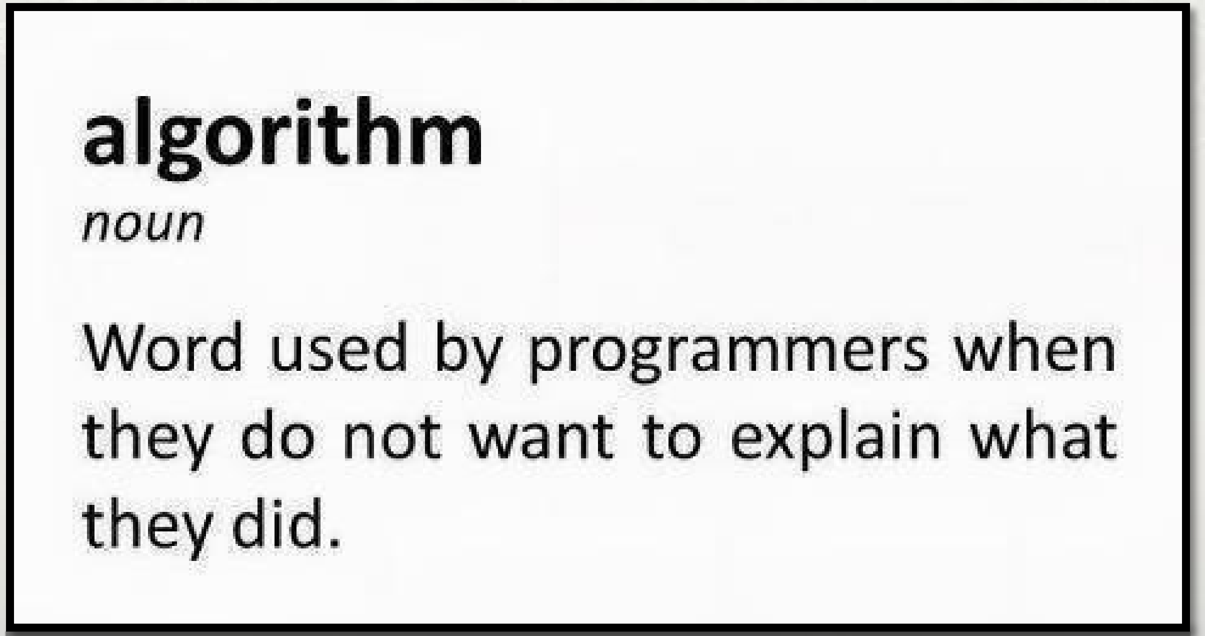
Algorithms 1 – An Introduction

by Hans Wichman



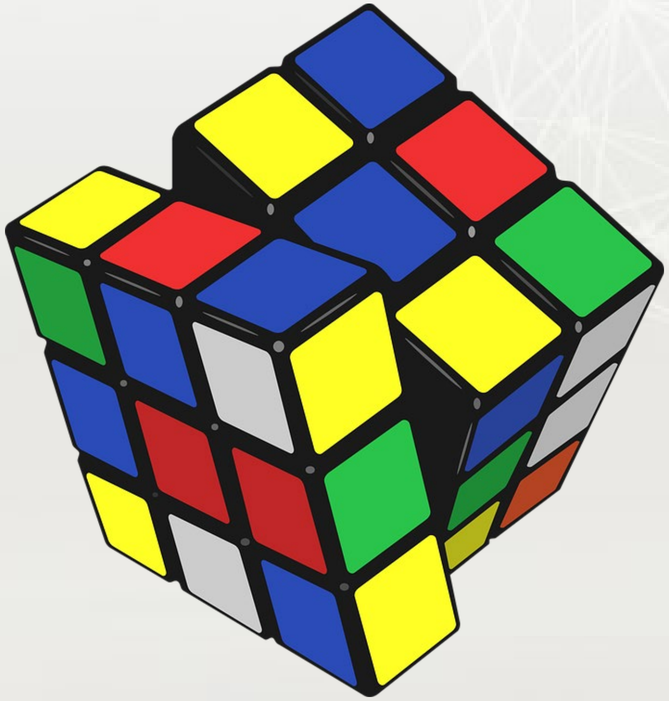
Today's topics

- What is an algorithm?
- What is a 'good' algorithm?
- Why should we learn about algorithms?
- What will we learn ? (AKA Learning objectives)
- Course approach and grading
- Getting started with algorithms & the assignments

What is an algorithm?

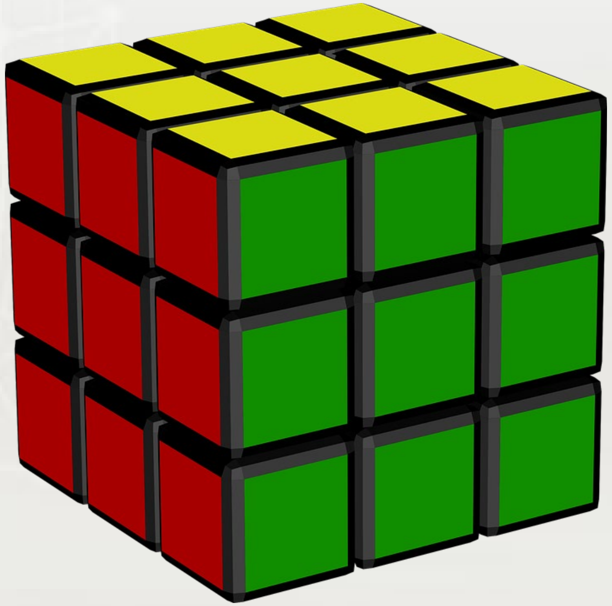
What is an algorithm?

PROBLEM



Algorithm:
the list of steps leading from the problem to the solution

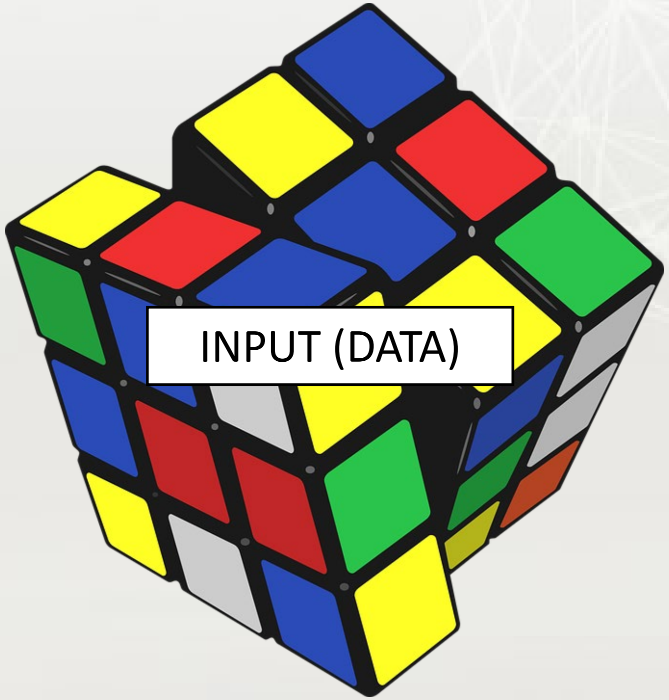
SOLUTION



For example:
If .... then rotate front, 2 times counterclockwise
If .... then rotate down, once clockwise

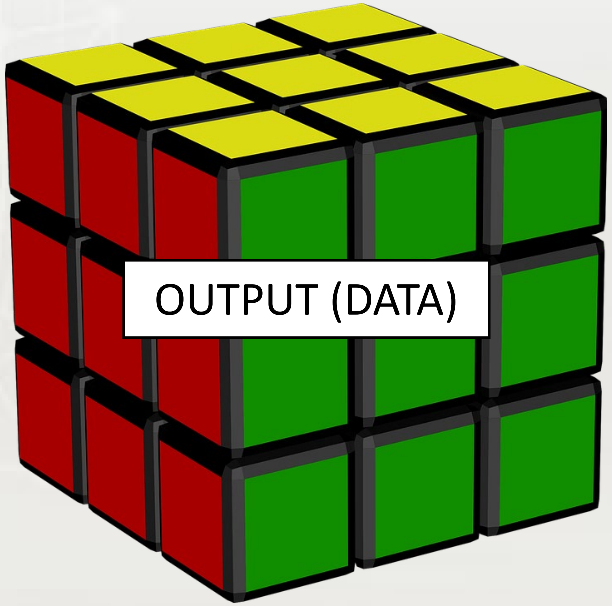
What is an algorithm?

PROBLEM

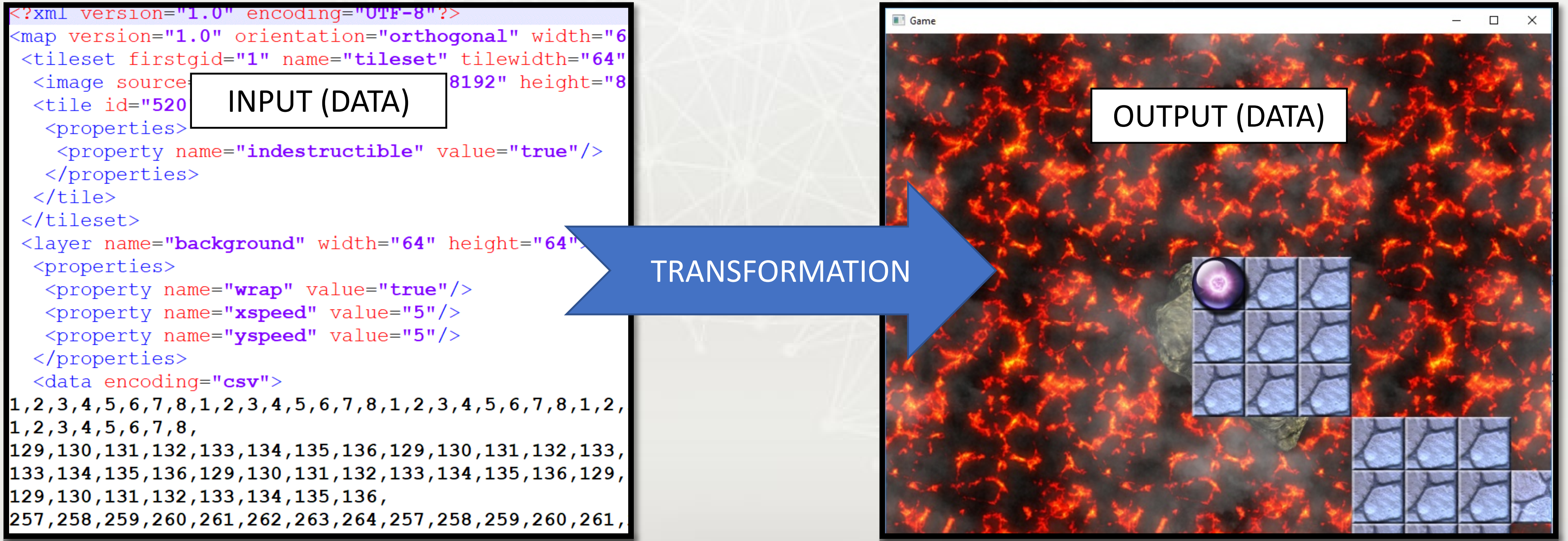


Alternatively we can view an algorithm as a TRANSFORMATION

SOLUTION

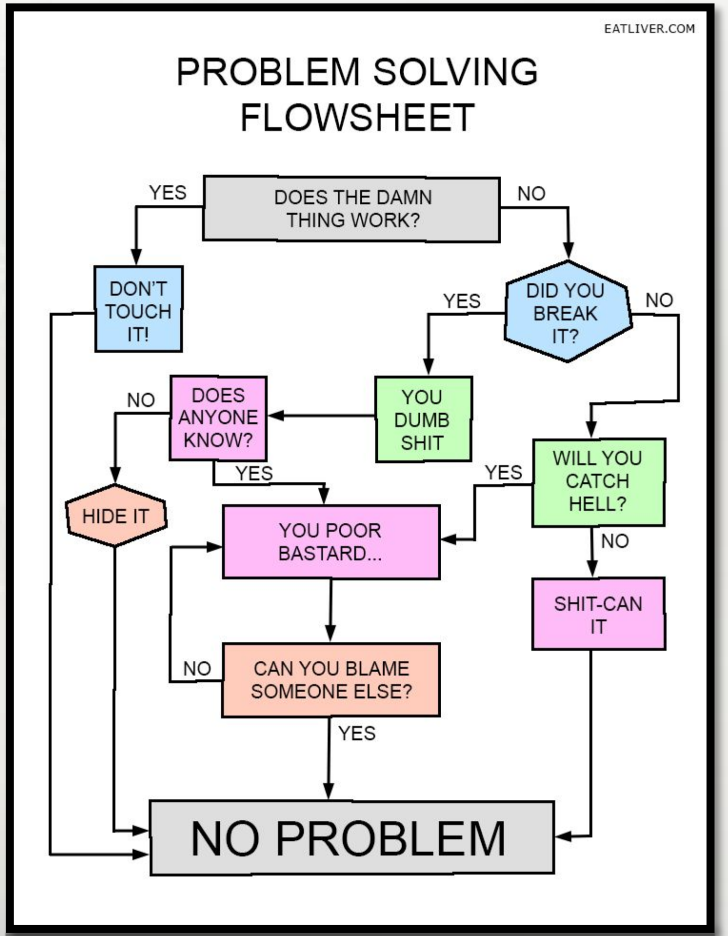


What is an algorithm?



Algorithms <u>exist independently</u> of computers

- Problems & thus algorithms have been around since long before computers ever existed.
- Any stepwise description of a solution to a problem can be called an algorithm, whether you use a computer to solve it or not.
- In fact it is often very helpful to start thinking about algorithms AWAY from the computer.



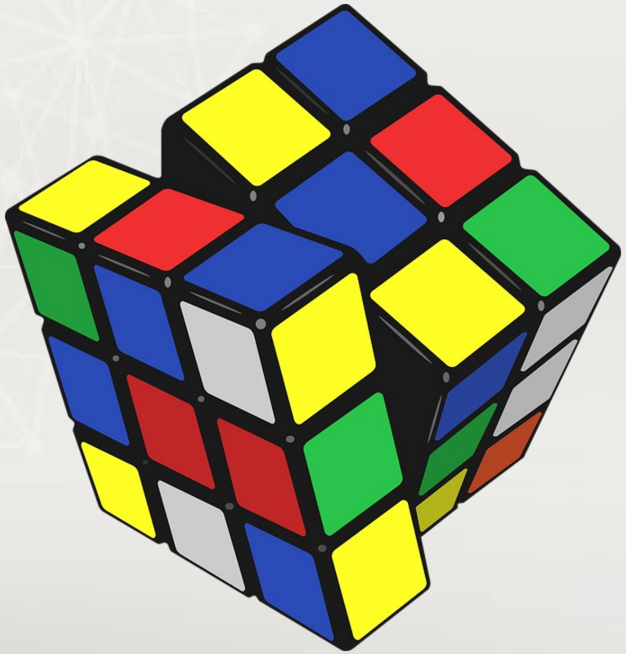
Computers + Algorithms =

- both computer programs and algorithms consist of a bunch of sequential instructions
- computers are very fast at executing (repetitive) instructions → complex algorithms often have a lot of them
- computers are very picky about precise instructions → algorithms need to be very precise

What is a good algorithm?

A ‘good’ algorithm ...

- Solves our specific problem
- Is efficient



Efficiency: Performance & Complexity

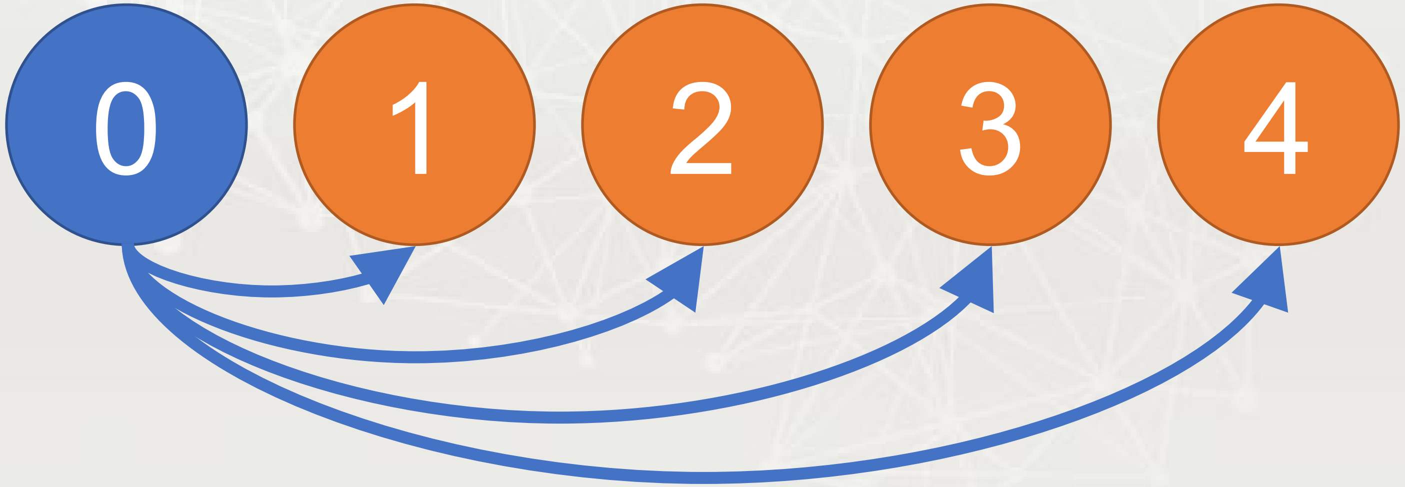
- Performance:
  - Runs within a specific predictable time frame
  - Which time frame is acceptable depends on your context
    - Finding the meaning of life → 7.5 million years is ok!
    - Pathfinding at 60 fps → 7.5 million years is not so ok!
- Complexity, meaning how well does the algorithm scale?
  - What happens to the execution time when we scale the amount of input data?
  - What happens to the memory requirements when we scale the amount of input data?

Time scaling example: collision detection

Given 5 balls:

How many checks do we have to do to see if any collide?

1^{st} iteration → 0 vs 1,2,3,4

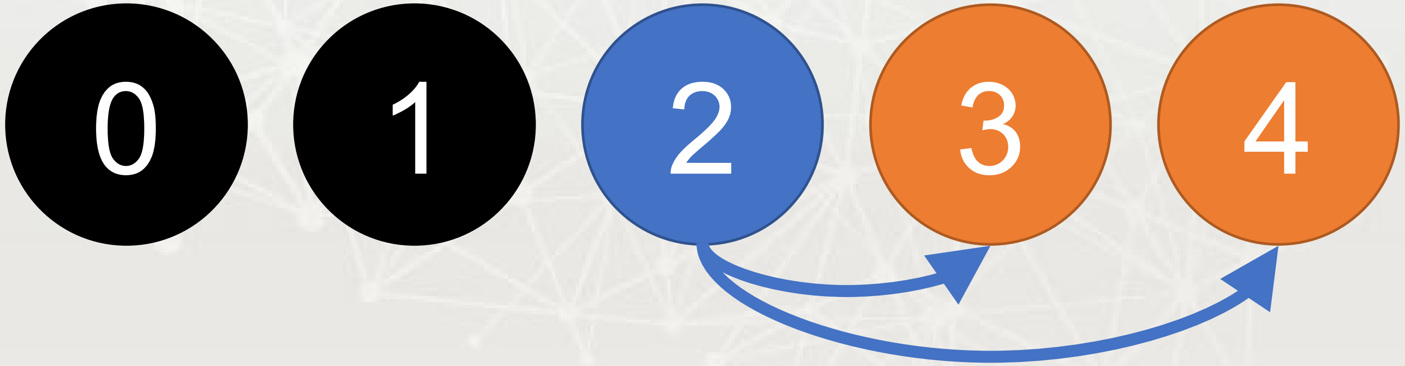


Running total = 4

2nd iteration → 1 vs 2,3,4

Running total = 4 + 3

3rd iteration → 2 vs 3,4



Running total = 4 + 3 + 2

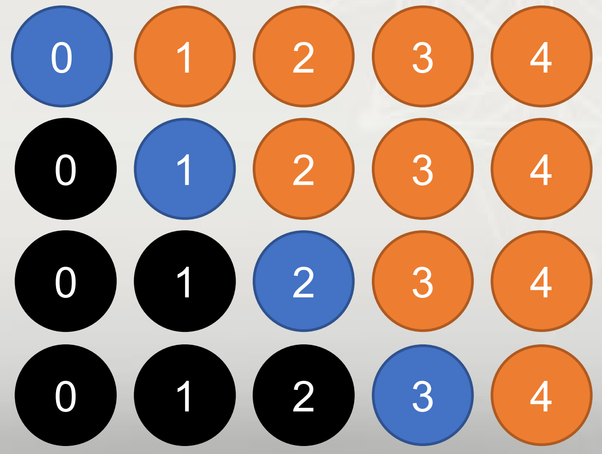
Last iteration → 3 vs 4

Running total = 4 + 3 + 2 + 1 = 10

Basically, in code (Our 1st algorithm!)

```
for (int i = 0; i < objects.Count-1; ++i) {
    for (int j = i+1; j < object.Count; ++j) {
        if (objects[i].hitTest (objects[j])) {
            /* do something */
        }
    }
}
```

This is the interesting part. The core loop that will be executed on every iteration!



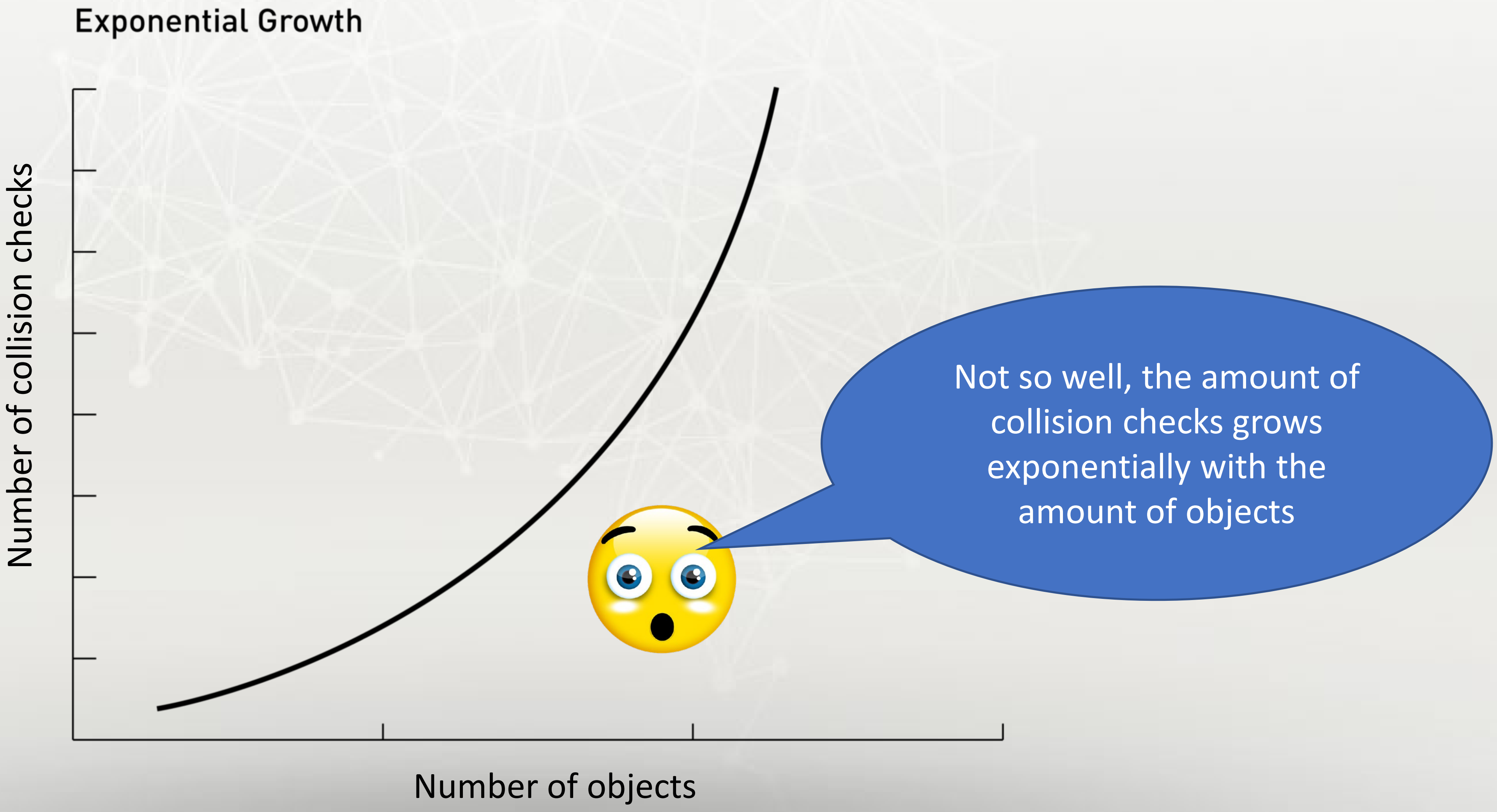
Number of collision check for n objects

Number of objects	Collision checks
5 = 4 + 3 + 2 + 1	10

Number of collision checks for n objects

Number of objects	Collision checks
5 = 4 + 3 + 2 + 1	10
10 = 9 + 8 + 7 + 6 + … + 1	45
100 = 99 + 98 + 97 + … + 1	4.950
1.000 = 999 + 998 + 997 + … + 1	499.500
10.000 = 9999 + 9998 + 9997 + … + 1	49.995.000
….	
1.000.000 = 999.999 + 999.998 + … + 1	499.998.500.001

How well does this algorithm scale?



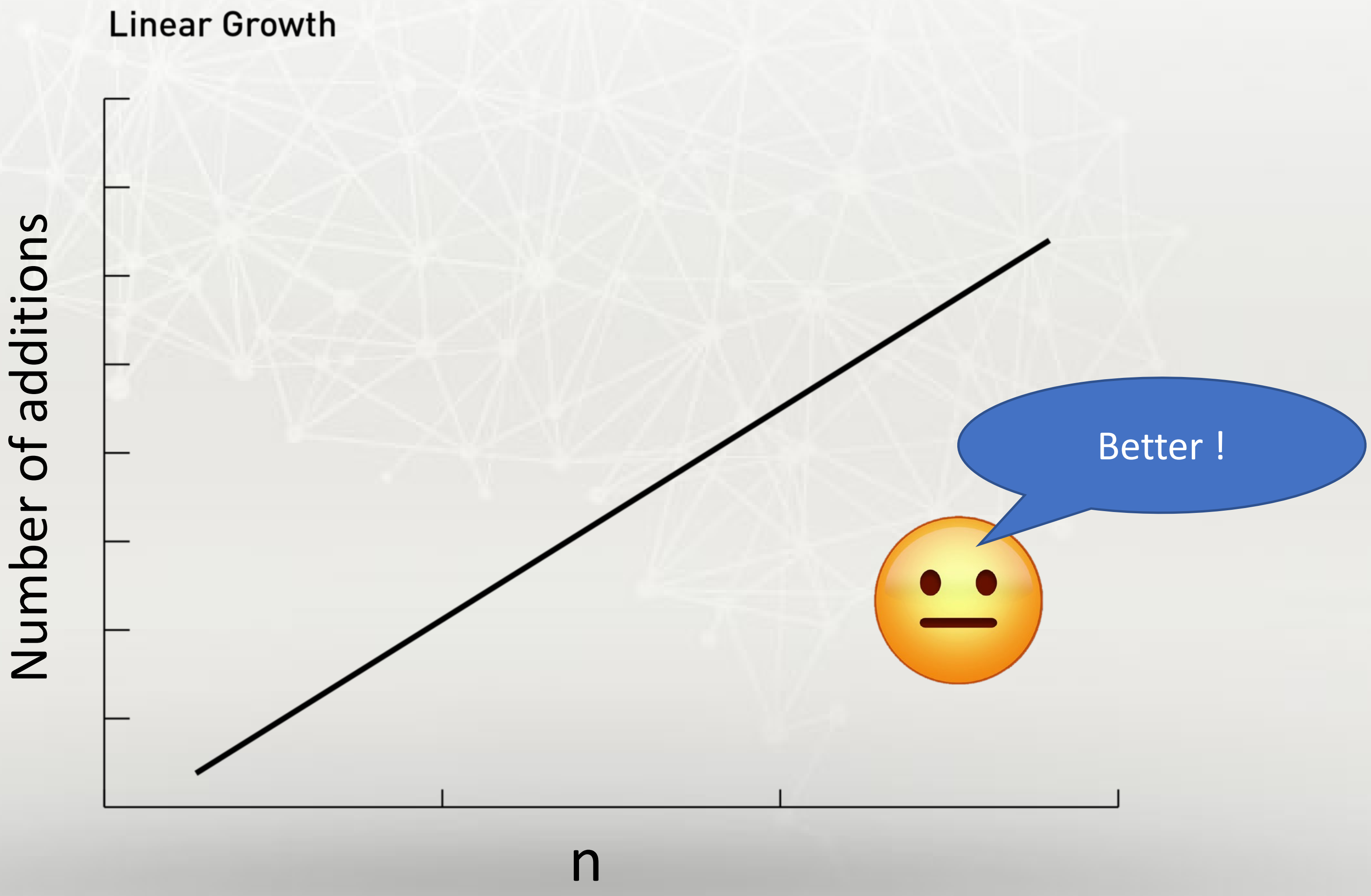
How about the algorithm we used to "Calculate the amount of collisions for n objects" ?

- 5 objects: 4 + 3 + 2 + 1 → 4 additions
- 10 objects: 9 + 8 + 7 + 6 + .. + 1 → 9 additions
- 1000 objects: 999 + 998 + .. + 1 → 999 additions
- etc

```
int amountOfCollisions = 0;
int amountOfObjects = …;
for (int i = 1; i < amountOfObjects; ++i) {
    amountOfCollisions += i;
}
```

This is the interesting part. The core loop that will be executed on every iteration!

How well does this algorithm scale?



But isn’t there a smarter way to calculate something like 4 + 3 + 2 + 1 (given n=5) ??

Given 4 + 3 + 2 + 1

Add 1 + 2 + 3 + 4

Total 5 + 5 + 5 + 5

Equals 5 * 4 → which is n * (n-1)
but it's twice the amount we need, so divide by 2.

We found a smarter way! → n * (n-1) / 2

“Calculate the amount of collisions for n objects” Old vs New comparison for n = 5

4 + 3 + 2 + 1 = 10

VS

5 * 4 / 2 = 10

“Calculate the amount of collisions for n objects” Old vs New comparison for n = 1000

999 + 998 + 997 + 996 + 995 + 994 + 993 + 992 + 991 + 990 + 989 + 988 + 987 + 986 + 985 + 984 + 983 + 982 + 981 + 980 + 979 + 978 + 977 + 976 + 975 + 974 + 973 + 972 + 971 + 970 + 969 + 968 + 967 + 966 + 965 + 964 + 963 + 962 + 961 + 960 + 959 + 958
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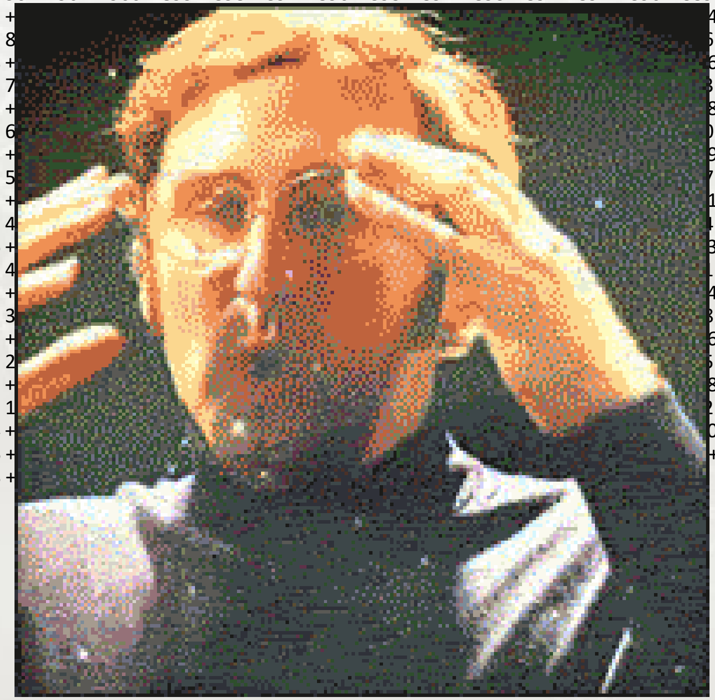
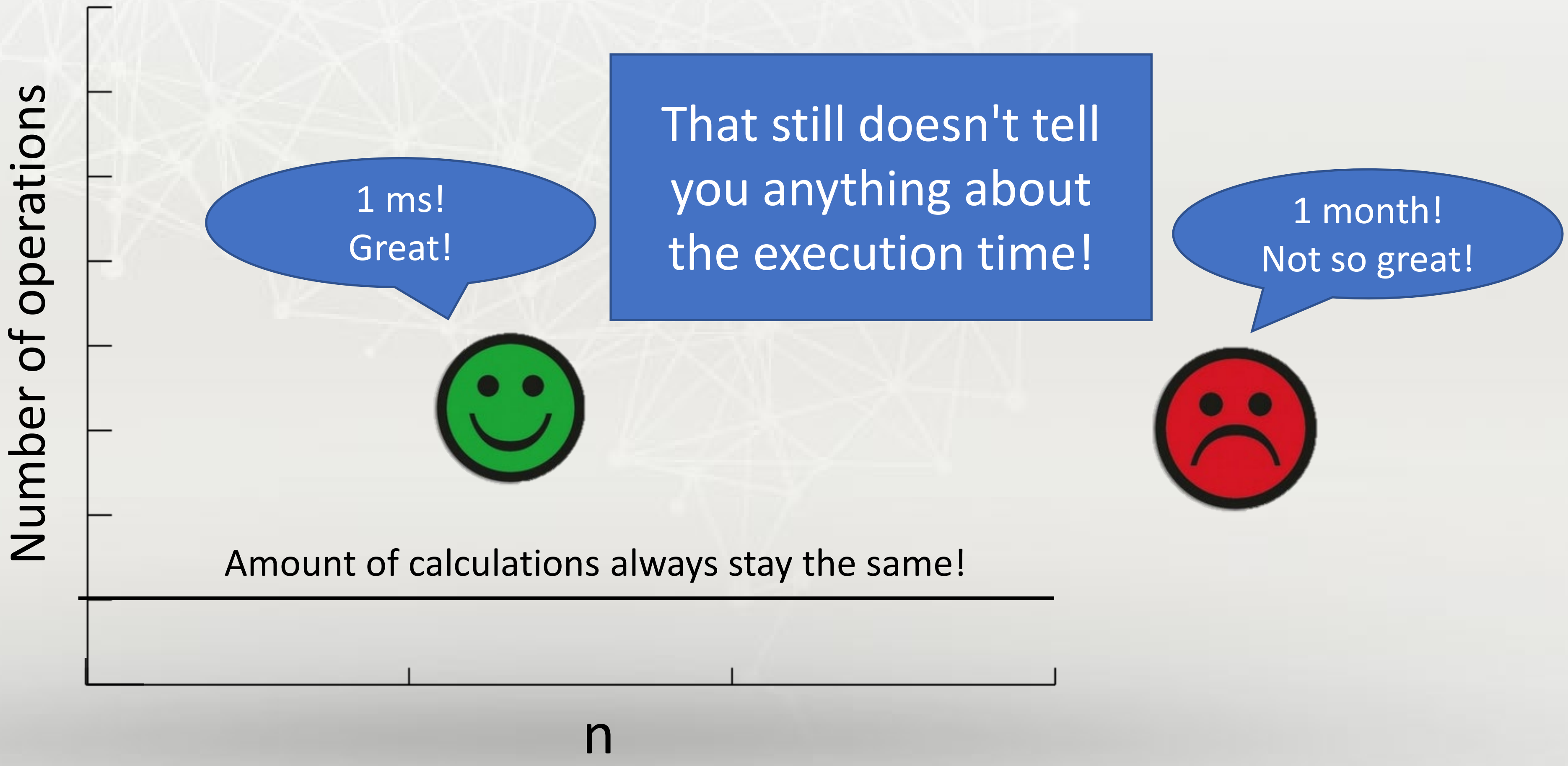


1000 * 999 / 2

So how well does this new algorithm scale?

No matter ‘n’, the calculation always **takes the same amount** of steps!



Algorithmic Complexity → Big O notation

- 'Algorithmic complexity' means 'how well does the algorithm scale'
- We saw three examples: constant, linear and exponential complexity
- Expressed using the Big O notation (O for Order of Magnitude).
- If we scale input size n, what happens to #algorithmicsteps?
  - constant amount → O = 1, written as O(1) (constant relation)
  - constant amount * n → O = n, written as O(n) (linear relation)
  - constant amount * n^2 → O = n^2, written as O(n^2) (exponential relation)
  - (... more variants later ...)

Algorithmic Complexity → Big O notation

- This usually takes some time to get used to:
  - Input size * 2 → #algorithmicsteps * 2 → Linear → O(n)
  - Input size * 2 → #algorithmicsteps * 4 → Linear → O(n)

Indicators

- A good indicator for algorithmic (time) complexity is the amount of nested loops ☺

- Amount of nested loops:
  - 0 → O(1) (constant time complexity)
  - 1 → O(n) (linear time complexity)
  - 2 → O(n^2) (exponential time complexity)

- Keep in mind: it's just an indicator not absolute truth

What do you need to write a good algorithm?

Algorithmic ingredients 1

- Algorithms are expressed in steps (flowcharts, pseudo code, text, etc)
- Steps are implemented using code structures (variables, loops, etc)
- Code structures are built on top of data structures (lists, maps/dictionaries, graphs, etc)

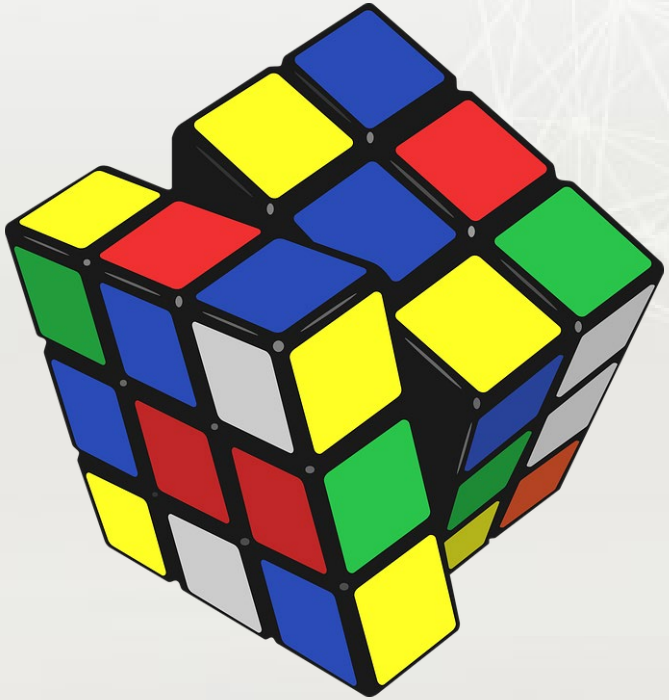
Algorithmic ingredients 2

- Problem solving skills:
  - How do you start?
  - What do you do if things go wrong?

- Time, examples, practice, luck/strokes of insight

Why a course on algorithms?

Algorithms are everywhere, but implementing/creating them is not trivial



Algorithm*:

F3 – U2 – D`1 – B1 – L2 – R'1 - D`1 – B1 – L2 –
R'1 - U2 – D`1 – B1 – L2 – R'1 - D`1 – B1 – L2 –
R'1 - U2 – D`1 – B1 – L2 U2 – D`1 – B1 – L2
U2 – D`1 – B1 – L2 – F1- R'1 - D`1 – B1 – L2 – R'1
-U2 – D`1 – B1 – L2 – R'1 - D`1 – B1 – L2 – R'1 -
U1 – B1 – L2 – R'1 - D`1 – B1 – L2 – R'1 -
U2 – D`1 – B1 – L2 – R'1 - D`1 – B1 – L2 – R'1 -.....

*https://ruwix.com/the-rubiks-cube/how-to-solve-the-rubiks-cube-beginners-method/

Learning more about algorithms allows you to...

- solve more complicated problems than before
- solve problems more efficiently than before
- write more interesting programs than before
- get internships/jobs
- stand on the shoulders of giants
- not get stuck

- basically: become a better programmer/problem solver

Learning Objectives

What should you already know

- Variables (int, float, bool)
- Code structures (if-then-else, for, while)
- Basic list/array manipulation (more on this in lecture 2)
  - new, Add, Remove, IndexOf, Contains, etc
- Basic object orientation:
  - objects & classes
  - inheritance and polymorphism ?
  - abstract classes and interfaces ?

- If any of these are not clear, some extra study/explanation during labs might be required (check additional resources on blackboard).

Official learning objectives for this course...

The student:

1. describes algorithms using
   e.g. flowcharts & pseudocode
2. uses/creates the right data structure
   to implement a given algorithm
3. implements list, dictionary and graph based
   algorithms iteratively and recursively
4. tests and debugs an algorithm
5. explains algorithmic complexity

Official CMGT Competencies

- CMGT 1. Technological research and analysis
- CMGT 2. Designing, prototyping and realizing
- CMGT 3. Testing and rolling out
- CMGT 5. Conceptualising
- CMGT 6. Designing

If, at the end of this course, you feel that you…

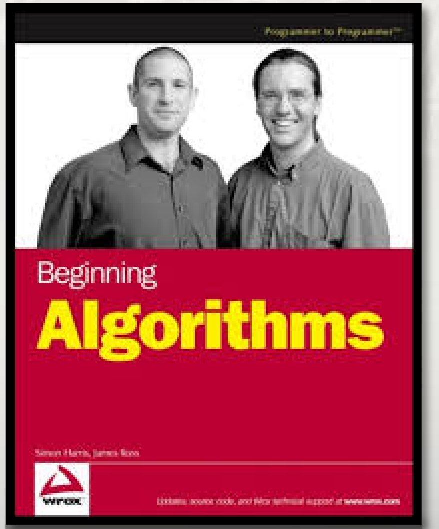
- … are more confident in tackling problems …
- … have more practical skills/tools to solve problems …
- … are able to do things that you were not able to do before …

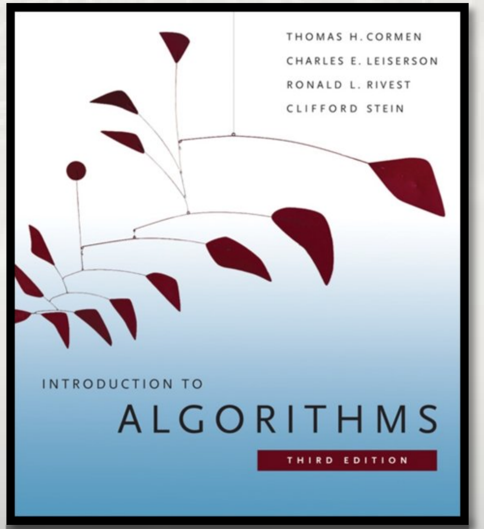
… then we can all be pretty happy and go and enjoy a well deserved holiday.

Course approach & grading

What we will *not* do in this course... 1/2

- We will ***not*** discuss all algorithms or all data structures
- We will ***not*** take the standard ICT approach of writing your own lists, sorting algorithms etc
- However there are some very good resources for that in case you are interested.
- Recommended reading material (during the course or during the holiday):





What we will *not* do in this course... 2/2

- Architecture
- Design patterns
- Unit testing
- Object oriented analysis & design

- **Not** part of this course, subject of next year's Architecture course
  (This also explains why the starting code looks the way it looks ☺)

(wo)

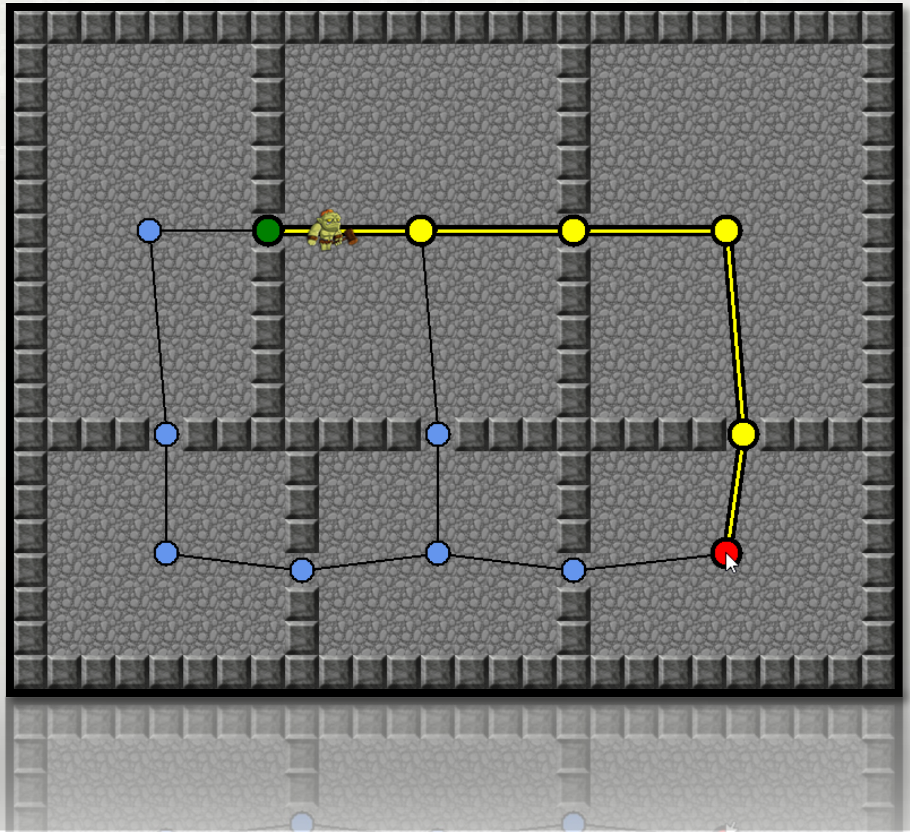
Give a man a fish
and you feed him for a *day*.
Teach a man to fish
and you feed him for a *lifetime*.

Chinese Proverb

Chinese Proverb

1 overall assignment + assessment

"Create a prototype for a roguelike dungeon crawler with procedurally generated levels & pathfinding"



The assignment is (supposed to be) a puzzle

- The goal is clear, but the steps aren't
- Doable, but challenging:
  - there are only 3 assignments (1 assignment per 2 weeks)
  - option to pick your own skill level
  - starting code has been provided
  - plenty of time per assignment → ± 20 hours per assignment (and you might need it)
- But yes, you will get frustrated & you will struggle sometimes

The *assessment* is more than the *assignment*

- It's not only about solving the problem, but also about:
  - up front design (drawings/pseudo code)
  - performance
  - code conventions
  - etc
- *Solving* the problem is priority No 1, but the other things have to be in order as well!
- Detailed assessment criteria can be found on blackboard (!)
- Check the grading form!!

Covered so far ...

- *What is an algorithm?*
- *What is a 'good' algorithm?*
- *Why should we learn about algorithms?*
- *What will we learn ? (AKA Learning objectives)*
- *Course approach and grading*

- ***Next up:* Getting started with algorithms & the assignments**

Getting Started

Divide & Conquer

Algorithmic design principle 1

Divide & Conquer

- An algorithm solves a problem
- Problems can often be split into smaller problems

- An assignment such as "Create a prototype for a roguelike dungeon crawler with procedurally generated levels & pathfinding" is too big to tackle in one go

We need to break it down so we can worry about 1 problem at a time

Divide & conquer in practice

"Create a prototype for a roguelike dungeon crawler with procedurally generated levels & pathfinding"

Big problem, broken down into 3 smaller problems/assignments:

- Assignment 1 → Generate a dungeon
- Assignment 2 → Generate a nodegraph (+ Morc da Orc)
- Assignment 3 → Implement pathfinding

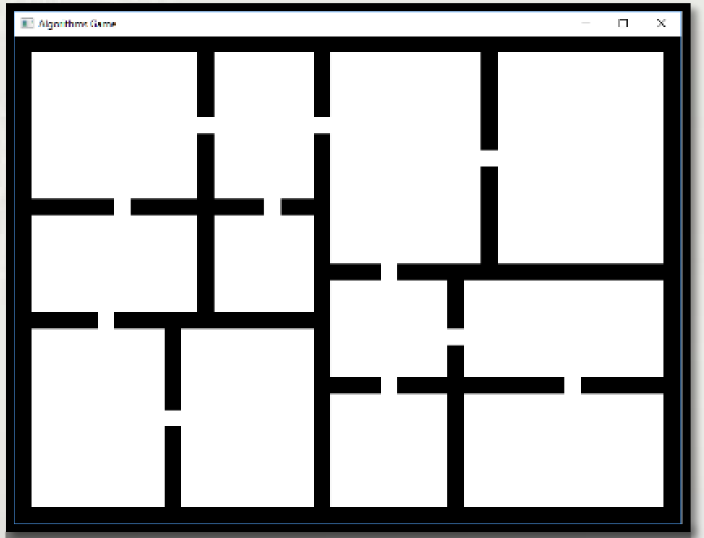
*The sprites for Morc and two of his brothers are available for free on blackboard

Assignment 1

- Generate a Dungeon based on 'binary space partitioning'
  - Binary means 2
  - Space partitioning means subdividing a space in some way

- In other words: generate a dungeon
  by subdiving a space in two until we
  can't subdivide it any more
  (and then find out where to place the doors).

- So part of the solution is already provided in this
  assignment (the approach/general idea) !



Questions to ask yourself

- Is this problem small enough or should we subdivide it any further?
- Are the *sub* problems small enough or should we subdivide *them* any further?
- When is a sub problem small enough? When you ...
  - know **what** to do
  - know **how** to do it
  - ... or at least have some idea of know where to start ...
- Divide & Conquer: Divide *until you can* conquer...

Divide & Conquer applied to ‘Generating a dungeon’

- Is the problem small enough or can we subdivide it any further?
  - Sounds like a pretty big problem (meaning: it still consists of multiple steps)
- Is it clear what we have to do?
  - Not exactly, need more info
- How can we find out what to do exactly?

Acting out the algorithm

Algorithmic design principle 2

Acting out the algorithm

If you cannot write down/visualize the algorithm step by step on paper, chances are you cannot implement it

- Step 1 – Literally step away from the computer
- Step 2 – Act out the algorithm on paper, recording the steps
- Step 3 – Prototype on the computer
- Step 4 – Start over at step 1 if necessary

- Important: keep a notebook/logbook! See grading criteria!

Example result

Generating a dungeon

- Is it more clear what we have to do now? Yes, a little bit!
- Is the problem trivial or can we subdivide it any further?
  - Well it's clearer, but we could subdivide it even further:
    1. Generate the rooms (through binary space partioning)
    2. Generate doors based on the rooms (through ... ?)

- Can these two sub problems be subdivided even further?

Generating the rooms

- Again, a problem we can split into multiple sub problems:
  1. Check whether a room can be subdivided
  2. Determine whether to do a horizontal or vertical split
  3. Subdivide a room (randomly)
  4. Repeat 1 until there are no more rooms to subdivide left

Generating the doors

- After generating the rooms, we have to generate doors!
  - Again: act out the algorithm, maybe even on squared scrap paper
  - Observe yourself and your thought processes as you decide where to place doors: why are you placing the door where you are placing it?
  - How can you break this down again into little steps?

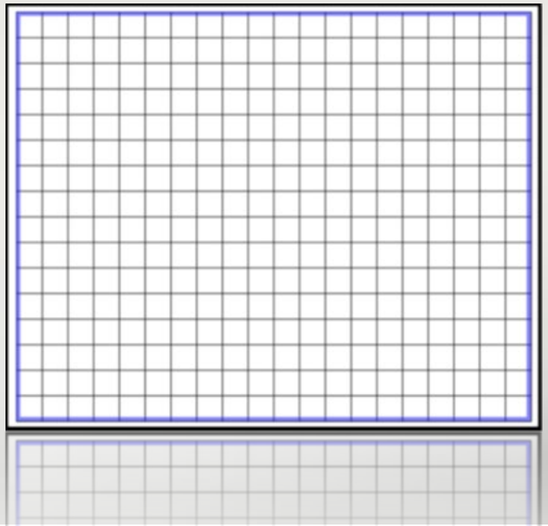
Iteration

Algorithmic design principle 3

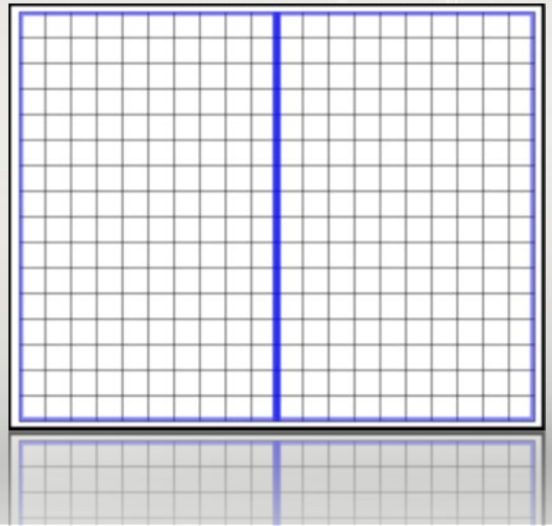
Iteration

- Algorithm execution involves a lot of iteration (eg for loops)
- But Algorithm development ALSO involves a lot of iteration
- We can view this as another example of Divide & Conquer

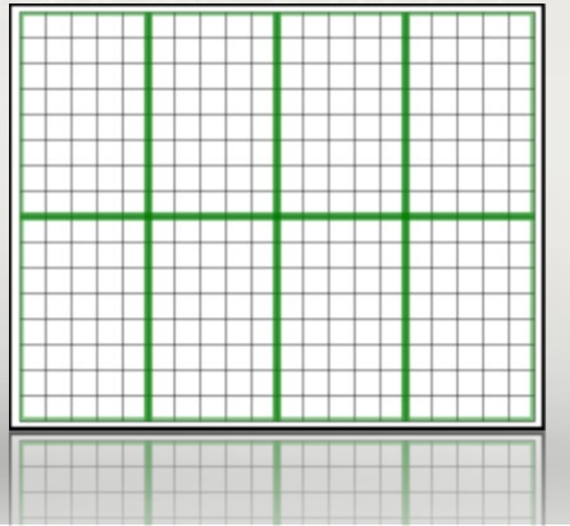
Step 1 – 1 room



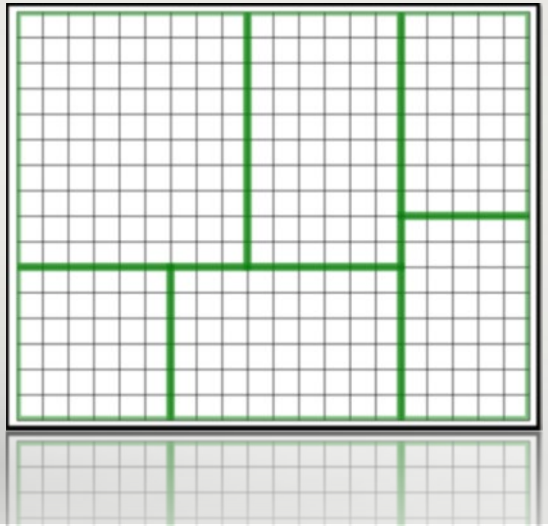
Step 2 – 2 rooms even splits



Step 3 – all rooms even splits



Step 4 – all rooms random splits



Experiment

Algorithmic design principle 4

Experimentation

- Given the input and output requirements of a problem, it is important to play around
- For example, given the dungeon size and minimum room size, can you:
  - generate 1 room with the size of the dungeon?
  - explain how the room coordinates work?
  - generate random rooms?
  - subdivide a single room into two rooms?
  - print whether a room meets the minimum size requirement?
  - print whether any rooms have an overlap?
- Constantly think: what else can I try that I haven't tried yet no matter how small
- The mindset of experimentation helps avoiding analysis paralysis

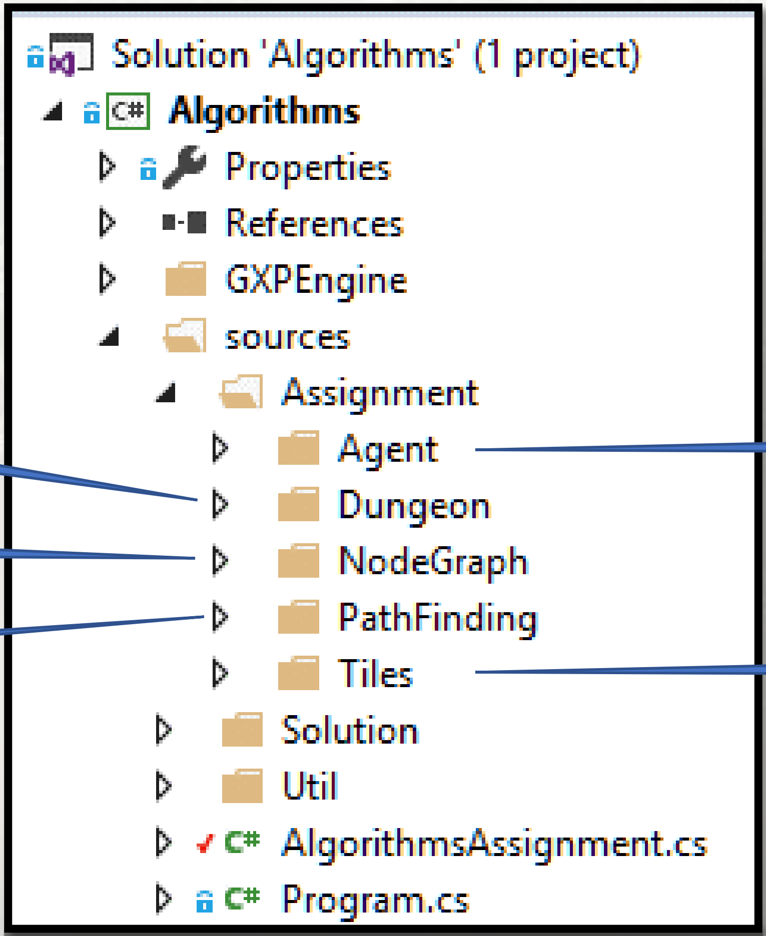
Other tips & principles

- Console spamming
- Code introspection through the debugger
- The binary elimination principle
- Trace tables
- etc etc

- Check the additional resources section on blackboard!

Short code walkthrough

Divide & conquer applied to the code setup



Starting code assignment 1

Starting code assignment 2

Starting code assignment 3

Starting code assignment 2

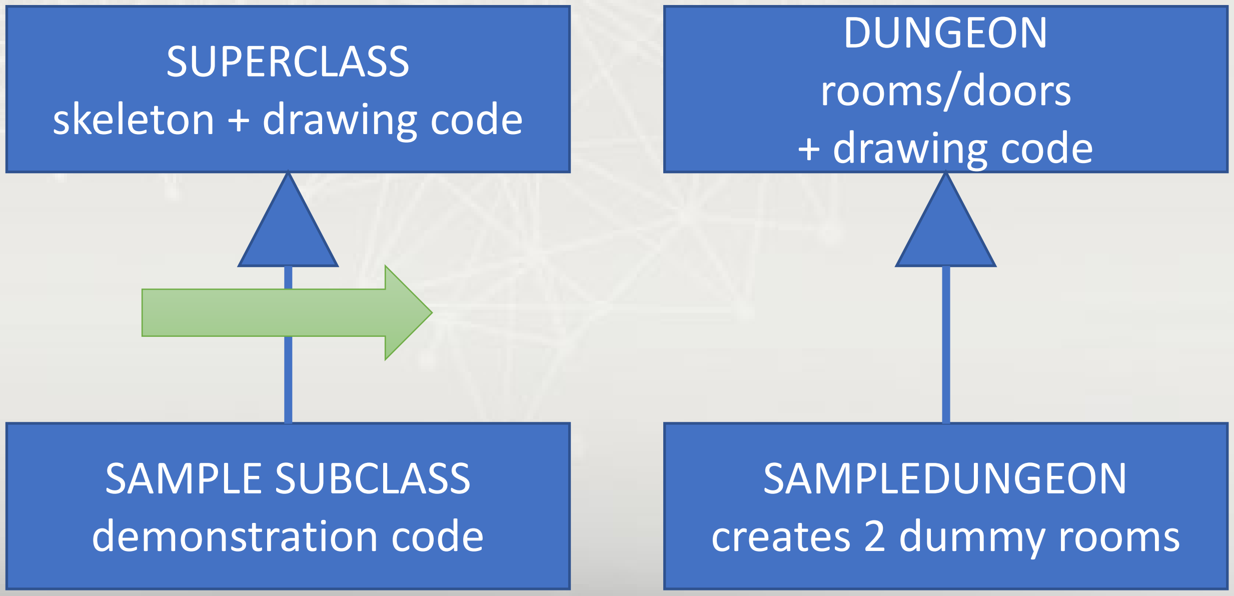
Extra code assignment 2

AlgorithmAssignment class

- Lists the code skeleton for all assignments
- (Un)comment as necessary
- Feel free to:
  - split into methods
  - remove to-do's while you are implementing
  - restructure etc.

What does the starting code provide?

- Minimal data structures (or the skeleton of it) for every assignment
- Drawing code for debugging/visualization for every assignment
- Setup for each package is the same:



The Dungeon class

- List<Room> _rooms;
- List<Door> _doors;

} the data*

- drawRooms() / drawRoom()
- drawDoors() / drawDoor()

} the view*

- No room/door generation logic whatsoever:
  - abstract void generate (...);

*if interested, some background info on the design choices with respect to the starting code architecture can be found on blackboard

The SampleDungeon class

- Subclasses Dungeon
- overrides generate
- adds 2 rooms and 1 door (just to show the general idea)

Your SufficientDungeon class

- Should:
  - subclass Dungeon
  - override generate
  - subdivide rooms, place doors etc until you have a dungeon ☺

Closing words

Summing up, we had a look at:

- What an algorithm is
- What a 'good' algorithm is
- Why it is important to learn about algorithms
- What we will learn during this course
- Course approach and grading
- Introduction to assignment 1
  (1.1 only, for 1.2 and 1.3 you are on your own)

What's next?

- This week lab/homework:
  - check the C# essential slides
  - check the grading criteria and assignments
  - download/start with assignment 1
  - try and solve a rubik cube ? ☺
- Next lecture:
  - all about ***Lists*** (& a bit about HearthStone)

- **Check the schedule on blackboard every week for details on homework and lecture preparation!!**

Your turn! Good luck!