GEM 1501 Problem Solving With Computers

Lecture 13:

Algorithmic Intelligence

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Overview

- Summary of previous lecture
- Artificial intelligence
- What to learn for final examination

Summary of Previous Lecture

Software Engineering

- Basic Model (Lifecycle): Requirements Analysis, Design, Implementation, Validation, Maintenance
- Object Oriented Programming
- The Models of Software Engineering

Lifecycle of Software

- **Requirements analysis.** What is needed for the product, what functionality should it have.
- **Design.** Break up the software into independent modules which might be designed by different programmers or subcontractors. Specify what each module has to do and how the information is interchanged between the modules.
- **Implementation.** Programme each module according to the given design. Integrate the various modules into one system.
- **Validation.** Make sure that the software does what it should. This is done by extensive testing; in some few cases also by explicit software verification with technical support for this process.
- **Maintenance.** Adjust the software to new requirements and developments, publish patches on the internet, help clients to get problems solved, repair bugs in the system and redeliver to clients (if necessary), write software connecting the system to other systems for data interchange and so on.

Object oriented Programming

- Modules have a clearly defined interface. They implement objects together with methods to modify or enquire information about objects. User functions can make new objects.
- The array object in Java Script can serve as an example. Its methods are mainly accessed by adding a dot and a method name:

```
x            Object
x.length     Length of the object, that is, number of array elements
x.pop()      Method moving off the last array element
x.join()     Method producing a text-representation of the object
x[2]         Second array element
x[3].length Length of the third array element (if an array again)
```

- Similar methods in different objects can have the same name:

```
11.88+33.55      Adding two numbers
"This "+"is "    Adding two texts
y.length         Length of array y or of string y
```

Information Hiding

- Modules and objects have interfaces and specifacations which tell users how to use functions and what the functions do.
- Specification and interface should not be changed. The user can rely on these things when he uses a function or a method of an object.
- The implementation can change and the user should either not know it or not exploit this knowledge when writing application programs.
- The principle of non-exploiting this information is called "information-hiding" — the user should act as if the implementation of the module is hidden away from him (what is also true in many cases).
- Example: Experiments reveal certain aspects of Java Script on certain browsers. Running programs using this (unofficial) source of information on other browsers might result in errors when the obtained information is not part of the official Java Script definition.

Algorithmics and Intelligence

- **Algorithmic intelligence?**
- Turing test
- Playing games
- Knowledge representation and expert systems
- Understanding natural language

Automatic Chess

- The Mechanical Chess Player
  `http://www.chesscentral.com/images1/capture-.jpg`
- In 1769 the Hungarian engineer Baron Wolfgang von Kempelen built a chess playing machine for the amusement of the Austrian Queen Maria Theresa. It was a purely mechanical device, shaped like a Turk. Naturally its outstanding playing strength was supplied by a chess master cleverly hidden inside the device. The machine was a fake.

Robot Stories I

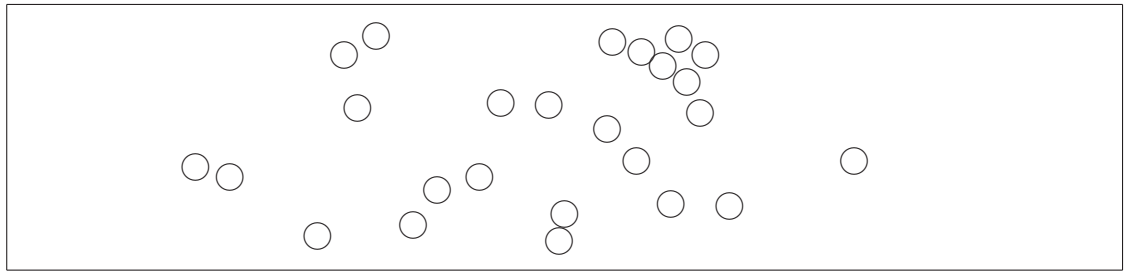
- **Blockworld**
  Robot should learn how to put together blocks to towers and so on by itself; performance not so convincing.
- **Housework**
  Robot should understand human commands and do the housework. Public performances often fake.
- **Robocup**: `http://www.robocup.org/`
  Various teams write software to control robots which play soccer. Robots are from the same manufacturer and identical for all teams. Two competitions: for doglike four-legged and humanoid two-legged robots.

Robot Stories II

- Space ships can travel to other planets and place their space-cars.
- Space-cars have been moving around on Mars where remote control commands need 10 to 20 minutes to travel both directions.
- Reasons for success:
  Wheels are easier to control than legs;
  much preprogrammed work permits to give more general goals than tiny steps;
  space-cars receive instructions in more adequate way than natural language;
  space-cars travel only at low speed (on average about 3 kilometres in a year) and use only good weather conditions.

Artificial Intelligence

- What is intelligent behaviour?
  - Being able to behave like a human ($\Rightarrow$ Turing test);
  - Being able to solve all problems an average humans can solve;
  - Being able to solve some important problems which are difficult for humans;
  - Being able to beat humans in games.
- Is art produced by computers human art (of the programmer) or machine art?



suna.comp.nus.edu.sg: "Random Circles"

Intelligence and value of a person

- The humans are the most intelligent animals; therefore many people believe that the value of a human comes from being intelligent.
- Nevertheless, "computers are intelligent" does not say that a computer would be entitled to have basic rights like a human or a human would be less worth than a more intelligent computer.
- Computers can today already calculate much faster and accurate than any human; nevertheless, computers, even intelligent ones, are a tool (which might cost a lot of money) but not a being with basic rights.
- Intelligent programs solving certain problems might be copied from one computer to another one, so that type of intelligence is not linked to a single machine or entity.

Artificial Intelligence and Workplace

- Technical progress has changed many workplaces during the last two centuries. For example, many craftsmen lost their jobs or changed from producing to repairing (as in the case of shoes).
- Computers kill not only manual jobs but also intellectual jobs: in the nineteenth century extraordinary calculation-skills qualified for many jobs, today it just qualifies for occasional television programs on that topic.
- Linking computers by the internet gave the next step of automatic revolution: Emails are sent automatically without anyone handling them in between, thus they are much cheaper than paper mail. At internet-commerce, the user enters all data through the internet and the processes of data entering and data manipulation are done automatically.
- All protests of people losing their job due to the machine revolution were vain. Only those countries keeping up with technological progress can on the long term avoid high unemployment rates.

What should a computer decide?

- Computer programs and data bases assist at decision-making: who gets a credit at a bank; at organ transplantation, which organ is given to which person; which freshman is permitted to study at which German university.
- Decisions are a mixture of programmers implementing some given task, governments setting the rules and computers which automatically learn from sample data on how such decisions should be made.

Algorithmics and Intelligence

- Algorithmic intelligence?
- **Turing test**
- Playing games
- Knowledge representation and expert systems
- Understanding natural language

Social Game

- Human interrogator IR
- Two rooms connected to IR via terminal
- One room has a man, one room has a woman
- IR has to find out which one is which

Turing Test

- Human interrogator IR
- Two rooms connected to IR via terminal
- One room has a human, one room has a computer
- IR has to find out which one is which

What a human knows?

- Linguistic skills: reading and writing in a language, understanding texts (see later)
- General facts: A person has two parents and might have children, the day has 24 hours and there are 365 or 366 days in a year.
- Facts about the country of origin:
  Who was the first chancellor of West-Germany?
  For which reason received Willy Brandt the Peace Nobel Prize?
  What happened on 09.11.1989?
  How many states has Germany and how many member countries has the European Union?
  Can all be found by searching the internet, so is accessible to computers in principal.
- Part of human knowledge depends on the country of origin and what is self-evident for a German to know might be unknown to a Singaporean.

How to pass the Turing test

- A computer should know enough background knowledge.
- Should a computer give occasionally wrong or delayed answers ("to err is human")?
- How should a computer deal with opinion questions like "Do you like coffee?"
- How should they react to jokes and obvious nonsense?
- How should a computer be taught that stuff?
- If a computer learns just from the internet, how should it distinguish facts from fake data out there?

Algorithmics and Intelligence

- Algorithmic intelligence?
- Turing test
- **Playing games**
- Knowledge representation and expert systems
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Playing Games

- Computer can play many games on strongest possible level.

  Examples: Tic Tac Toe, Nine Men's Morris.

- In some games, computers beat the strongest players (Backgammon).

- In some games, medium-strength players beat strongest computer programs (Go).

Chess

- Single games won by a computer (out of several ones)
  1978: Chess 4.7 defeated international master David Levy
  1988: Deep Thought defeated grandmaster Bent Larsen
  1996: Deep Blue defeated world champion Gary Kasparov
- Tournament won by a computer
  1997: Deep Blue defeated world champion Gary Kasparov 3.5 to 2.5 in a tournament. Deep Blue was just designed to play against Gary Kasparov; Kasparov did not know anything about Deep Blue while the programmers of Deep Blue had access to all of Kasparov's tournament matches.
- Turing-Test with Chess
  1980: Belle and several human players played grandmaster Helmut Pfleger in simultaneous games. Six games were evaluated by a panel of experts. Most failed to identify the game which was played by Belle. Victor Korchnoi was wrong; Gary Kasparov was right.

Computers Playing Games

- Game trees
- Heuristic search
- Evaluating positions (minimax)
- Opening and endgame databases

Minimax Search

- Evaluation of position x is $f(x)$ with high numbers giving good positions, low numbers give bad positions.
- $m(x, y)$ says there is a move from x to y for the player who's turn to move, alternate moves assumed.
- Search depth n moves beyond the current one, here example with n being 3.
- For each y_1 with $m(x, y_1)$, let

  $$f_3(y_1) = \min\{\max\{\min\{f(y_4) : m(y_3, y_4)\} : m(y_2, y_3)\} : m(y_1, y_2)\}$$

  and take move with maximal value $f_3(y_1)$.
- Minimax-strategy tries to predict future moves; search-depth depends on number of possibilities taken into account at every level.

Example - Tic Tac Toe

At Tic Tac Toe players write alternately symbol "O" or "X" onto 3*3 sized board.

Tic Tac Toe: +1 means player wins, -1 opponent wins, 0 otherwise.
Player writing the symbol "X" has to move in this situation:

```
X O .
O O X
. . X
```

Possibilities and Evaluation with one and two moves search depth

```
X O .  Evaluation -1:  X O .  Evaluation 0       X O X  Evaluation +1:
O O X  Opponent can    O O X  or +1 depending    O O X  Player wins
X . X  win at next     . X X  on search depth:   . . X  now.
       move.                  after two moves
                              player has won.
```

Search Tree

```
Player "X", 3  Moves      Player "O", 2 Moves     Player "X", 1 Move
  Move 1                    Move 1.1, "O" wins
                            Move 1.2                Move 1.2.1, "X" wins
  Move 2                    Move 2.1                Move 2.1.1, "X" wins
                            Move 2.2                Move 2.2.1, "X" wins
  Move 3, "X" wins

f(Move 1) == Min{-1,Max{+1}} == -1,  bad move
f(Move 2) == Min{Max{+1},Max{+1}},   good move
f(Move 3) == +1,                     good move
```

Minimax Search

- Based on Evaluation Function.
  For chess, king 10000, queen 900, castle 500, bishop 325, knight 300, pawn 100
  evaluation = value(own pieces) - value(opponents' pieces)
- On average 40 legal moves in given situation and 1600 possibilities for full move (white and black)
- Pruning off certain uninteresting moves permitted search depth 6 half-moves in 1958
- Special purpose computer Belle (1980): 8 to 9 half-moves
- Search depth of 14 half-moves (= 7 moves) might be equivalent to challenge world champion
- In addition: data bases on how to start and finish games where much historic data is available
- More information
  `http://www.chessbase.com/columns/column.asp?pid=102`

Algorithmics and Intelligence

- Algorithmic intelligence?
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- Playing games
- **Knowledge representation and expert systems**
- Understanding natural language

Knowledge Representation

- $2 \cdot 4 = 8$
- "Giraffes have long necks."
- "Alan Turing was brilliant."
- How to collect and store knowledge?

Logic Programming

- Logic programming works in highly structured domains
- These domains are subject to "predicate logic"
- The truth of every statement can be rigorously judged

Example

- "John is Mary's father."
- "A parent of any ancestor of a person is also an ancestor of the person."
- ```
  father(john,mary). mother(anne,mary).
  ancestor(X,Y) :- father(X,Y).
  ancestor(X,Y) :- mother(X,Y).
  ancestor(X,Y) :- father(X,Z), ancestor(Z,Y).
  ancestor(X,Y) :- mother(X,Z), ancestor(Z,Y).
  ```
  ```

Expert Systems

- Some domains of knowledge require large amounts of data
- Data is sometimes highly structured
- Organic chemistry, genetics, microelectronics
- Expert systems formalize such knowledge and support the human decision maker
- Would you trust an expert system as your doctor in intensive care?

Algorithmics and Intelligence

- Algorithmic intelligence?
- Turing test
- Playing games
- Knowledge representation and expert systems
- **Understanding natural language**

Natural Language Processing

- Under investigation since early 1960s
- Good success in voice recognition
- Systems for language recognition currently being commercialized
- Spell checking and rudimentary syntactic correctness check in many typesetting programs
- Language understanding in very limited domains possible
- General-purpose language understanding would require "true intelligence"

An Experiment

- Google's translation algorithm has been tested. A text was translated from English to German and back. The result of this translation is the following.
- Google-Übersetzung Algorithmus wurde getestet. Ein Text wurde übersetzt aus dem Englischen ins Deutsche und wieder zurück. Das Ergebnis dieser Übersetzung ist folgende.
- Googles Übersetzungsalgorithmus wurde getestet. Ein Text wurde aus dem Englischen ins Deutsche übersetzt und zurück. Das Ergebnis dieser Übersetzung ist das folgende.
- Google's translation algorithm has been tested. A text was translated from English to German and back again. The result of this translation is the following.

Comments on Experiment

- Translation had been corrected before retranslation. Without the correction, the result has been much worse.
- Translation quality much better than two years before.
- Google's Algorithm is very sensitive to minor grammatical errors which every German makes frequently. Such errors mess up the translation.
- Translation does not always give grammatically correct sentences; this should be possible with today's language tools.

Problems at automatic translation

- One word, several possibilities: Does "English" denote the adjective belonging to England, the language or the people? When translating from English to German or Spanish: Is a teacher, author, worker, secretary, office-clerk, ... male or female? In German and Spanish, each word has two forms like actor and actress. When translating to Japanese or Chinese, is a brother or sister older or younger?
- Adding information needed for one language which is missing at the source. Several languages permit to omit words like "he", "she", "I", "we" when they can be found from the context. Some languages have to different words for "we": inclusive (speaker and audience) and exclusive (speaker without audience).
- Knowing when to put articles and when not.
- Proper names can cause a problem because one does not know how to write them in a different alphabet.

Summary Today's Lecture

- Algorithmic intelligence?
- Turing test
- Playing games
- Knowledge representation and expert systems
- Understanding natural language
- **What to learn for final examination**

What to learn for final examination

- List of 30 topics (with subtopics)
- This list covers topics of all questions
- Final examination has 50 marks for 10 questions
- Marks of assignments, midterms and final summed up
- Quotas for how many A and B per class; a C needs more than a third of the marks, aim for 40 marks; a D is passed only if S/U option is not set.

Mathematical Functions, Efficient Computing

(1) Certain functions come up in mathematics all the time
Product, sum, difference, division, faculty $1 * 2 * 3 * ... * n$, root, logarithm where log(2) is 1, exponentiation, Fibonacci numbers where a_1, a_2 are 1 and a_{n+2} is $a_n + a_{n+1}$, choose(n, m) which is the coefficient of x^m in $(1+x)^n$, polynomials of all type, easy variations of these all.
Other functions might occur, but need not to be recognized.

(2) Computing can be made efficient by using arrays

```
function choose(n,m)
  { if ((m<0)||(m>n)) { return(0); }
    var a = new Array(n+1); var i; var j;
    for (i=0;i<=n;i++)
      { a[i]=new Array(i+1); a[i][0] = 1; a[i][i] = 1;
        for (j=1;j<i;j++)
          { a[i][j] =  a[i-1][j-1]+a[i-1][j]; } }
    return(a[n][m]); }
```

Syntax Check, Understanding Programs

(3) Underline all syntax errors in the following program

```
funktion fakultaet(n)
  { var m; var k,
    fuer (m=1;m<=n;m++)
      { k=k*m, }
    rueckgabe(k); }
```

(4) What does this function compute? Determine $c(i,j)$ for i,j in $\{0,1,2,3,4\}$. What is the worst time complexity, is it optimal?

```
function c(i,j)
  { if ((j<0)||(j>i)) { return(0); }
    else if ((j<1)||(j>=i)) { return(1); }
    else { return(c(i-1,j-1)+c(i-1,j)); } }
```

Programming Languages,History of Computing

(5) Learn basic facts about programming languages
Nevertheless, all what you need to know is on slides of this lecture

(6) Knowledge about some basic facts on the history of computing is good.
About what time was the first computer build?
☐ 1789, ☐ 1942, ☐ 1968.
Did the machine constructed by Charles Babbage ever work?
☐ Yes, ☐ No.
What is Hermann Hollerith famous for?
☐ Being a pioneer of Fortran,
☐ Producing tabulating machines for the 1890 census in the USA and founding a company which became a part of IBM,
☐ Finding an algorithm which shows that nondeterministic PSPACE and deterministic PSPACE are the same.

Programming Basics, Terminology

(7) Fundamental terminology of Programming
What is a binary, a decimal and a hexadecimal number?
What is a compiler?
What is an interpreter?
What is an editor?
What is html?
What is a webpage?

(8) What is a correct program?
What is a partially correct program?
When does a program terminate?
Are there programs which sometimes but not always terminate?

Information and Control

(9) Data Structures
Numbers, Strings, Arrays, Records
How can these things be implemented in Java Script?

(10) Control Structures
Write a sample program which uses all of the following Control Structures in Java Script:

```
if (....) { .... }
if (....) { .... } else { .... }
for (....;....;....) { .... }
while (....) { .... }
do { .... } while (....);
```

Searching and Sorting

(11) What is the time complexity of the following sort algorithms? Give average case and worst case complexity.
Merge Sort, Bubble Sort, Pivot Sort, Linear Search, Binary Search.
Why is sorting important for search and retrieval?

(12) Consider the following algorithm.

```
var b = new Array(a.length); var k = 0;
while (k<a.length)
  { b[Math.floor(a[k]/100)] = a[k]; }
```

Let n be a.length. Under which of the following conditions would b produce a sorted copy of a? The array a contains

- ☐ the first n prime numbers;
- ☐ exactly one year out of each of the first n centuries;
- ☐ the first n years of the twentieth century.

Towers of Hanoi, Order

(13) What is the complexity of the Towers of Hanoi with 3 pegs and n Rings?

$\square$ $n^2 - 1$ Moves, $\square$ $2^n - 1$ Moves, $\square$ n^n Moves.

Write down the algorithm for your answer.

There are better bounds for the Towers of Hanoi with 4 or 5 pegs.

How much needs the Towers of Hanoi with 3 pegs for 10 rings?

Give a better bound for Towers of Hanoi with 5 pegs for 10 rings.

(14) Often one is just interested in the order of an algorithm.

What is the order of the Towers of Hanoi?

What rules hold for working with the order?

Give the order of $n^2 + 17n^3 + 48n^2 \log(n)$:

$\square$ $O(n^2)$, $\square$ $O(n^2 \log(n))$, $\square$ $O(n^3)$, $\square$ $O(n^3 \log(n))$.

Greedy versus Divide and Conquer

(15) A greedy algorithm always considers only few choices and takes from these the most promising one.
Example: Railroad Constructors.

(16) A divide and conquer algorithm splits the problem into subproblems of equal size. It solves the subproblems and then combines these solutions to an overall solution.
Example: Merge Sort, Pivot Sort, Parallel Algorithm for Maximum.

Graphs and Matrices

(17) Graphs can be coded into matrices.
Easiest method: `a` is $n \times n$ matrix and `a[i][j]` is 1 if there is a connection from node i to node j in the graph and 0 otherwise.
Following questions might be asked:
Given i, find all j which can be reached from i.
Given i, j, find shortest path from i to j.
Related topic: Dynamic Programming

(18) General questions for matrices:
Provide an algorithm to compute the determinant.
Write a program to check whether two rows of a matrix are equal.
Write a program to add two matrices.
Write a program to multiply two matrices.

Machines

(19) What are the definitions of Finite Automata, Counter Programs and Turing Machines?
What are One-Stack and Multiple-Stack Automata? Do they have the same computational power?
What problems can a Finite Automaton solve?
What problems can be solved by a Turing Machine but not by a Finite Automaton?
Write some counter programs for everyday operations.

(20) Write finite automata recognizing the following languages:
All binary words containig exactly four times a 1;
All binary words which are a multiple of 3 when viewed as a number;
All binary words starting with 110101;
All binary words ending with 10 or 11.

Complexity Classes

(21) Write down the definitions of P, NP, PSPACE, EXPTIME, LOGSPACE, POLYLOGSPACE, NC, RP.
How does one define sublinear space for Turing machines?
Why does one use additional tapes for that?

(22) What are the relations between the complexity classes?
A known chain of inclusions is LOGSPACE $\subseteq$ NC $\subseteq$ P $\subseteq$ RP $\subseteq$ NP $\subseteq$ PSPACE $\subseteq$ EXPTIME.
Is it known whether PSPACE $\subseteq$ P?
Give some examples for typical problems in various classes.
The inclusion P $\subset$ EXPTIME is proper. Do you know also of other inclusions among this classes to be proper?

Easy and Hard Problems

(23) Name complete problems for the various complexity classes.
For example, the winning strategy problem of $n * n$ checkers is EXPTIME-complete.
3SAT, 4SAT, 5SAT, Travelling Salesman, Monkey Puzzle and Solvability of certain types of mathematical equations is NP-complete.
2SAT is not NP-complete as witnessed by the Resolution Algorithm.
Some problems like the Halting Problem are outside the here considered complexity classes and undecidable.

(24) Which are famous undecidable problems?
Monkey puzzles for all areas; Halting problem; Post Correspondence Problem; Totalness problem (which functions do halt on all inputs).
What does Rice' Theorem say?
What are decidable and recursively enumerable (r.e.) sets? Which of the famous undecidable problems are recursively enumerable?

Randomized Computation and Cryptography

(25) How is the class RP defined?
What is in the definition of RP and NP the main difference?
What is a typical problem in RP which is not known to be in P?

(26) Explain the differences between private and public key cryptography.
Would public key cryptography be possible if P = NP?
Which problem must be difficult to solve to make the RSA cryptography possible?
In the case that Alice and Bob have enough time to exchange data privately before they move to different towns and rely on telecommunication, can they run secure private key cryptography?

Software Engineering

(27) Explain the waterfall model of software engineering. What are the five main steps?
How does this model differ from the spiral modal?

(28) Explain the advantages of the following programming styles:
Why should a programmer use time for documentation?
Is structured programming really better than the moderate use of goto-statements?
What are the advantages of object-oriented programming (if any)?
Why is the principle of information hiding useful? Why is it not better to know as much as possible and to pass as much knowledge as one has?

Turing Test, Artificial Intelligence

(29) What is a Turing test?
Did any machine yet pass the Turing test in the original setting?
Can Chess players tell the difference between a computer playing and a human playing?

(30) Artificial Intelligence
What is a winning strategy?
What is the optimal result at the game Tic Tac Toe, if both players play as good as possible?

☐ Player "X" wins; ☐ Player "O" wins; ☐ Draw.

In which of the following games is it more difficult for computers to win against a good human player:

☐ Chess; ☐ Go.

Summary

- Artificial Intelligence
- What to learn for the examination

  Sample questions cover topics, but the actual questions are different and can be more difficult. See also

  `http://www.comp.nus.edu.sg/~fstephan/testsolutions.html`