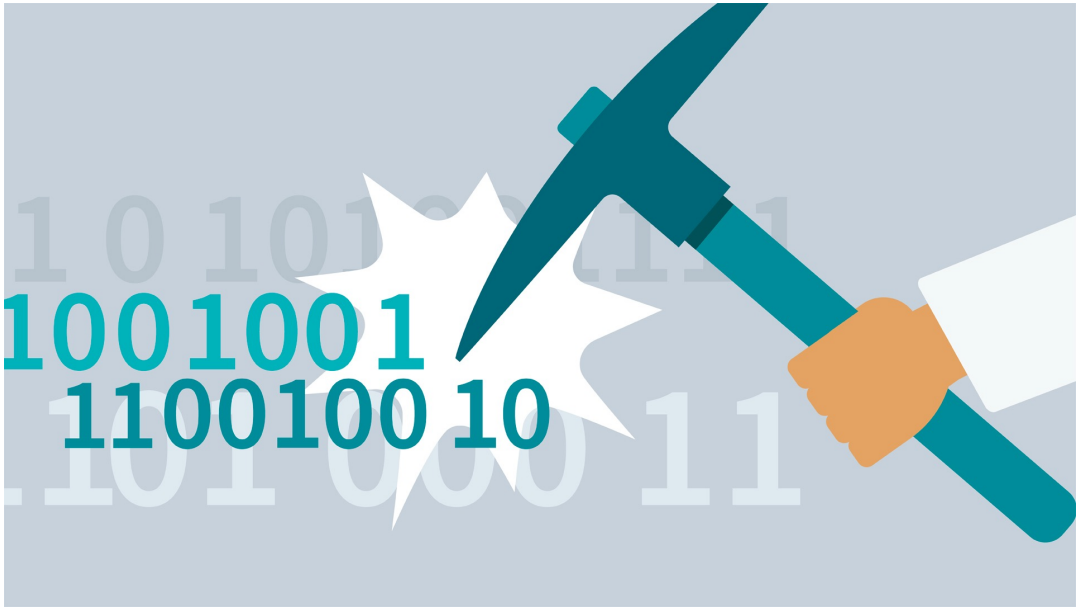
Machine learning

- Study of algorithms and statistical models that computer systems use to perform a specific task without using explicit instructions, relying on patterns and inference instead.
- Machine: automatic, minimal human intervention
- Learning: human do not specify everything; machine itself evolves



Data mining

- Discovery of patterns in data
- Using machine learning, statistics, and database systems
- Application of machine learning
- “Big Data”
  - Amount
  - Heterogeneity



Machine learning algorithms

- Linear regression/classification
- Nonlinear regression/classification
- k-nearest neighbor, clustering
- Tree regression/classification
- Support vector machine
- Neural networks
- Deep neural networks

Artificial intelligence

- Any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals
- Colloquially, the process of maximizing chance of success should be a non-trivial one
- For example, automatic transmission is responsive to environment (throttle and brake), but the response is trivial; hence this is not considered as AI
- But self-driving is responsive to the environment with a much more sophisticated mechanism, so it is AI

Coding

- Basic knowledge of coding is required!
- No sophisticated algorithms; mostly simulation of smart city applications
- For help with coding, see
  - MATLAB: https://ocw.mit.edu/resources/res-18-002-introduction-to-matlab-spring-2008/lecture-notes/
  - Python: https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-01sc-introduction-to-electrical-engineering-and-computer-science-i-spring-2011/index.htm
  - C++: https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-096-introduction-to-c-january-iap-2011/

Control vs. Optimization

Control

- Decisions in real time
- Typical objective: find a feasible way to fulfill a certain task
- Electrical engineering

Optimization

- Decisions at one shot
- Typical objective: find the optimal way to fulfill a certain task
- Industrial engineering

But actually, the boundary between control and optimization can be quite vague…

- **Optimal control…**
- **Rolling horizon optimization…**

Hence, this course is titled “decision making”.

Discussion: human vs. computers

- If we have computers, why we need to learn all of these? Why don’t we just throw everything into a computer?

Summary

This course helps you build **awareness** of

- Smart city modules
  - Smart mobility
  - Smart grid
  - Smart economy
  - Smart governance
  - …
- Core concepts
  - Learning
  - Control
  - Optimization

Next time

Autonomous driving: speed tracking