

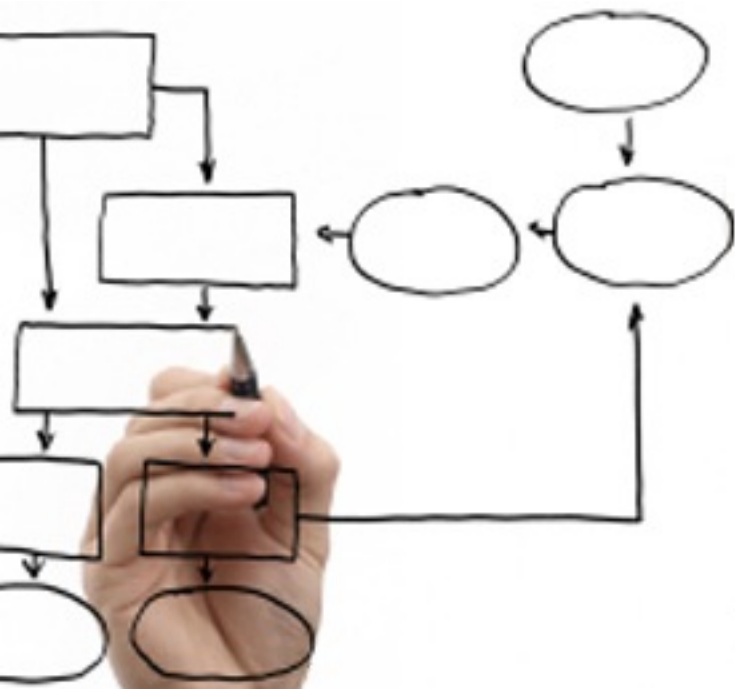
Business Processes Modelling

MPB (6 cfu, 295AA)

R. Bruni (+ A. Vandin)

<http://www.di.unipi.it/~bruni>

01 - Introduction







Classes

Every

Tuesday:

09:00-11:00



C1

Thursday:

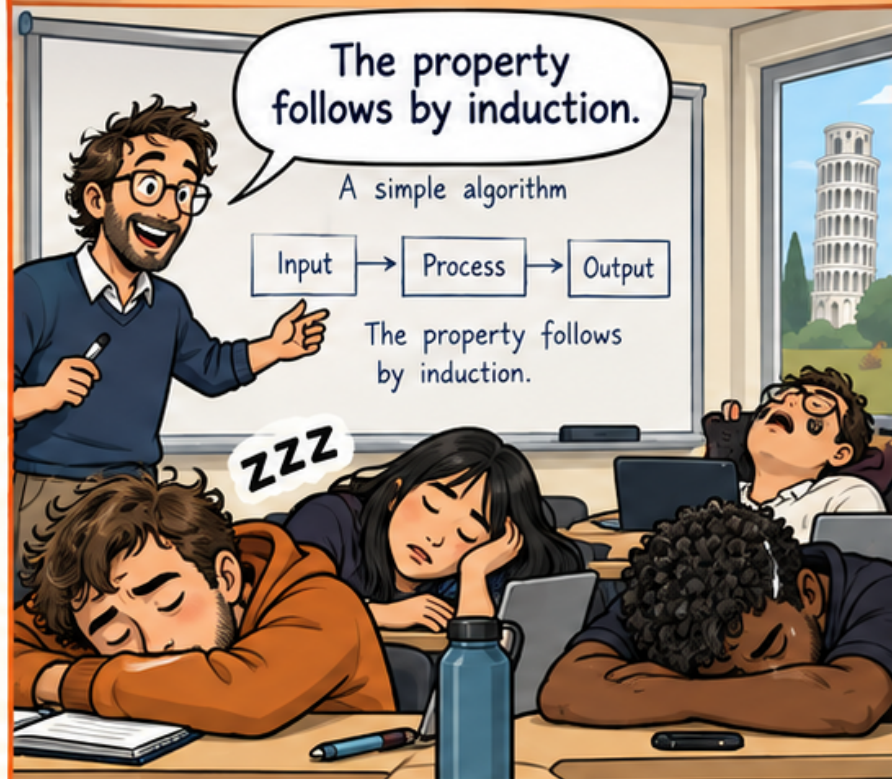
16:00-18:00



A1

CLASS PROTOCOL: LET'S INTERACT

I TALK, YOU DON'T SLEEP



Don't do this

I ASK, YOU DON'T PANIC



Don't worry, it's not an exam

YOU ASK, I'M HAPPY!



Ask questions!

≡ INTERRUPT, ASK, RESPOND, DISCUSS! ≡
This is a conversation, not a monologue



Course Material shared on [Microsoft Teams](#) and [DidaWiki](#)

No streaming, no recording

Who am I?



<http://www.di.unipi.it/~bruni>



bruni@di.unipi.it



Office hours: by appointment
Thursday 14:00-16:00

Who is Andrea Vandin?



Sant'Anna
School of Advanced Studies – Pisa



ASSOCIATE PROFESSOR

Institute of Economics

Andrea Vandin



andrea.vandin@santannapisa.it



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Complesso edilizio Sede Centrale

Who are you?

Hi, I'm ... from ...

I have studied ... at the University of ...

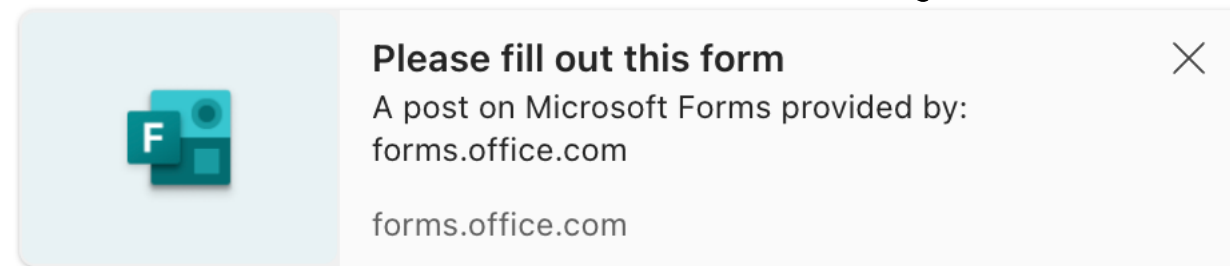
I am now a student of the MSc degree in ...

Hi, I'm **Paolo Rossi** from **Italy**

I have studied **Computer Science** at the University of **Pisa (Italy)**

I am now a student of the MSc degree in **Data Science and Business Informatics**

Who are you?



Background check (form)

Enrollment number:

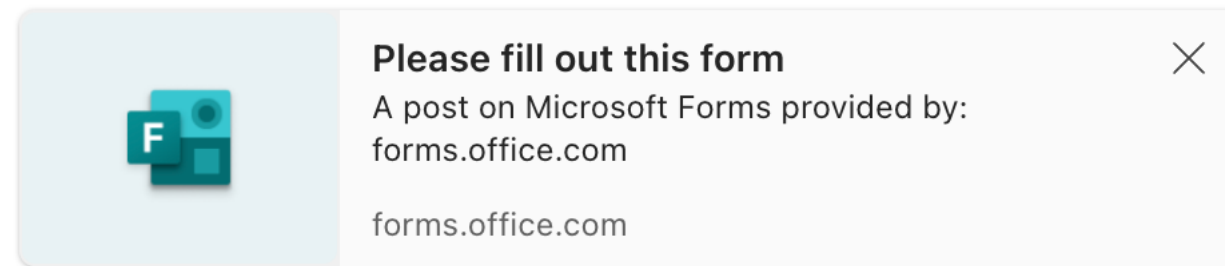
Bachelor degree:

MSc course of enrollment:

Subjects of interest:

... :

Who are you?



Background check (form)

Enrollment number:

Bachelor degree:

MSc course of enrollment:

Subjects of interest:

... :

Some quotes

All models are wrong, but some are useful.

— George Box



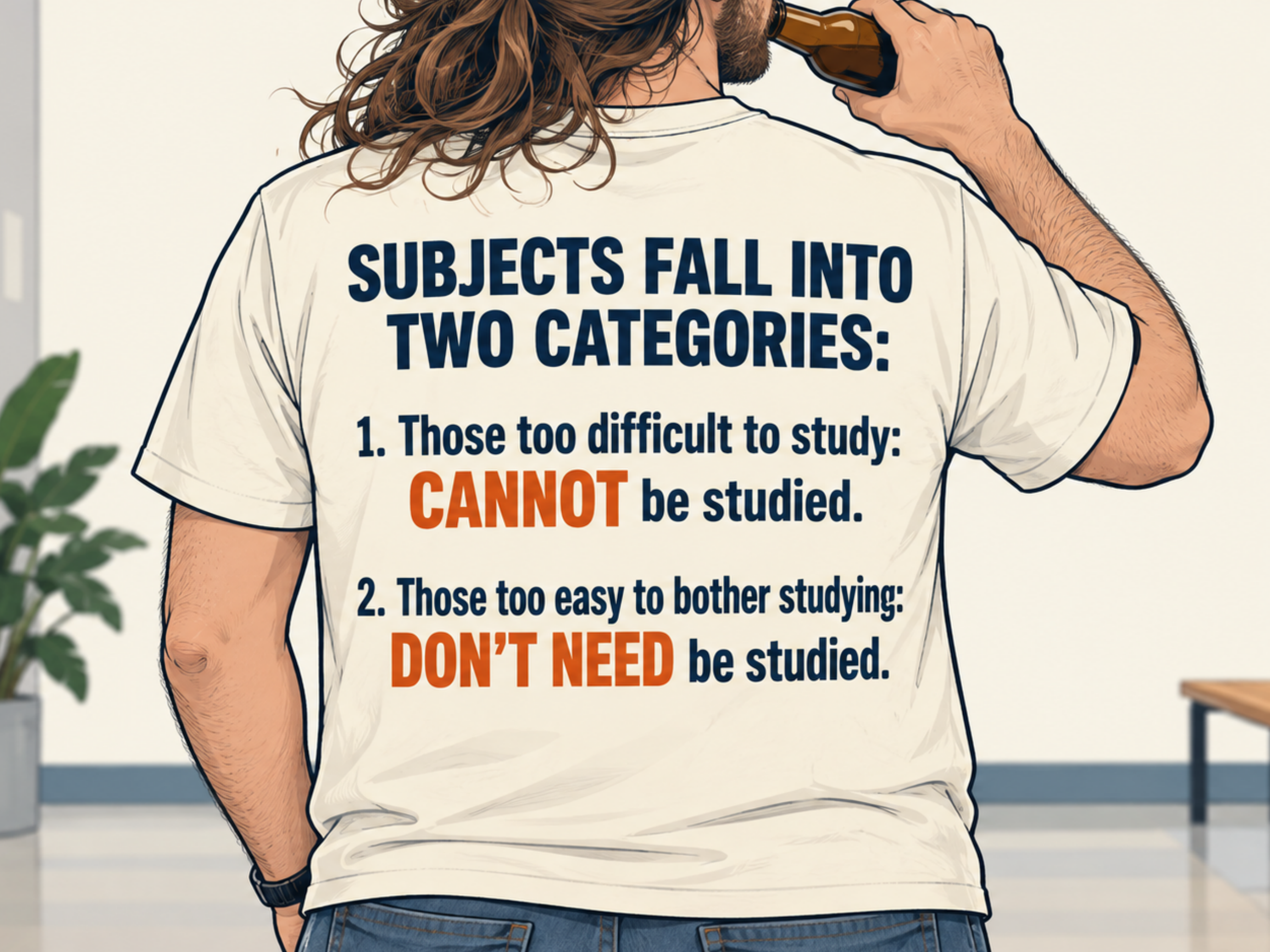
Reality



Model

Good enough
for this question!



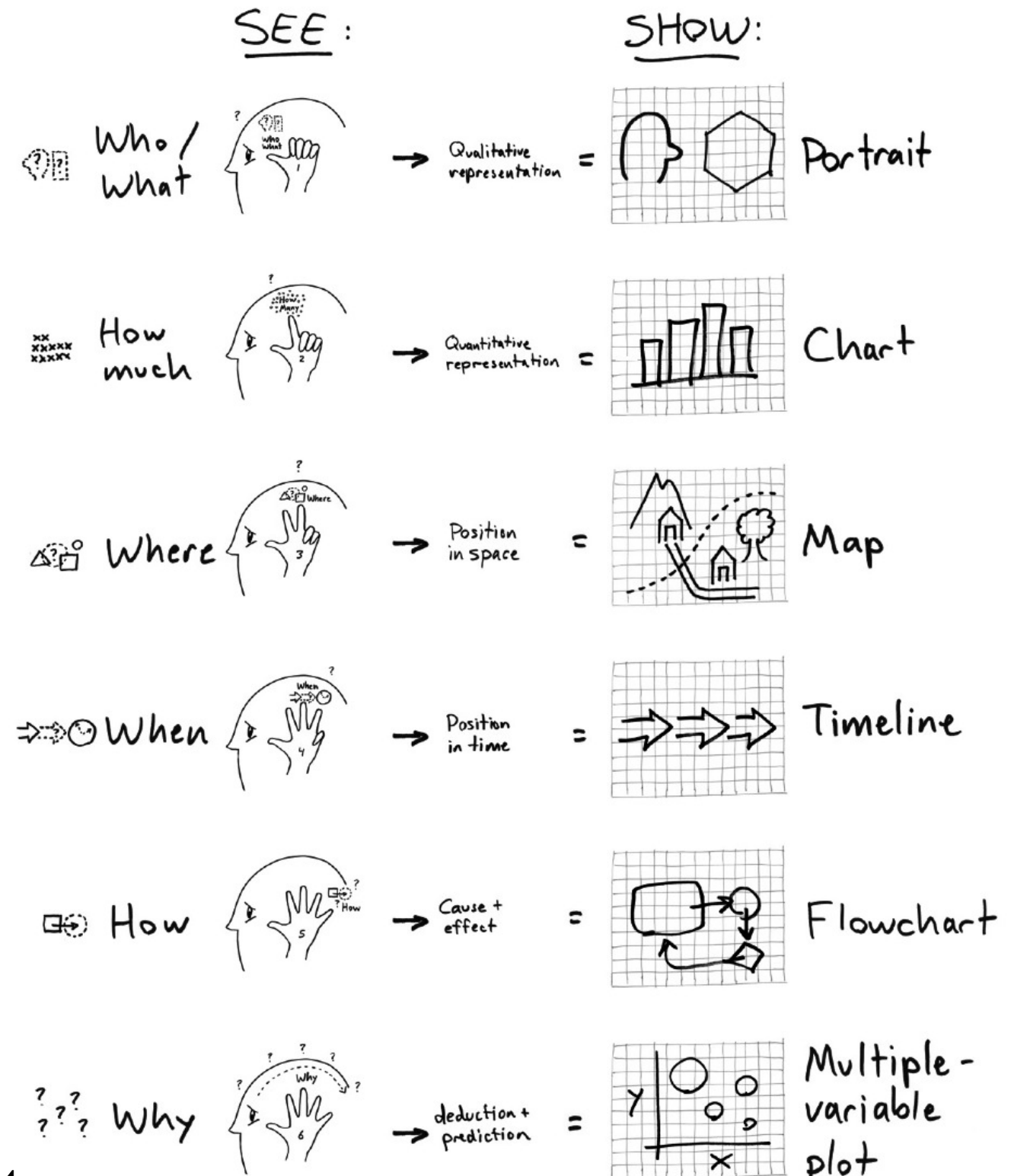
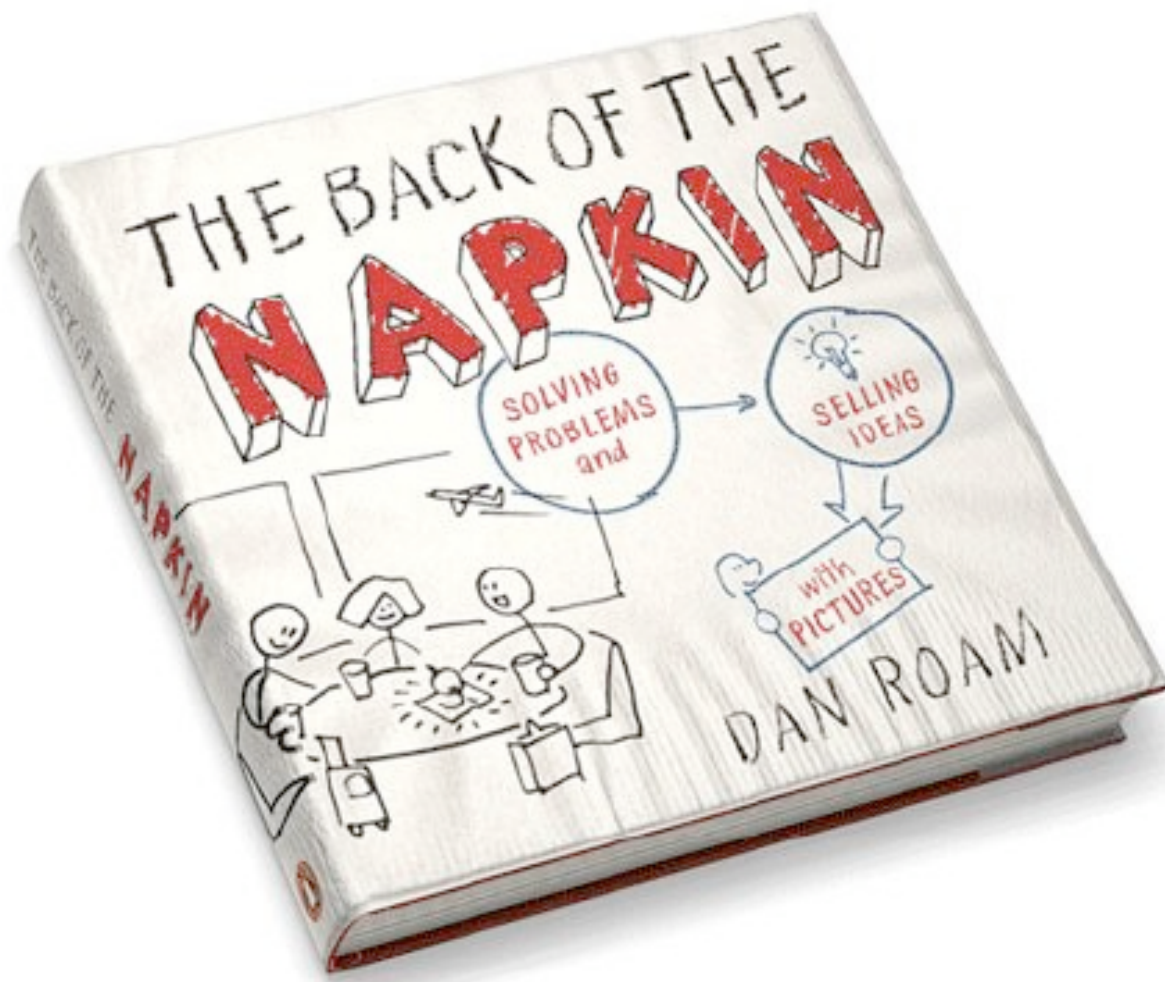
An illustration of a man from behind, wearing a white t-shirt and blue jeans, drinking from a brown beer bottle. The t-shirt has text printed on it. The background is a simple indoor setting with a plant on the left and a table on the right.

SUBJECTS FALL INTO TWO CATEGORIES:

**1. Those too difficult to study:
CANNOT be studied.**

**2. Those too easy to bother studying:
DON'T NEED be studied.**

Sometimes the best way to understand an idea is to sketch it and discuss it together.



The Course

What is a Business Process?

Any set of steps aimed to reach some outcome

from opening an account...



... to processing a custom order

What is BPM about?

automate workflow and
orchestrate processes,

reduce risk of errors,

provide metrics,

real time status,

enforce deadlines,

validate data,

reduce training costs,

...

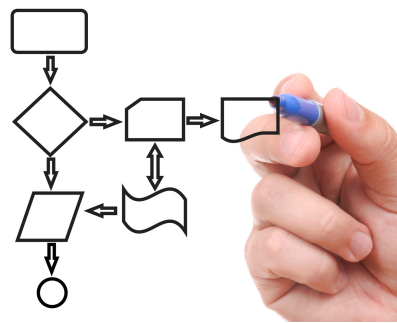


Course objectives



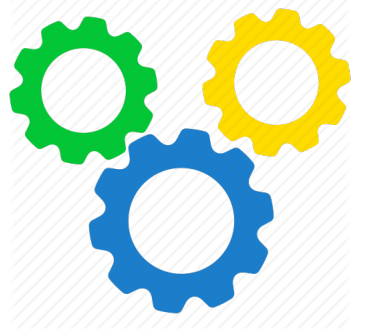
Key issues in Business Process Management (patterns, architectures, methodologies,...)

Analysis techniques and correctness by construction (soundness, boundedness, liveness, free-choice,...)



Graphical languages & visual notation (BPMN, EPC, ...)

Tool-supported verification (WoPeD, ProM, Woflan, ...)



Structural properties, behavioural properties and problematic issues (dead tasks, deadlocks, ...)

Performance analysis (bottlenecks, simulation, capacity planning,...)



Formal models (automata, Petri nets, workflow nets, ...)

Process mining (discovery, conformance checking, enhancement,...)

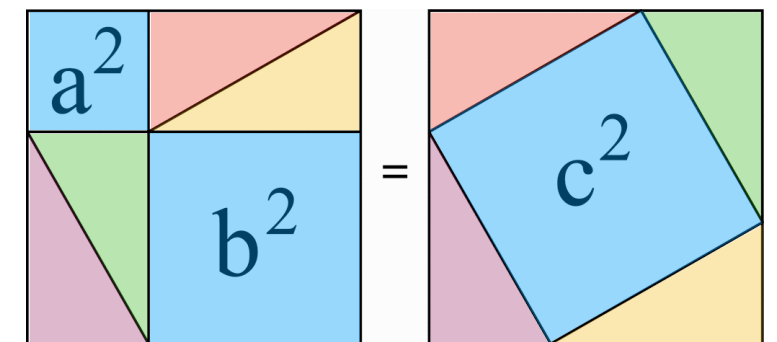


Course activities



attend classrooms:
ask questions!
(sleep quietly)

learn theorems:
(drink many coffees)



do some thinking:
solve ALL exercises
(at least try to)

deliver a project:
practice with concepts,
experiment with tools

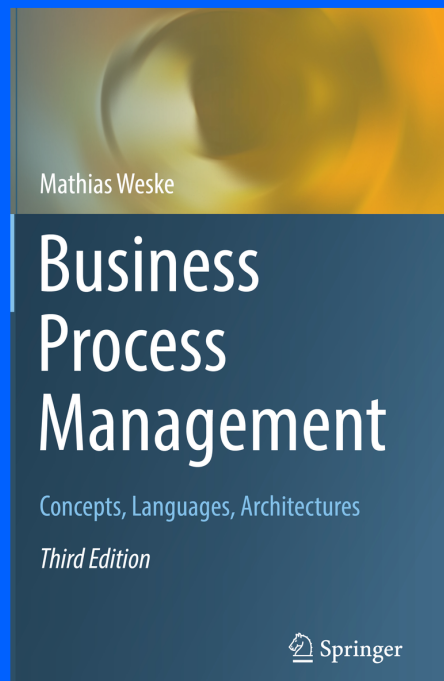


give the exam:
time for a party!

Exam

- Project + Oral exam (see [FAQ](#) for more infos)
- Group project
 - at most 2 students for group
 - can be requested any time
 - no deadline
 - modelling + analysis + short report
 - once approved, the project is valid for the current academic year
- Oral exam
 - registration mandatory
 - actual date fixed at the time of project delivery
 - group discussion of the project
 - followed by individual questions on course topics

Main Textbook



Mathias Weske

Business Process Management: Concepts, Languages, Architectures
(3rd ed.) Springer 2019

<http://bpm-book.com>

Suggested Reading

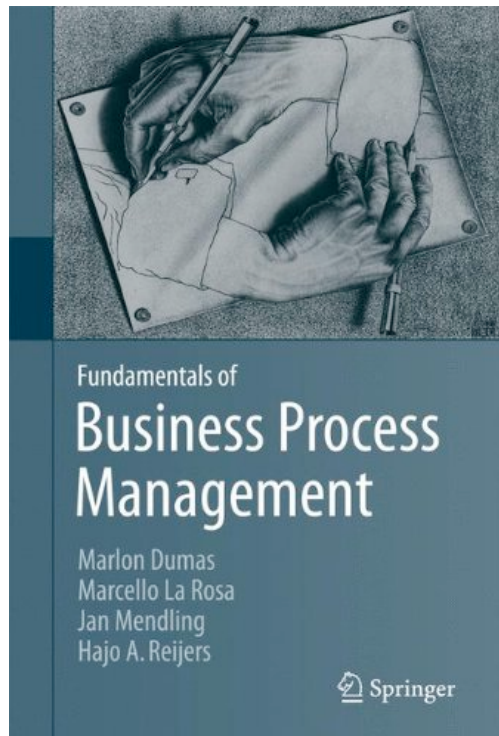


Joerg Desel and Javier Esparza

Free Choice Petri Nets

Cambridge Tracts in Theoretical Computer Science 40, 1995

<https://www7.in.tum.de/~esparza/bookfc.html>



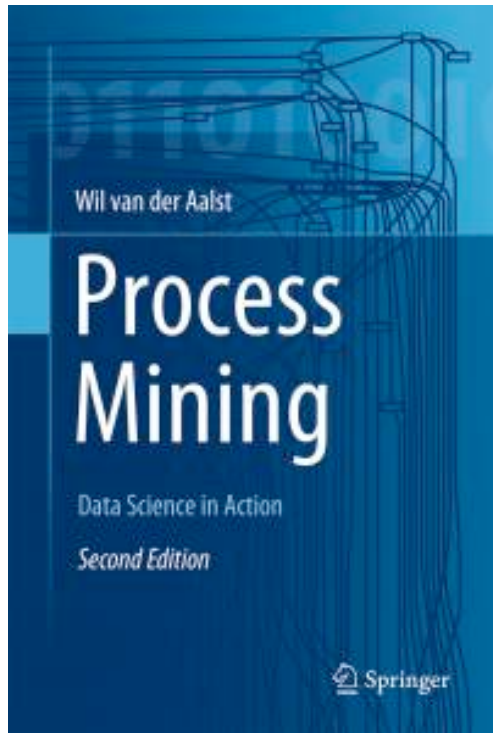
Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo Reijers

Fundamentals of Business Process Management

(2nd ed.) Springer 2018

<http://fundamentals-of-bpm.org>

Other Resources



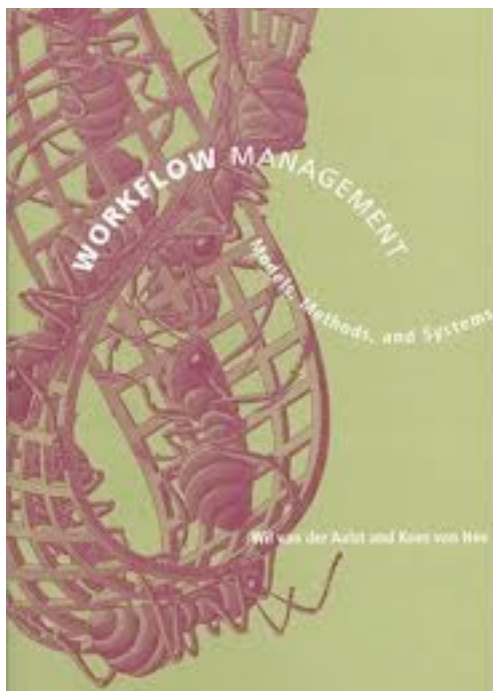
Wil van der Aalst
Process Mining
(2nd ed.) Springer 2016

<http://springer.com/978-3-662-49850-7>



BPMN

<http://www.bpmn.org>



Wil van der Aalst, Kees van Hee
Workflow Management: Models, Methods, and Systems
MIT Press (paperback) 2004

<https://mitpress.mit.edu/books/workflow-management>

Main analysis tools

BPMN to Petri net translator

bpmn2petrinet.com

WoPeD

<http://www.woped.org>

ProM (and Woflan)

<http://www.promtools.org/>

<http://www.win.tue.nl/woflan>

Diagnosing workflow processes using Woflan. H.M.W. Verbeek, T. Basten, W.M.P. van derAalst. Computer J. 44(4): 246-279 (2001)

<http://www.padsweb.rwth-aachen.de/wvdaalst/publications/p110.pdf>

How to survive this course

Lectures are not like TV series episodes!



Watching isn't learning.

There's no season finale
that explains everything.

Take notes, not photos



Your camera won't take
the exam: you will!

Read some books



There's more to learn
than fits on a slide.

Slides are just the
roadmap

Don't sit in the back rows



Come closer,
join the conversation

Wherever you sit,
stay involved.

90% of low grades come from the back row.

Source: a statistically significant sample of my thinking.

Even if it looks easy, try it!



Try solving all exercises.

Watching other's
solutions isn't the same
as working out your own.

You don't build muscles by watching others lift.

Before trying divination, ask the teacher



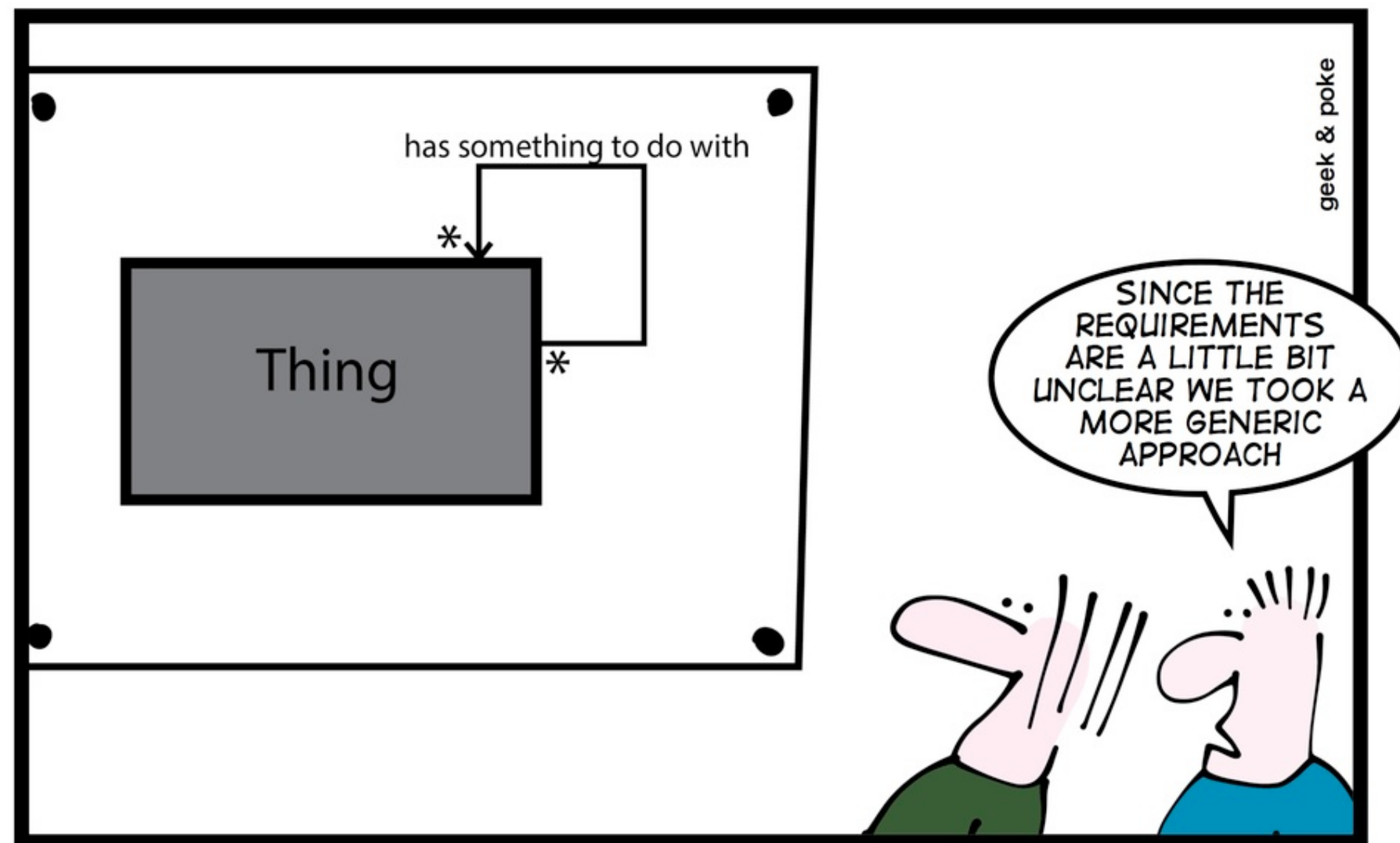
Feel free to ask!

Building models

What

Data and processes

Traditionally, information systems used **information modelling** as a starting point

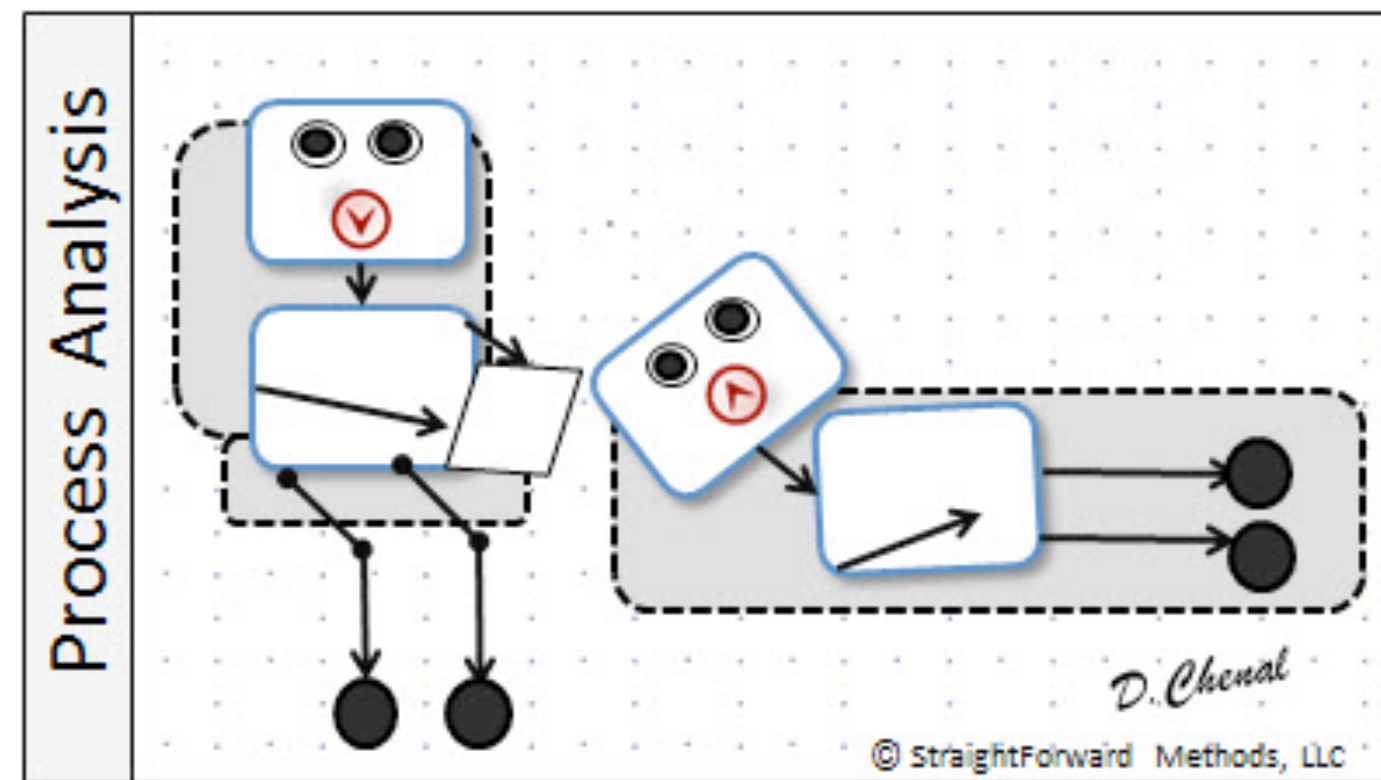
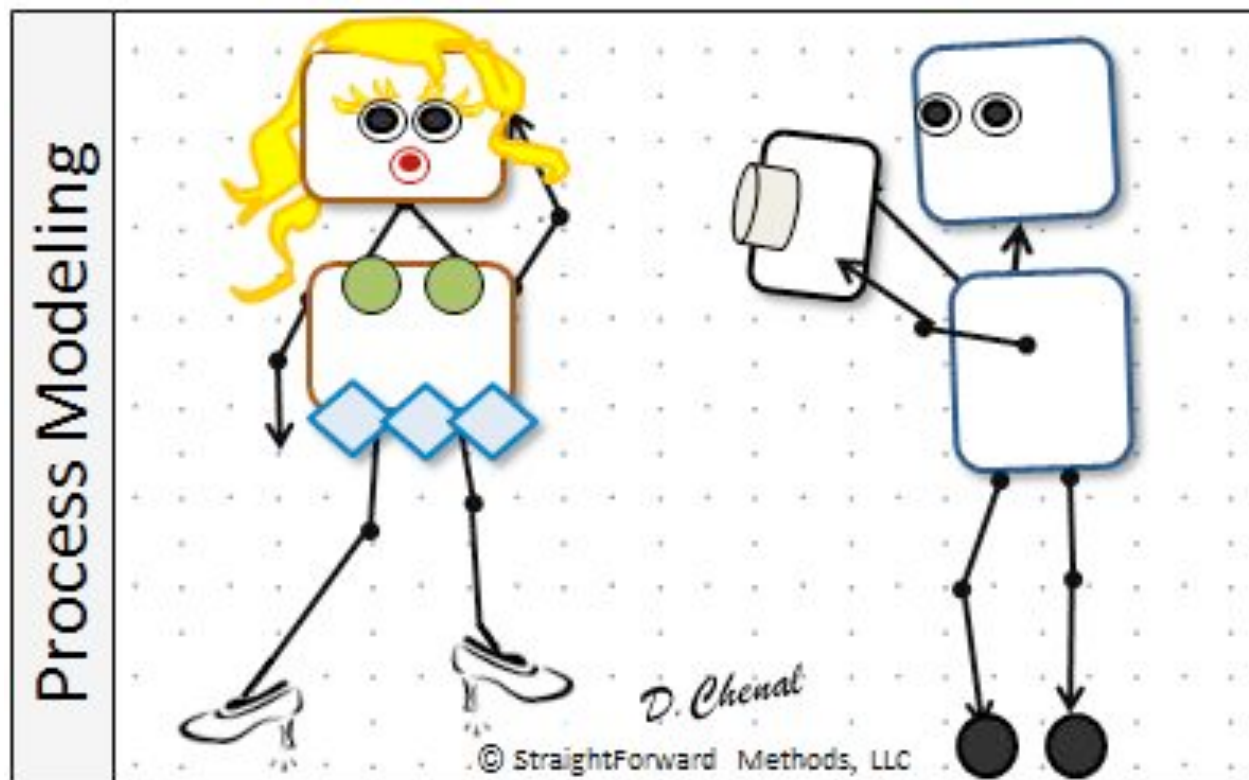


~~What~~

How

Data and processes

Nowadays, **processes** are of equal importance and need to be supported in a systematic manner



Motivation

- Each product is the outcome of a number of activities performed
- Competitive advantages of successful companies:
 - the ability to bring new products to the market rapidly and
 - the ability to adapt an existing product at low cost
- Business processes are the key instrument:
 - to organize activities
 - to improve the understanding of their relationships
- IT is an essential support for this aim

Quoting Michelangelo

*Every block of stone has a statue inside
it and it is the task of the sculptor to
discover it*



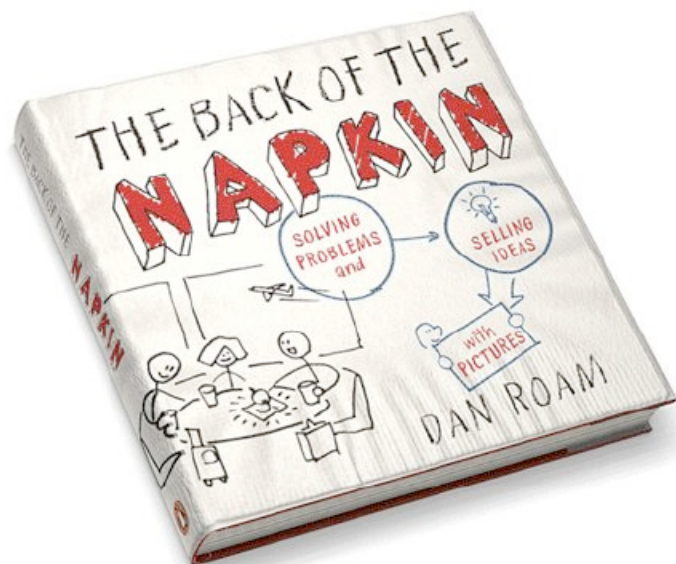
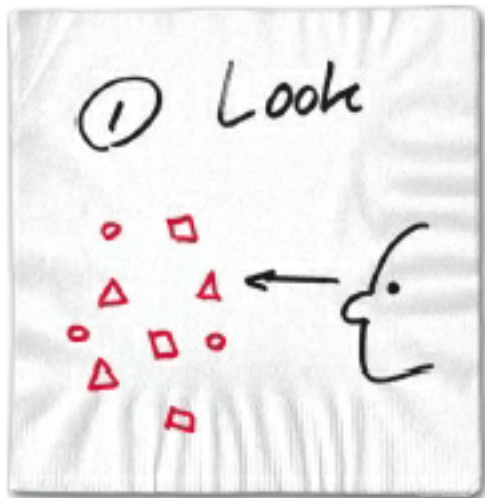
Quoting Michelangelo

*Every organization has some processes
running inside it and it is the task of
the designer to discover them*



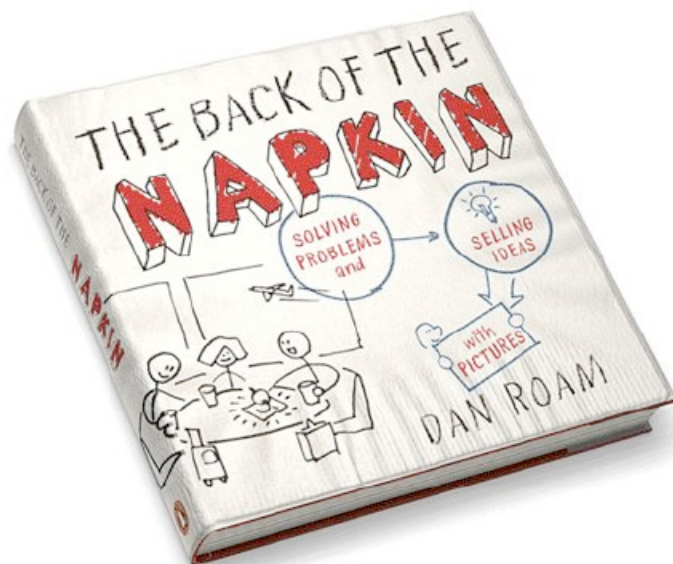
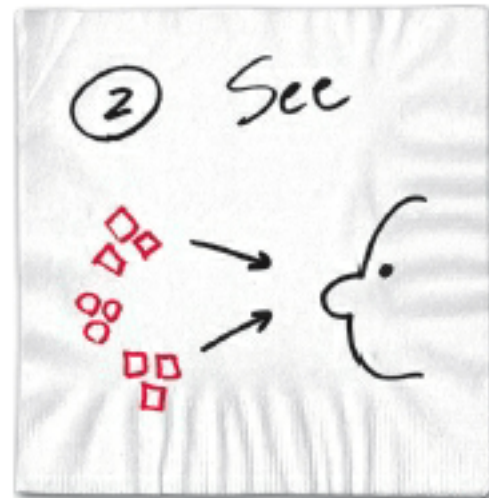
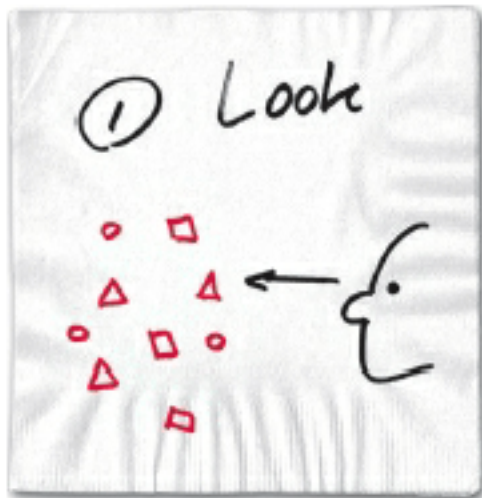
Modelling

Giving shape to ideas, organizations, processes, collaborations, practices



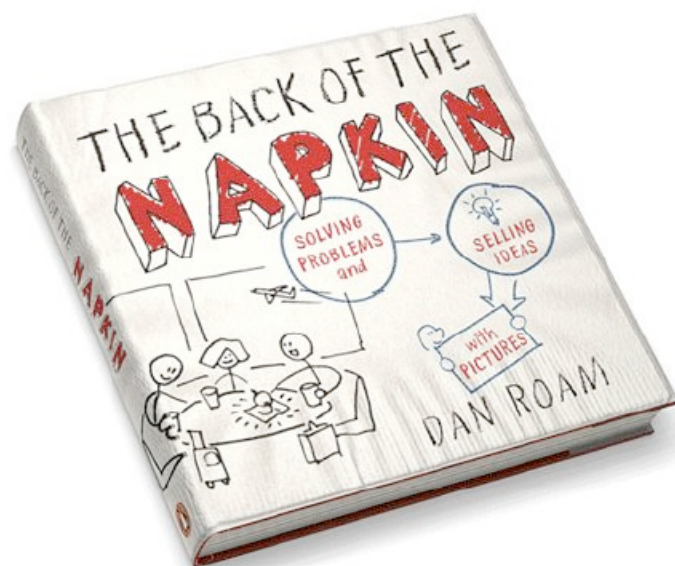
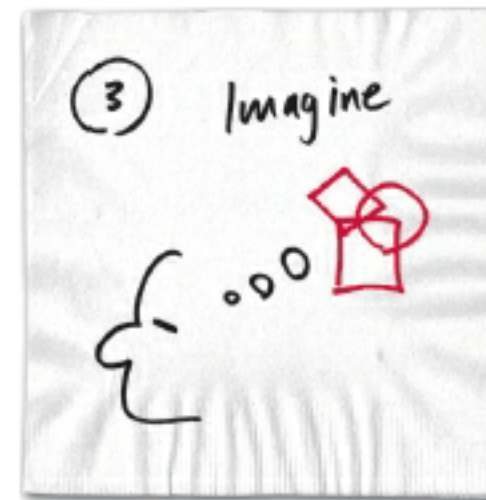
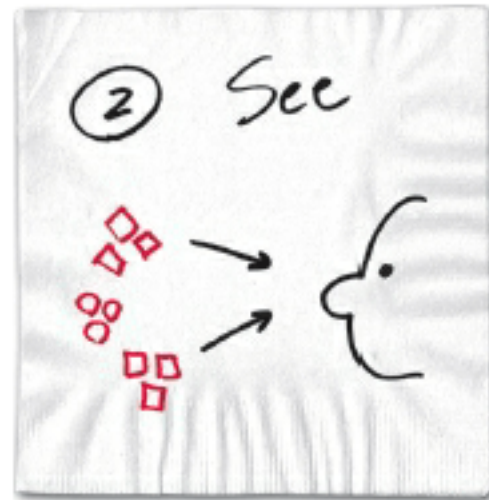
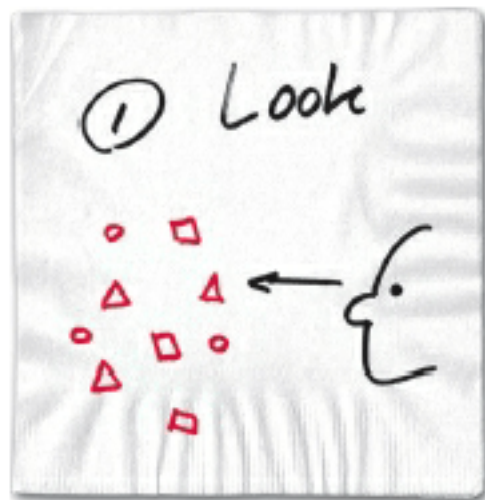
Modelling

Giving shape to ideas, organizations, processes, collaborations, practices



Modelling

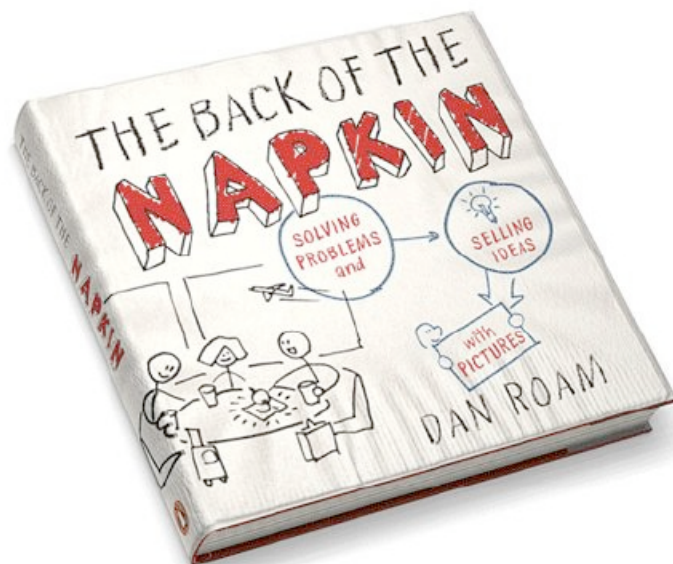
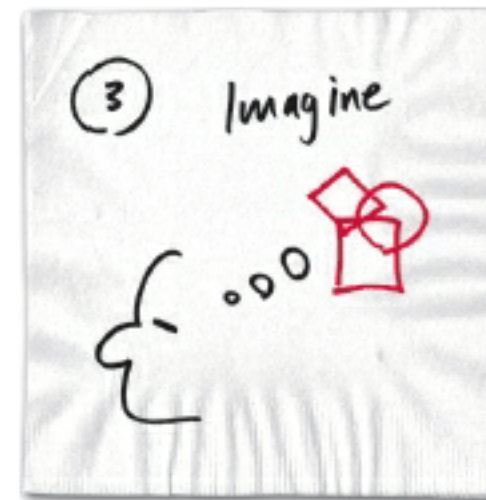
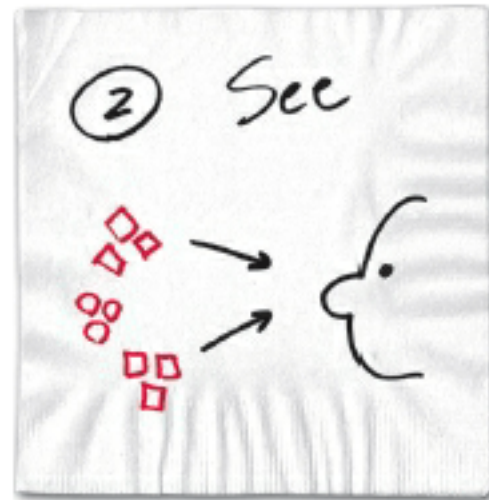
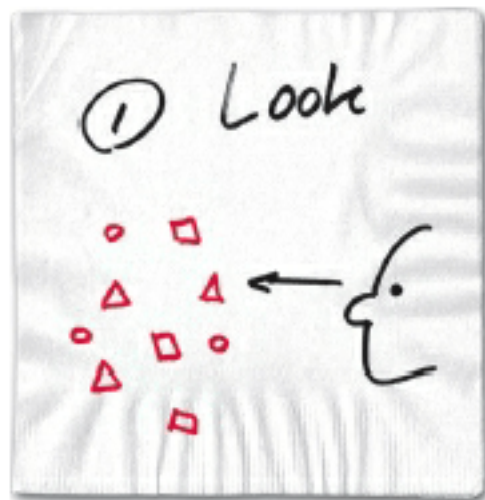
Giving shape to ideas, organizations, processes, collaborations, practices



To analyse them

Modelling

Giving shape to ideas, organizations, processes, collaborations, practices

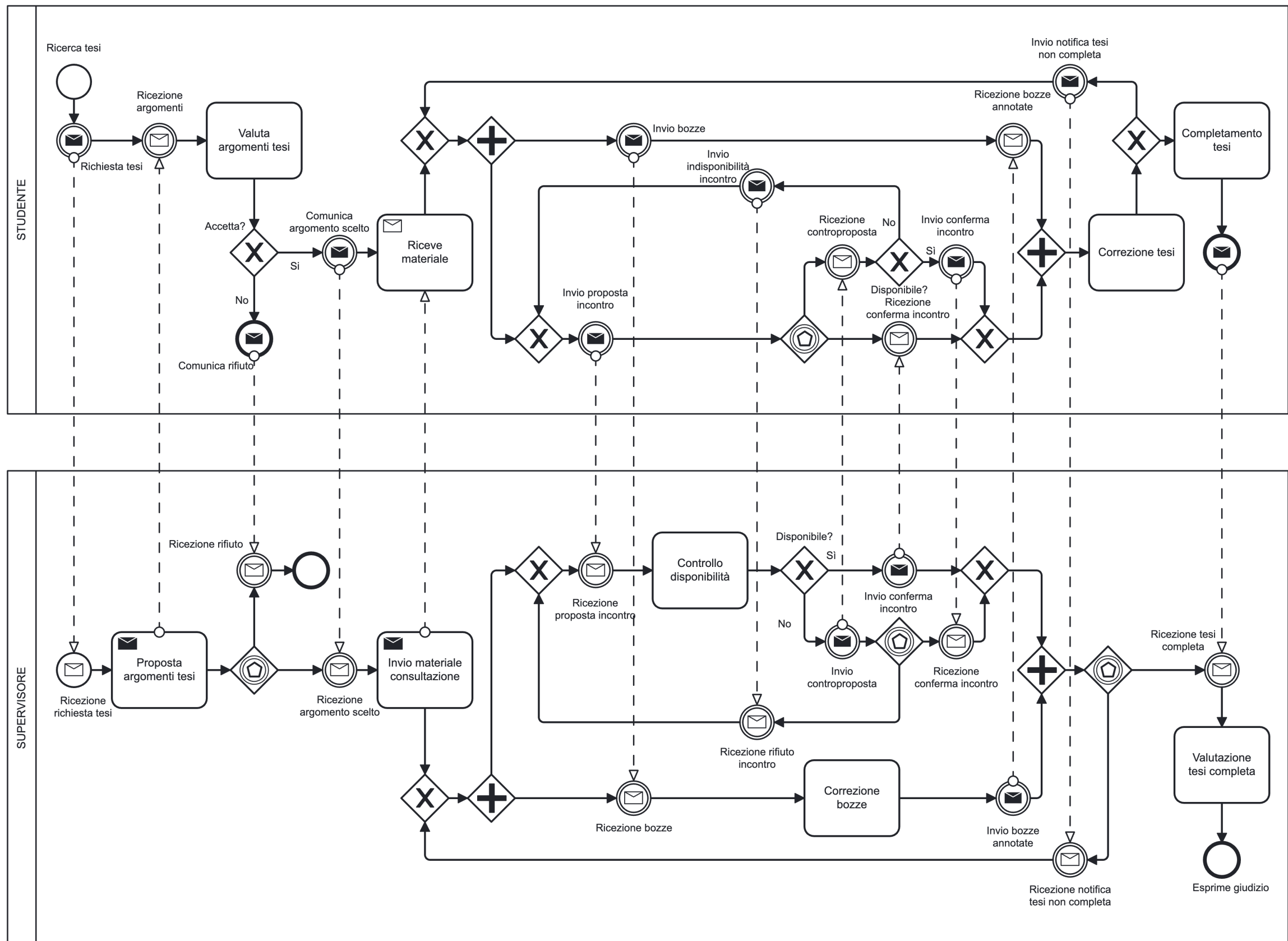


To analyse them

To communicate them to others

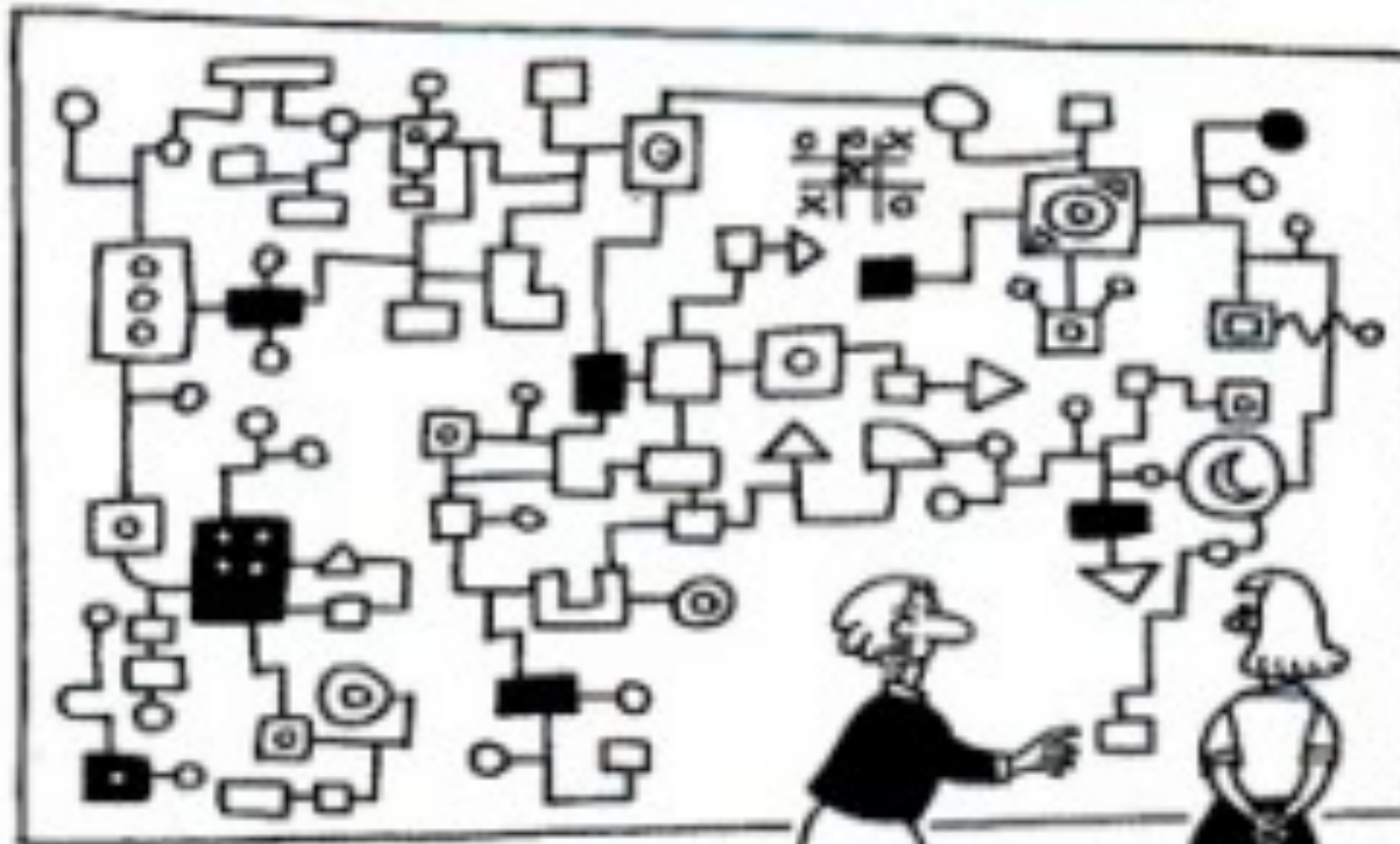
To change them if needed

A taste of BPMN



Workflow wave

WORKFLOW REDESIGN



In the mid-nineties, workflow management systems aimed to the automation of structured processes

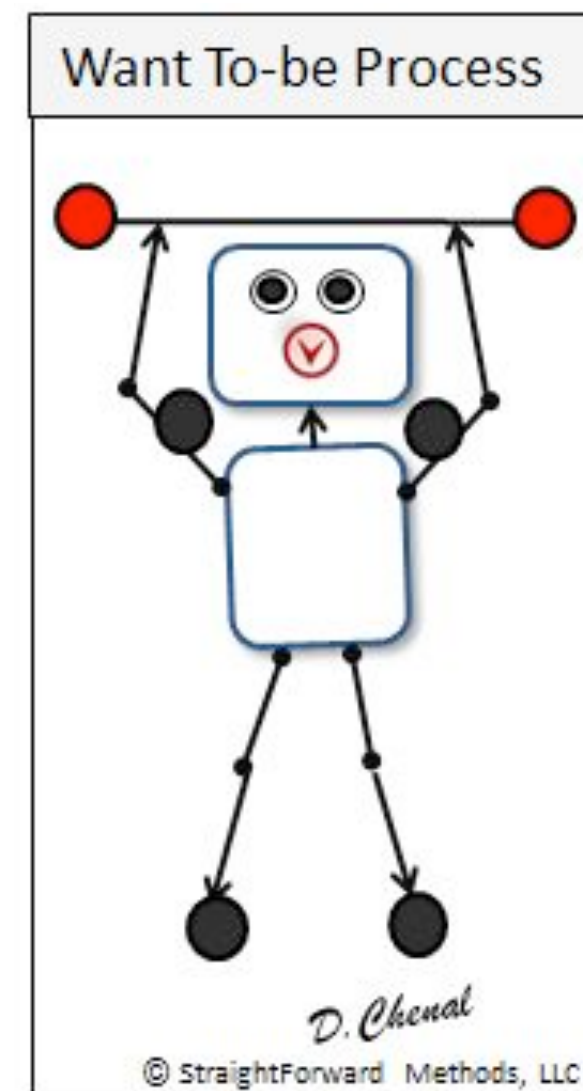
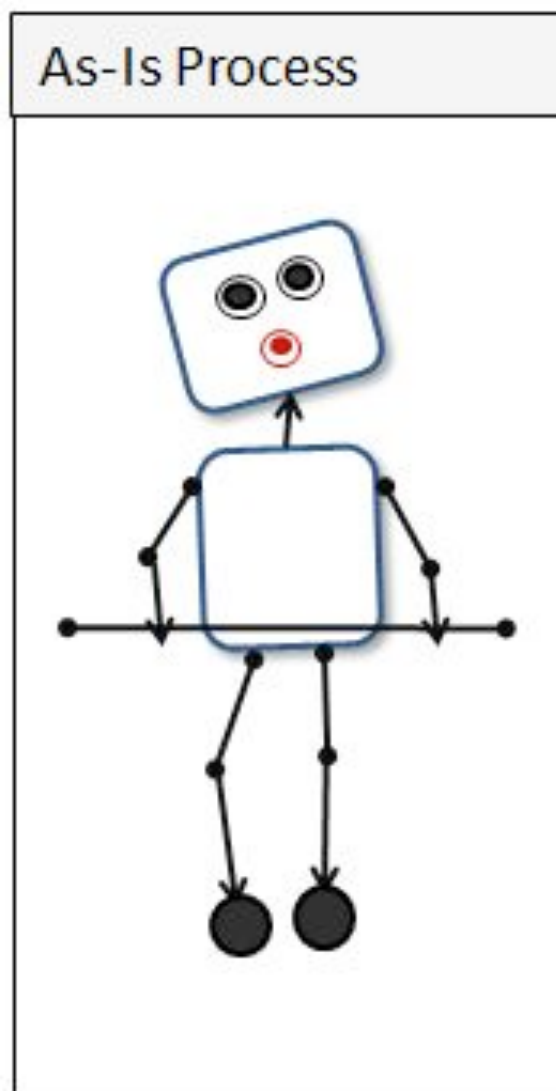
but their application was restricted to only a few application domains

"And this is where our ED workflow redesign team went insane."

Process awareness

BPM moves from
workflow management systems
(intra-organization)

to the broader perspective of
process-aware
information systems
(inter-organizations)



What is the BPM maturity of your organization?

1 initial

No structured BPM activities in the area of responsibility of the stakeholder.

2 awareness

Awareness of BPM exists in the organization.

(Planning) activities have started for the definition of the subject.

3 defined

BPM is defined.

Implementation is yet missing or ongoing.

4 managed

BPM is implemented. (People assigned. Communication to relevant people done. Training done, etc.)

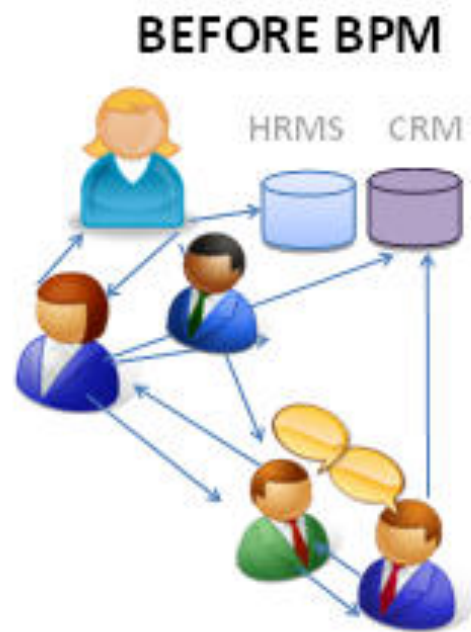
5 excellence

BPM is implemented enterprise-wide. A continuous review & improvement process is **implemented** to exchange lessons-learned & address required changes proactively.

© 2008 IDS SCHEER



Before and after BPM

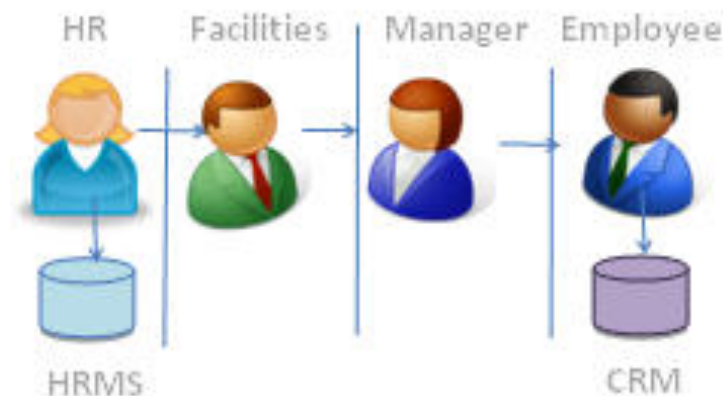


Know end goal

Handled differently
every time



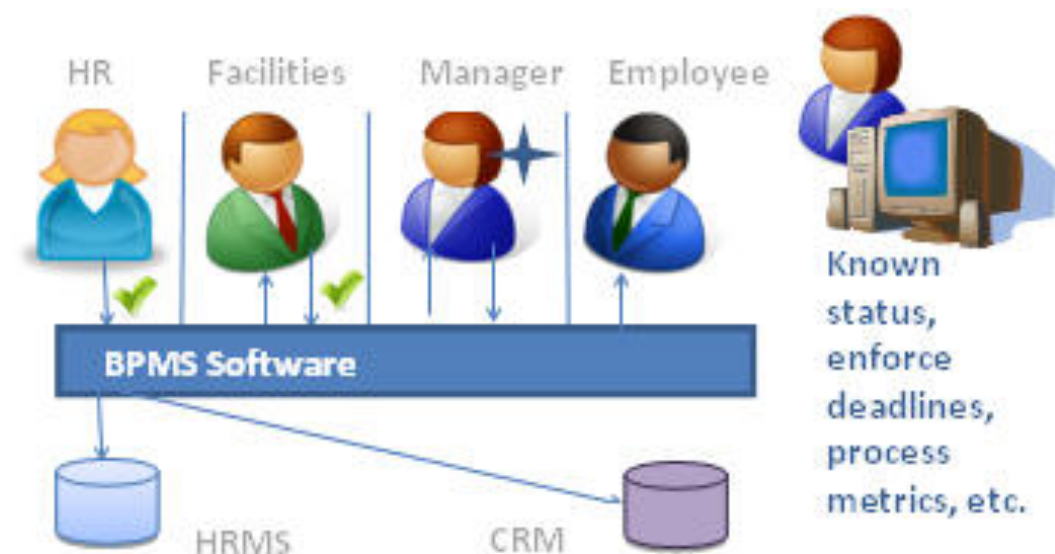
AFTER BPM



Know how to handle
each occurrence



AFTER BPMS



Why BPM?

Highly relevant for
pratictioners

Offers intellectual challenges for
software developers and
computer scientists

BPM angles

Analysis: simulation,
verification, process mining, ...

Influences: business aspects,
social aspects, training, education, ...

Technologies: interoperability,
standardization efforts,
service orientation, ...

Essential concepts

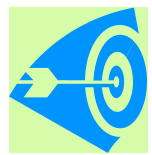
Different educational
backgrounds and interests
are in place

This course is not about a
particular XML syntax (e.g., BPMN)
or tool (e.g. ProM)

It is about using some process
languages to describe, single out,
relate, compare essential concepts

Which target?

Formal methods people



- investigate properties
- detect and correct deficiencies
- abstract from "real world"

Software develop people



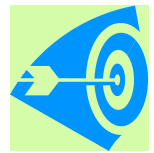
- provide robust and scalable sw
- integration of existing sw
- look at new technology trends

Business admin people



- increase customer satisfaction
- reducing costs
- establishing new products

BPM aims at



robust and correct realization of



business processes in software that



increases customer satisfaction and
ultimately contributes to the competitive
advantage of an enterprise

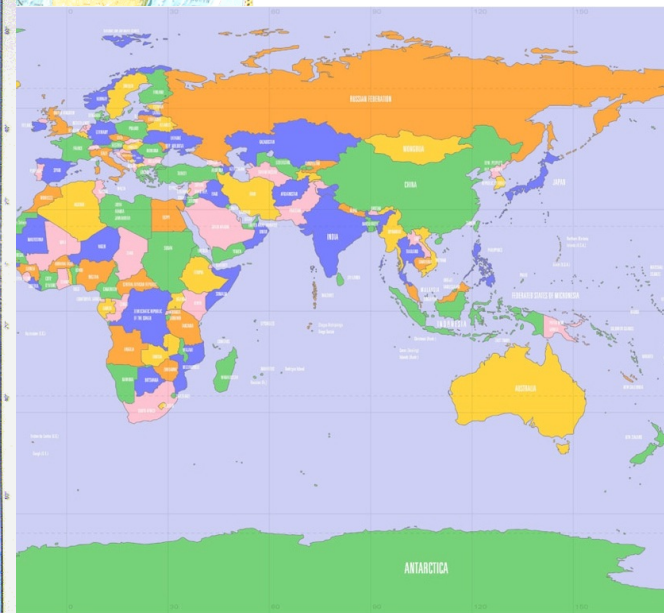
Abstraction

Abstraction

- Business admin people
 -  – IT as a subordinate aspect (for expert technicians)
 - This course: too much math!
- Software develop people
 -  – Current technology trend as main concern
 - This course: too abstract!
- Formal methods people
 -  – Underestimate business goals and regulations
 - This course: too much handwaving!

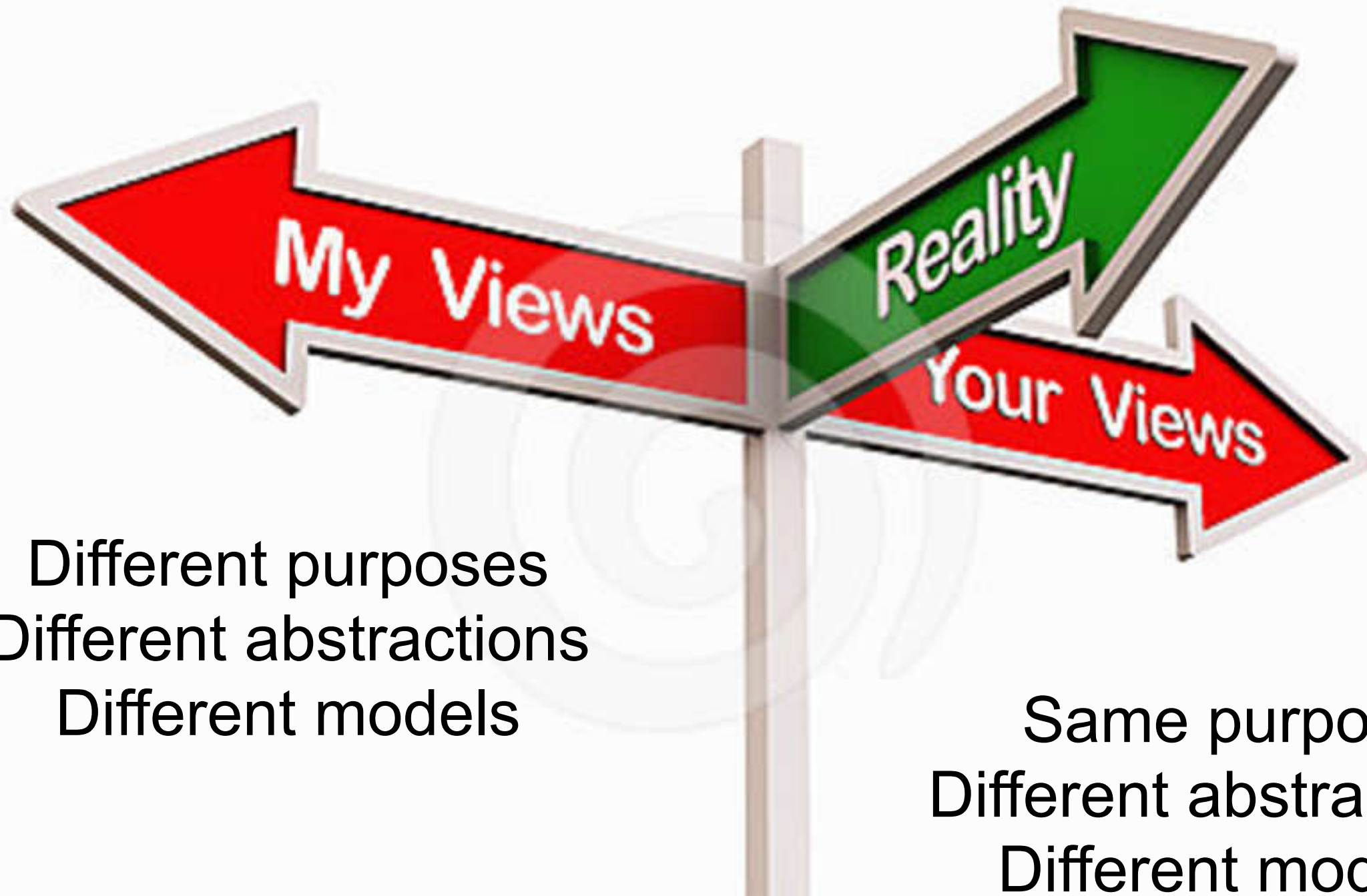
Abstraction as the key to achieve some common understanding, to build a bridge between views...

Levels of abstractions



One object,
many views

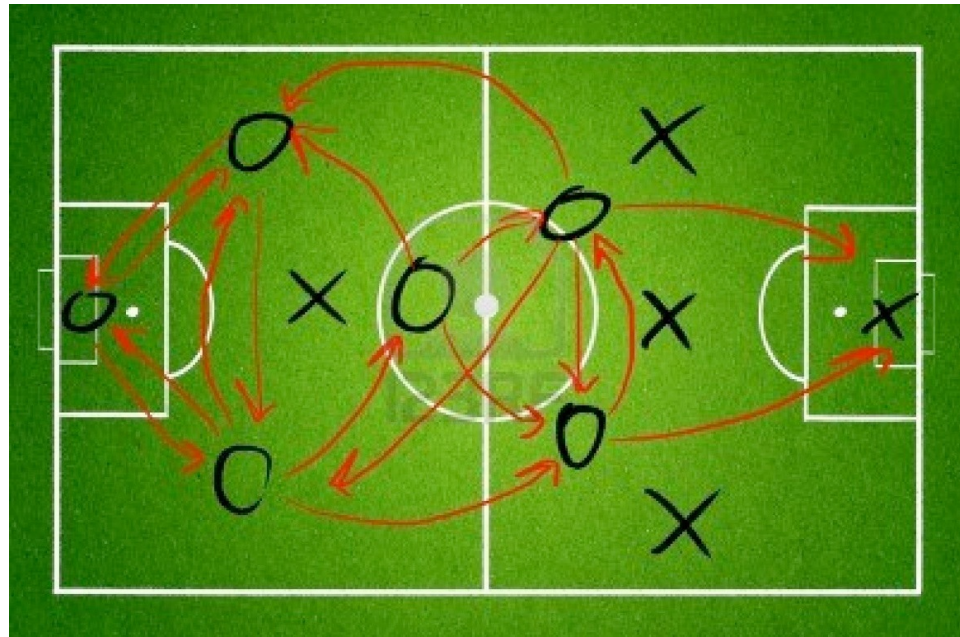
Different views are common



Different purposes
Different abstractions
Different models

Same purpose
Different abstractions
Different models

Everybody wanted~~ed~~ to be the Italian soccer team coach



What about the adversaries?

Can we find out their plan?

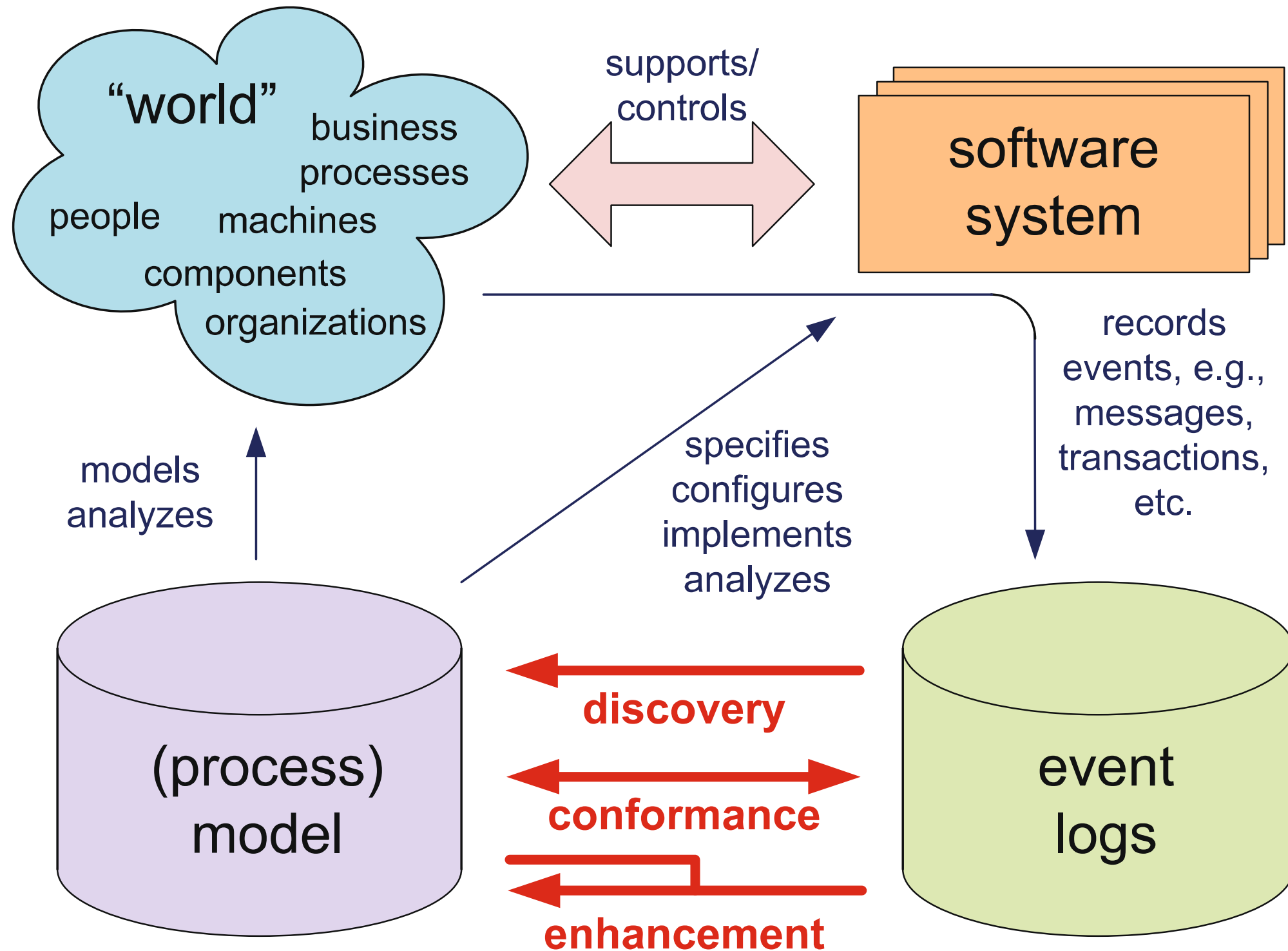


Knowing it would
be quite helpful

Any idea how to?

(abstractions can be designed but can also be derived)

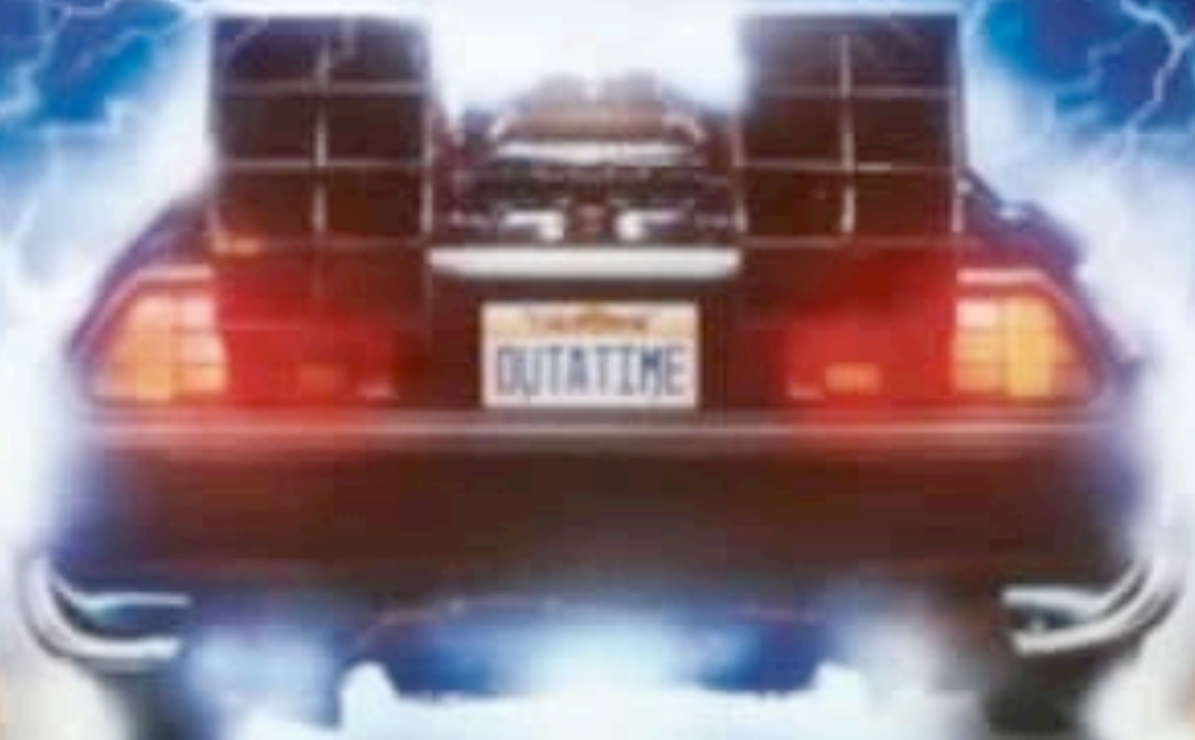
A taste of Process Mining



Digression:
formal modelling
and the importance of proofs

BACK TO THE FUTURE

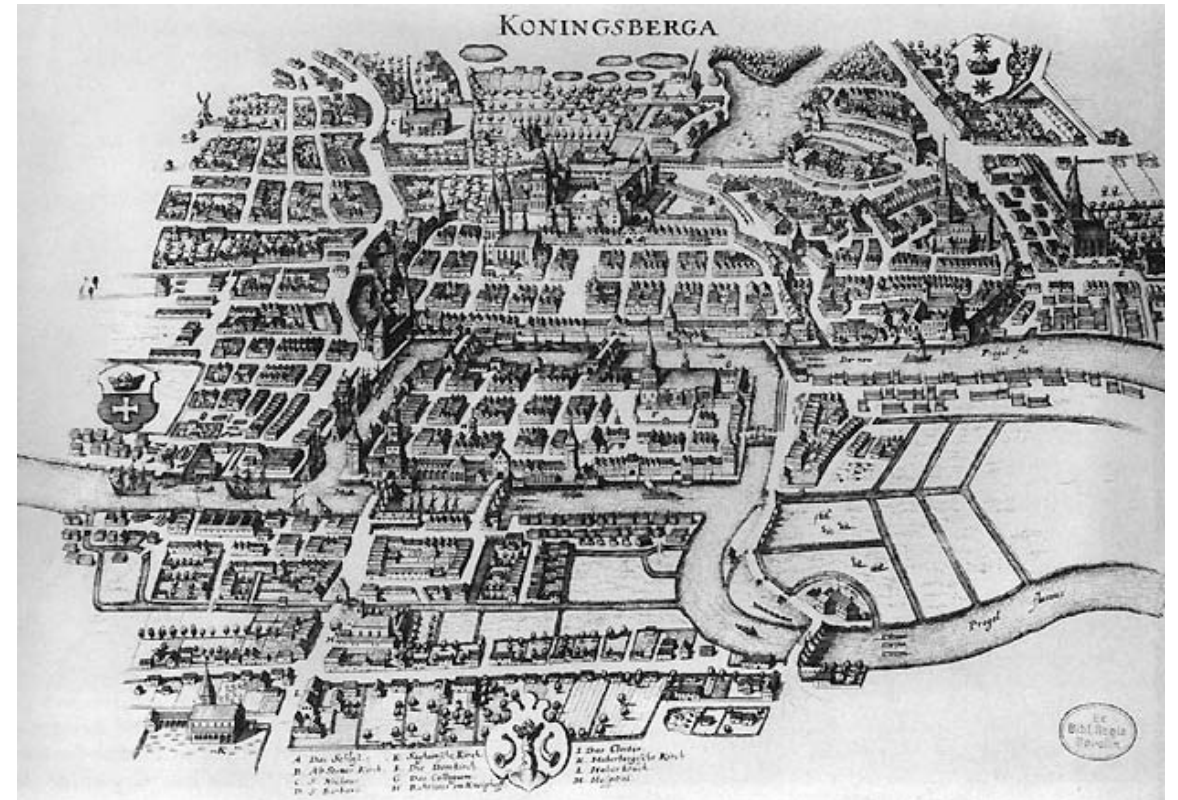
1736



Digression...

Let us travel back in time to the 18th century, in the beautiful Prussian city of Königsberg:

it was thanks to the layout of that city that **Leonhard Euler** answered a puzzle which eventually contributed to the birth of two new areas of maths known as **topology** and **graph theory**.

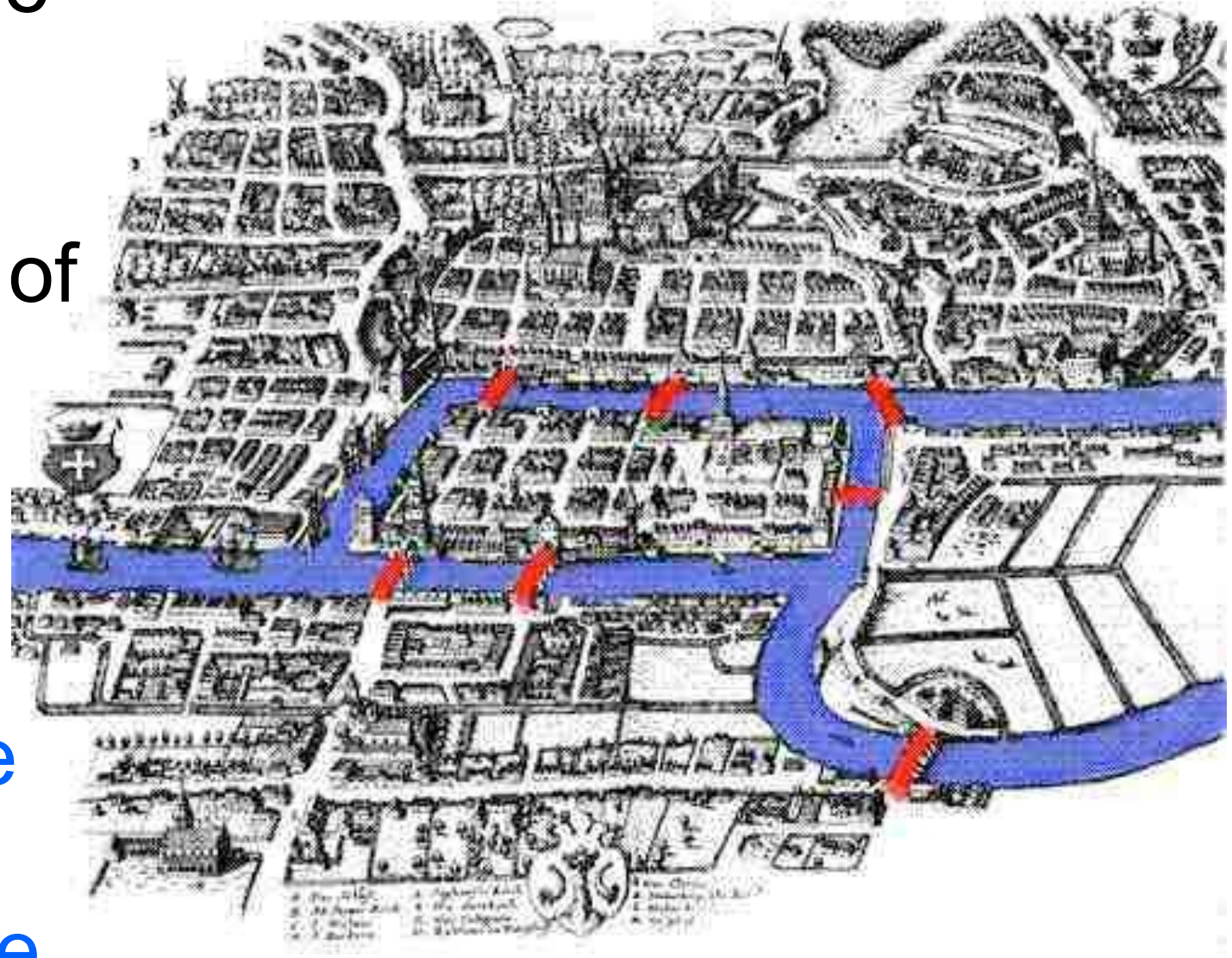


Digression...

Königsberg was built on the bank of the river Pregel.

Seven bridges connected two islands and the banks of the river (see map).

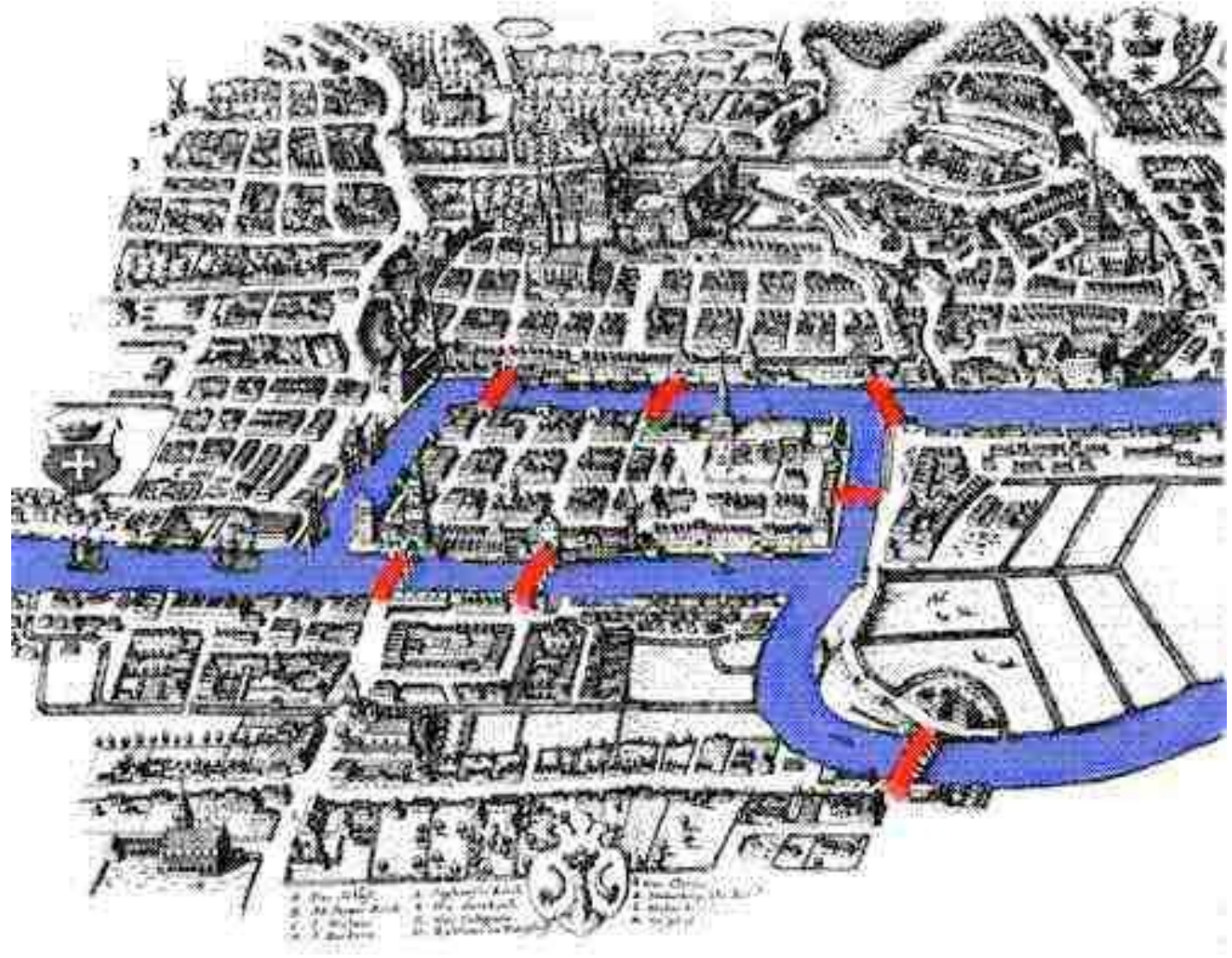
A popular pastime of the residents was to try to cross all the bridges in one complete circuit (without crossing any of the bridges more than once).



Digression...

A seemingly simple task was more than tricky...

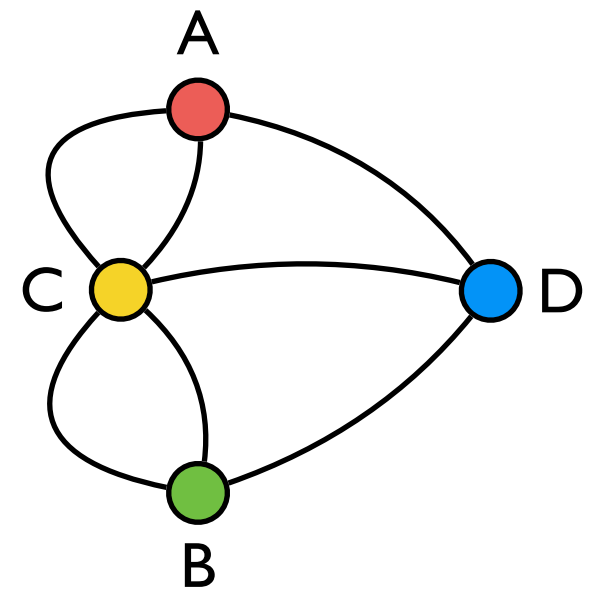
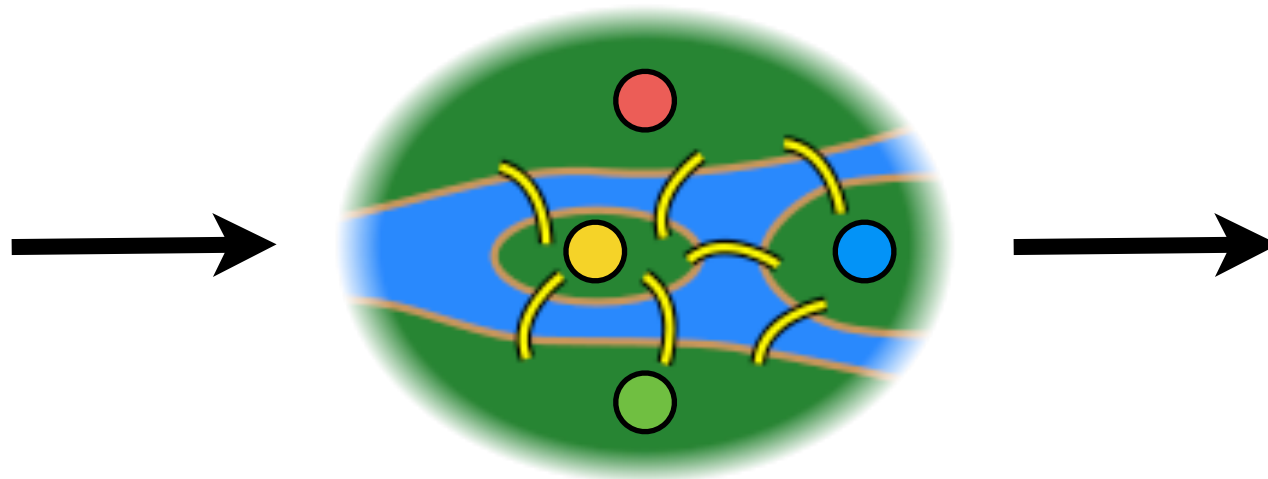
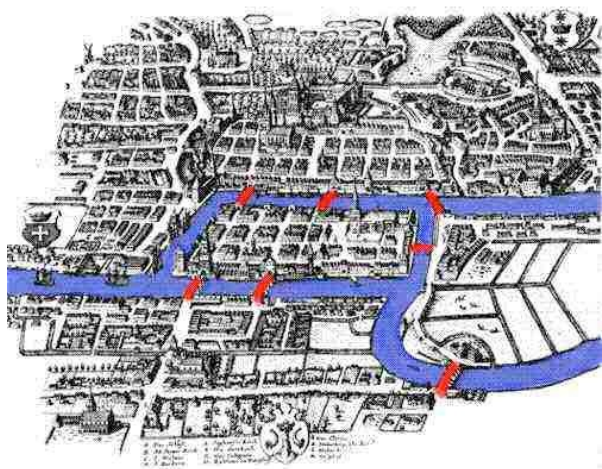
Nobody had been able to find a solution to the puzzle when Euler first heard of it and, intrigued by this, he set about **proving** that **no solution was possible!**



Digression...



In 1736, Euler analysed the problem by converting the map into a more abstract diagram... and then into a **graph** (a formal model):



areas of land separated by the river were turned into points, which he labelled with capital letters.

Modern graph theorists call these **vertices** or **nodes**.

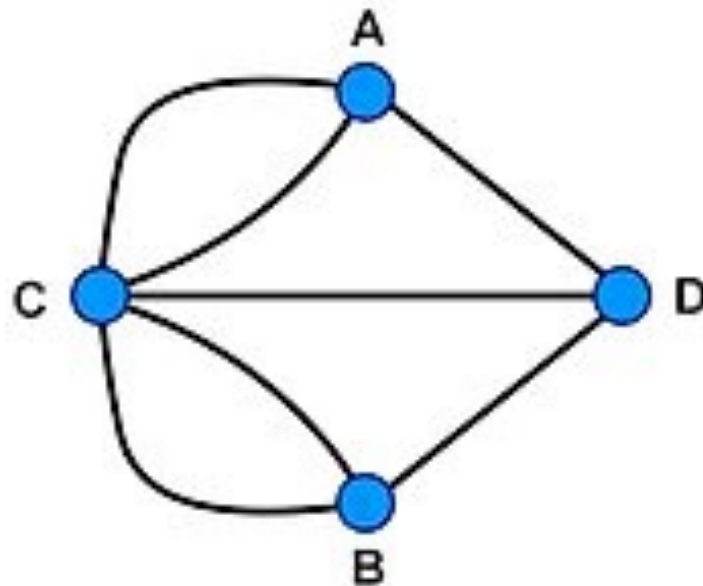
The bridges became **edges** between nodes.

Digression...

Modeling activities require several steps of abstraction that **must preserve the set of solutions**: in other words the abstractions must preserve the topology of the problem.

Original problem: *seven bridges of Königsberg*

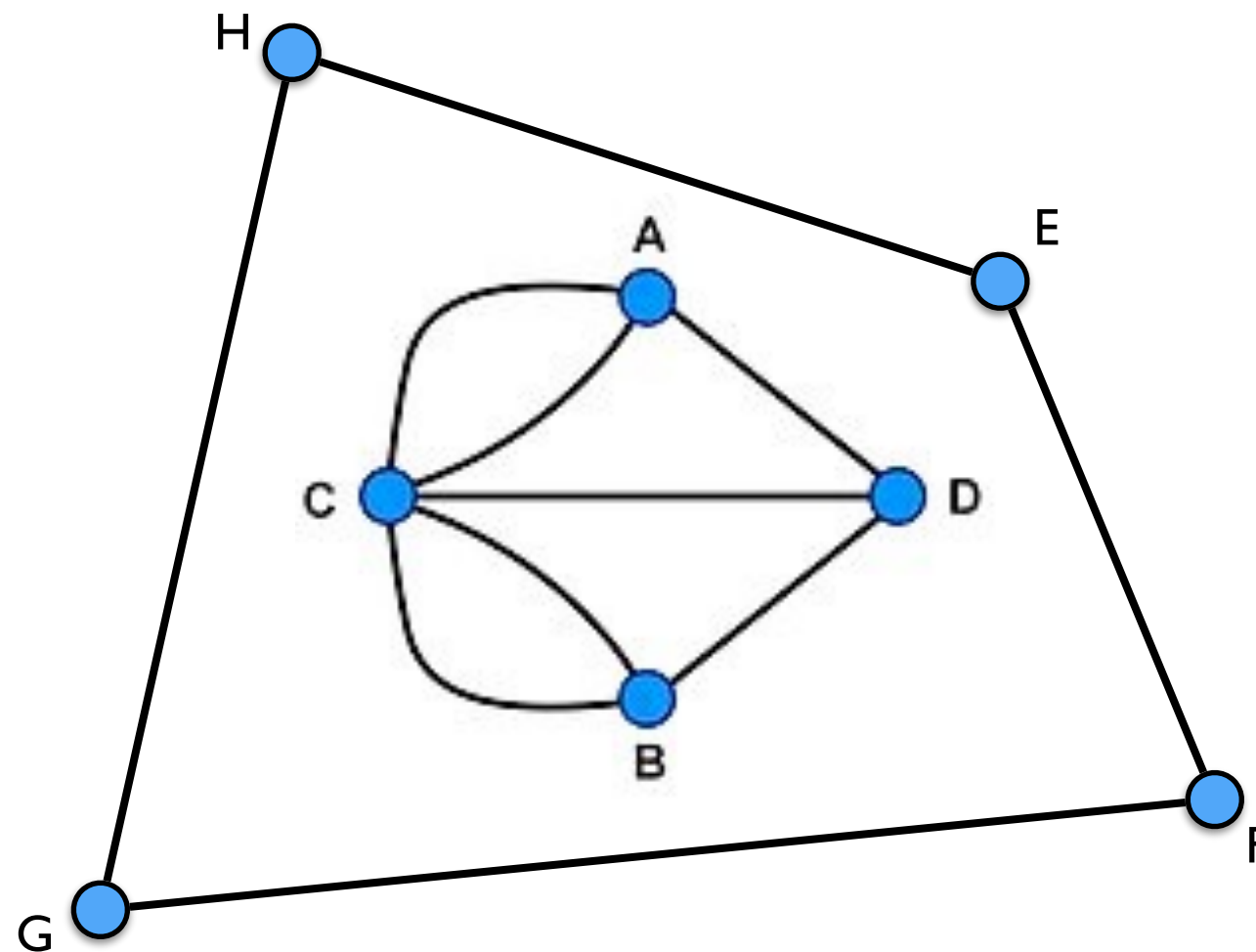
Graph problem: *redrawing this picture without retracing any line and without picking your pencil up off the paper*



Generalized problem: *given a **connected** graph, find a **circuit** that visits every edge precisely once, **if it exists***

Terminology

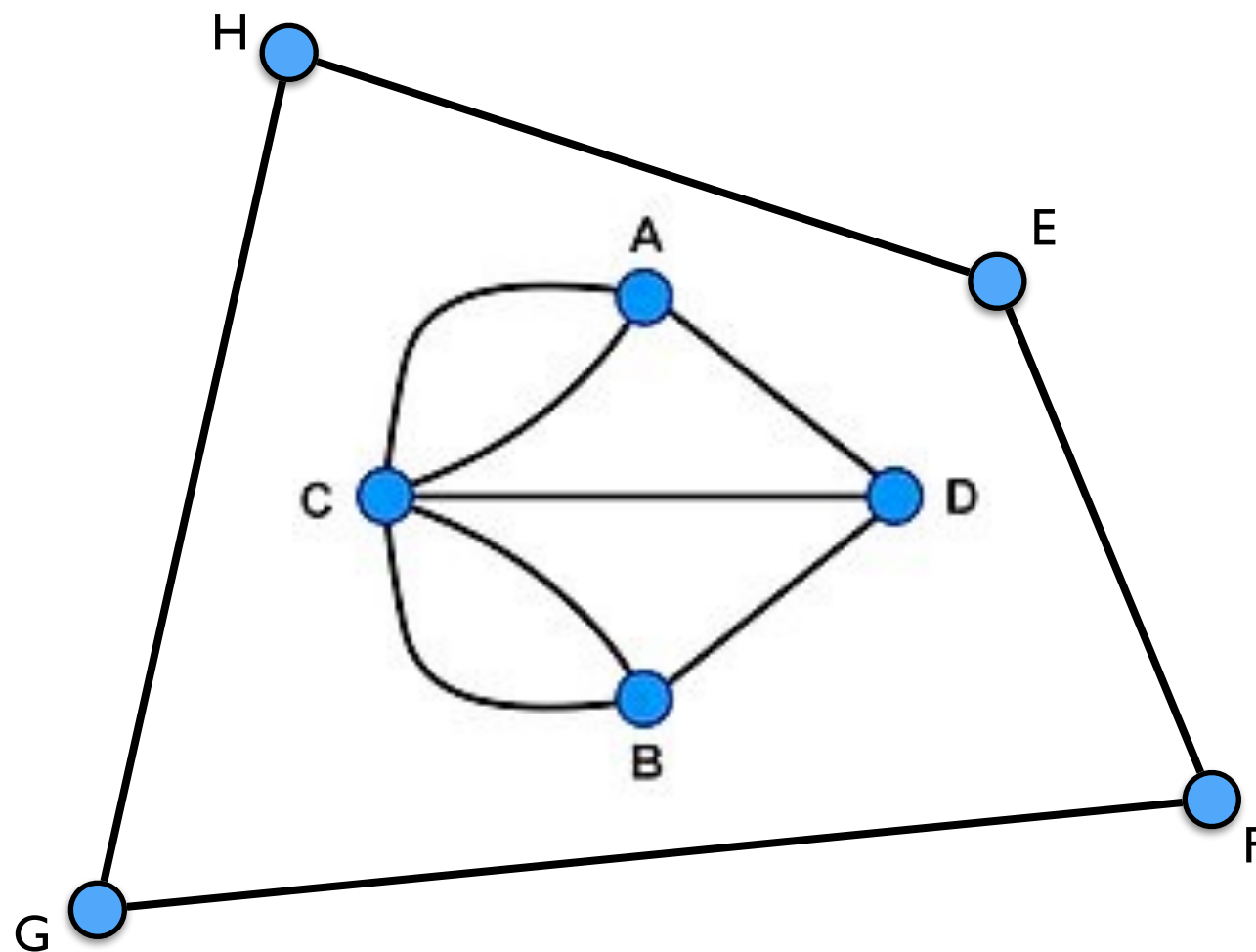
A non-connected graph



Generalized problem: *given a **connected** graph, find a **circuit** that visits every edge precisely once, **if it exists***

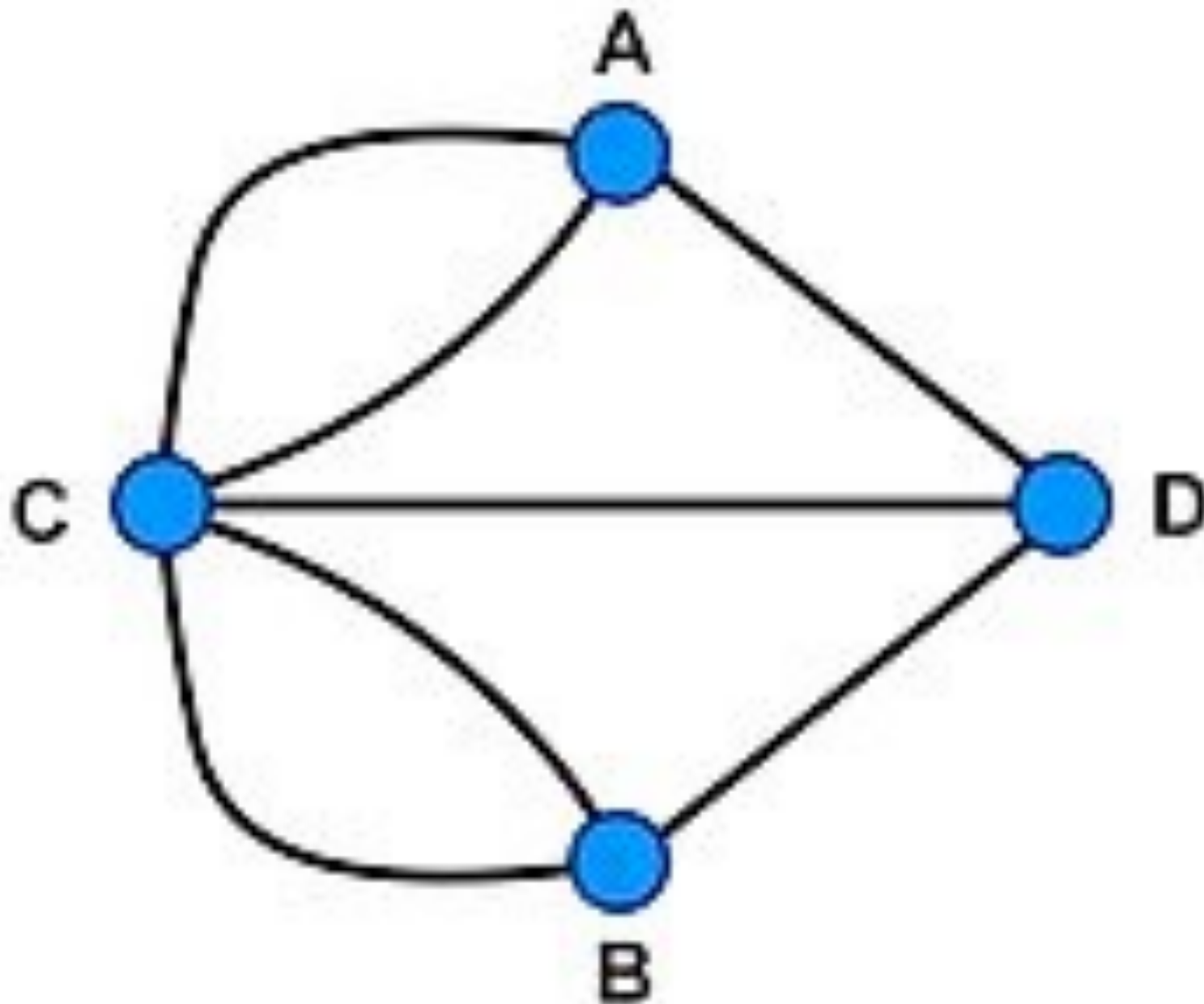
Terminology

A circuit: $E \rightarrow F \rightarrow G \rightarrow H \rightarrow E$



Generalized problem: *given a **connected** graph, find a **circuit** that visits every edge precisely once, **if it exists***

Let's play

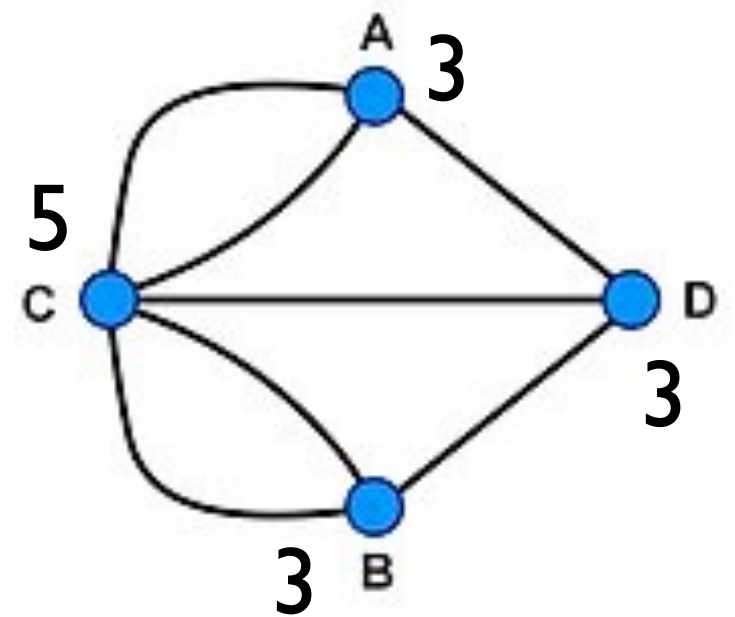
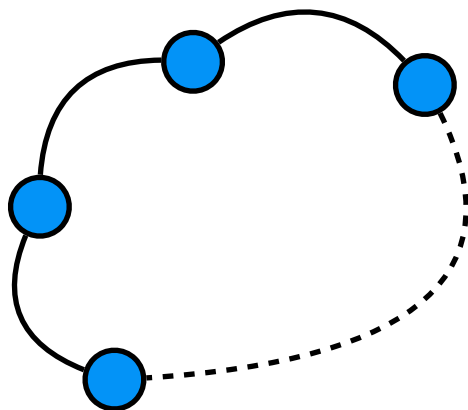


$A \rightarrow C \rightarrow A \rightarrow D \rightarrow C \rightarrow B \rightarrow C \rightarrow ?$

Digression...

Informal reasoning:

In a circuit every time you enter a node you must be able to leave it: thus, every vertice must be connected to an **even** number of edges!



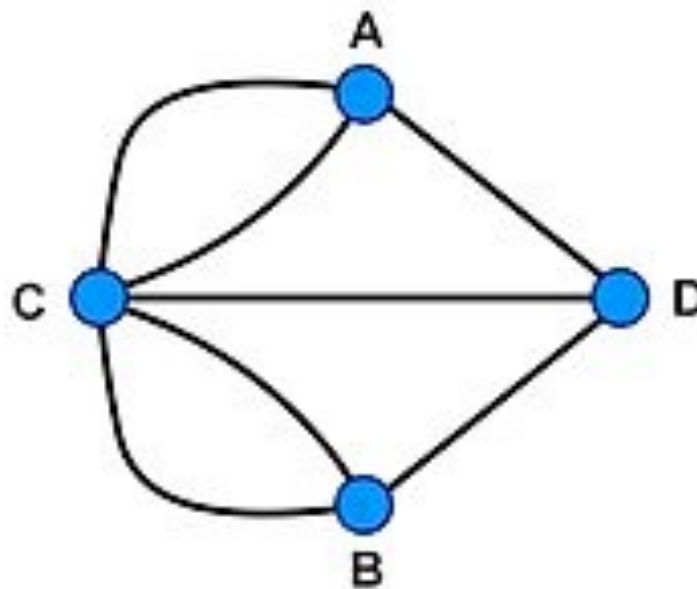
Informal reasoning:

All the vertices in the picture are connected to an **odd** number of edges

This suffices to establish that no solution can be found!

Digression...

Take one of these vertices, say A, and start trying to trace the figure out without picking up your pencil: then two edges are left from/to A.



Next time you arrive in A, one edge will be left, and when you will leave A, no edge to re-enter it will be left!

Analogously for B, C, D: No circuit is possible!

Digression...

Formal reasoning:

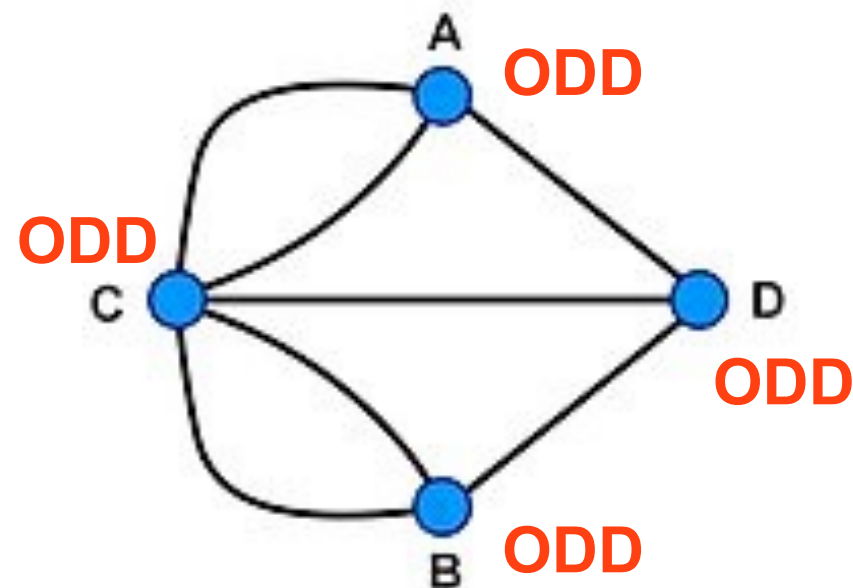
Definition: A **path** is a (finite) sequence of contiguous edges. It is a **circuit** if it ends in the same vertex where it starts.

Definition: An **Eulerian path** is a path that passes through every edge of the graph once and only once.

Definition: The number of edges attached to v is called **degree** of v . A vertex is called **odd** if it has an odd degree, **even** otherwise.

Theorem: A (connected) graph G contains an Eulerian circuit **if and only if** each vertex is even.

Digression...



Theorem: A (connected) graph G contains an Eulerian circuit if and only if each vertex is even.

Digression...

Proof of necessity:

(If G has an Eulerian circuit, then any vertex is even)

Suppose G contains an Eulerian circuit C .

Then, for any choice of vertex v , C contains all the edges that are adjacent to v .

*Furthermore, as we traverse along C , we must enter and leave v the same number of times, and it follows that v must be even. **qed***

While this proof of necessity was given by Euler, the converse was not stated in his paper.

It is not until 1873 (137 years later) when a young German mathematician, [Carl Hierholzer](#) published the proof of sufficiency.

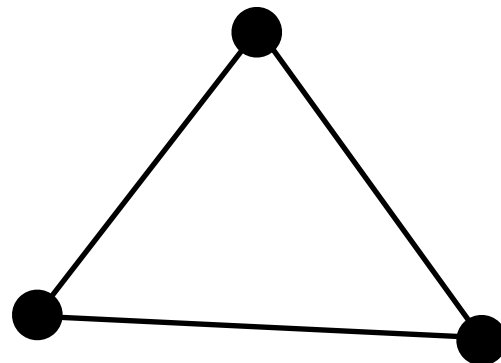
Digression...

Proof of sufficiency:

(If any vertex is even, then G has an Eulerian circuit)

The proof is by **induction** on the numbers of edges, ctd)

Base case: the smallest possible number of edges is 3 (i.e. a triangle) and the graph trivially contains an Eulerian circuit.



Digression...

Proof of sufficiency: (by **induction** on the numbers of edges, ctd)

Inductive case:

*Inductive hypothesis: Let us assume that any connected graph H that **contains k or less than k edges** and such that every vertex of H is even, contains an Eulerian circuit.*

Now, let G be a graph with $k + 1$ edges, and such that every vertex is even. We want to prove G has an Eulerian circuit

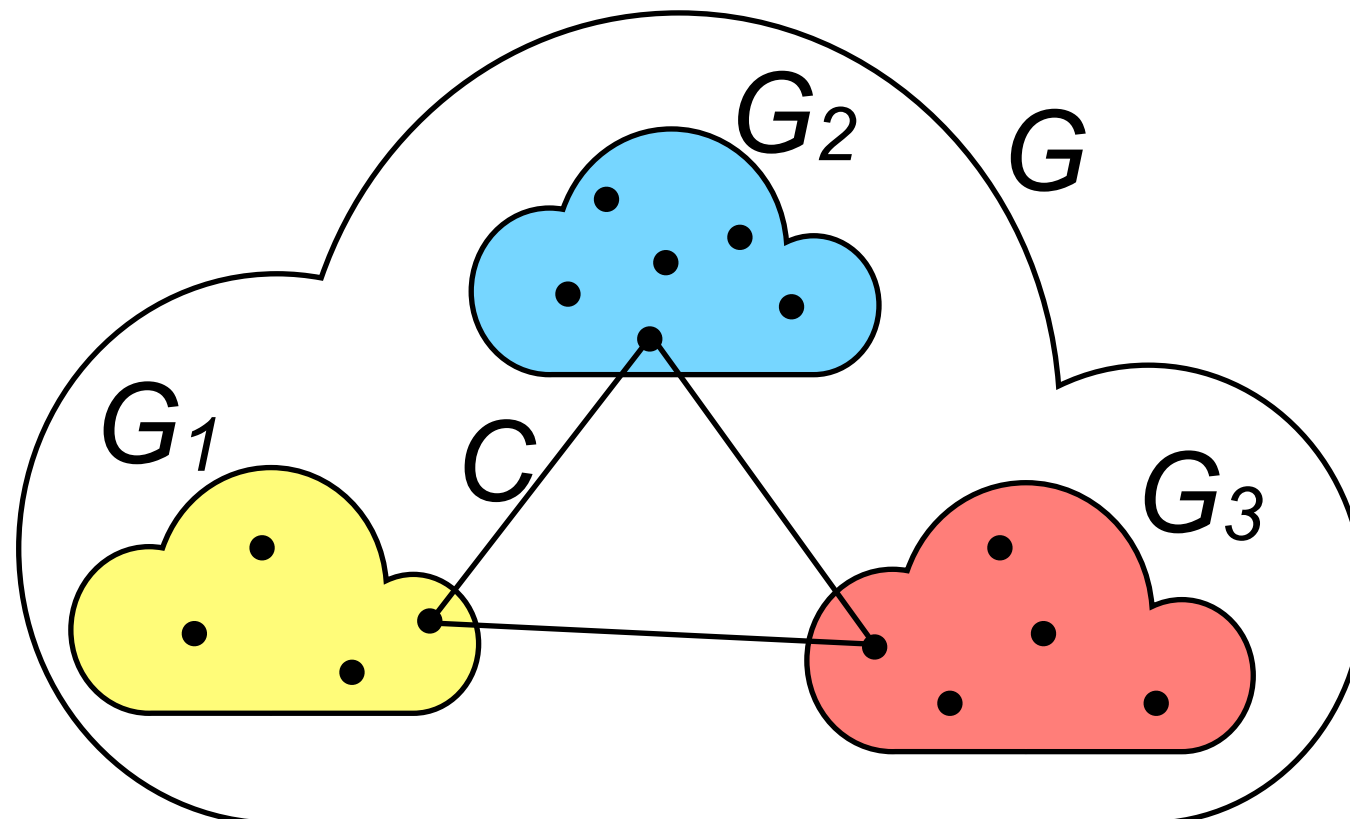
*Since there is no odd vertex, G cannot be a tree (no leaves).
Thus, G must contain at least one cycle C .*

...

Digression...

Proof of sufficiency: (by [induction](#) on the numbers of edges, ctd)
... Remove the edges of C from G , and take the remaining graph G' .

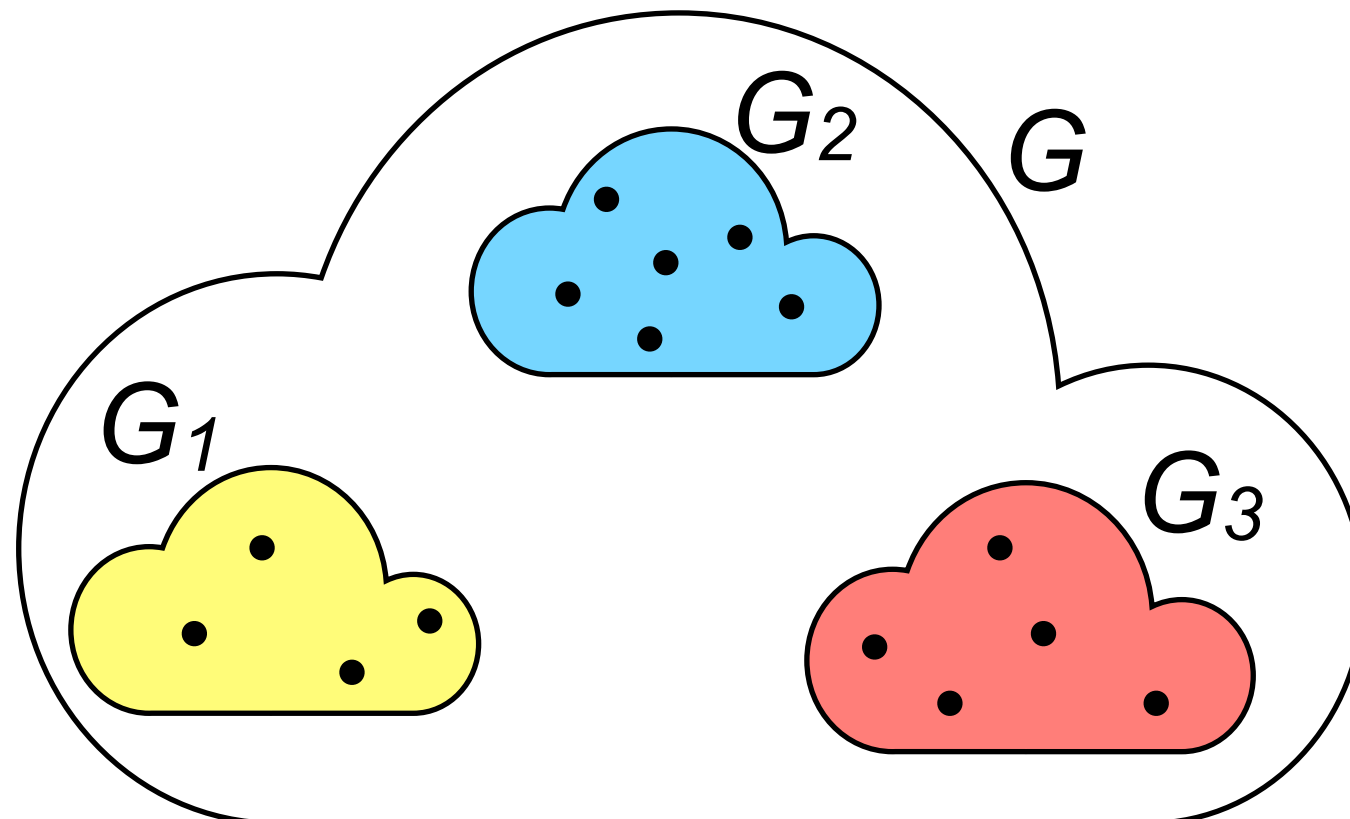
Since removing C from G may disconnect the graph, G' is a collection of connected components, namely $G_1, G_2, \dots$, etc.



Digression...

Proof of sufficiency: (by [induction](#) on the numbers of edges, ctd)
... Remove the edges of C from G , and take the remaining graph G' .

Since removing C from G may disconnect the graph, G' is a collection of connected components, namely $G_1, G_2, \dots$, etc.



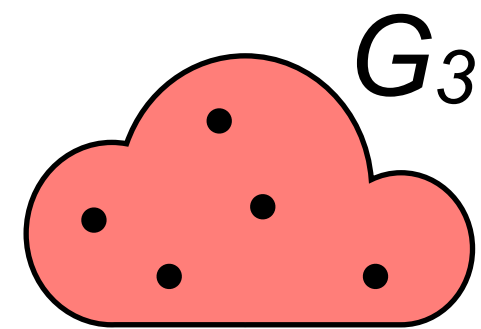
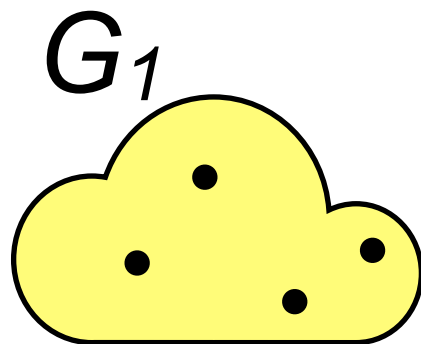
Digression...

Proof of sufficiency: (by *induction* on the numbers of edges, ctd)
... When the edges in C are removed, each vertex loses an even number of adjacent edges.

*Thus, the *parity* of each vertex is unchanged in G' .*

It follows that, for each connected component of G' , every vertex is even (and G' must have less than k edges).

Therefore, by the inductive hypothesis, each of G_1 , G_2 , $\dots$ has its own Eulerian circuit, namely C_1 , C_2 , etc.



...

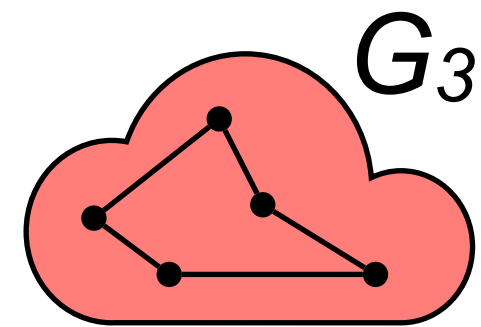
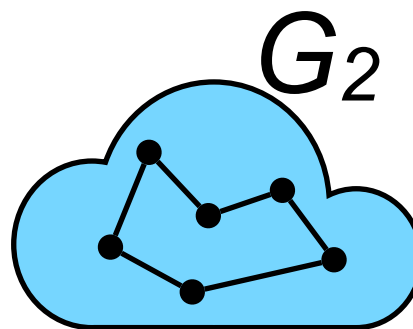
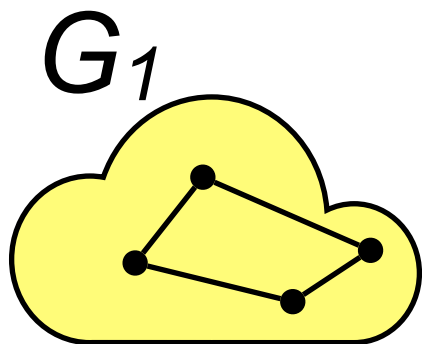
Digression...

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Therefore, by the inductive hypothesis, each of $G_1, G_2, \dots$ has its own Eulerian circuit, namely C_1, C_2 , etc.



...

Digression...

Proof of sufficiency: (by **induction** on the numbers of edges, ctd)
... We can now build an Eulerian circuit for the whole graph G .

Pick an arbitrary vertex v from C .

Traverse the edges along C until we reach a vertex v_i that belongs to one of the connected components G_i .

Then, traverse G_i along its Eulerian circuit C_i until we traverse all the edges of C_i .

We are now back at v_i , and so we can continue on along C .

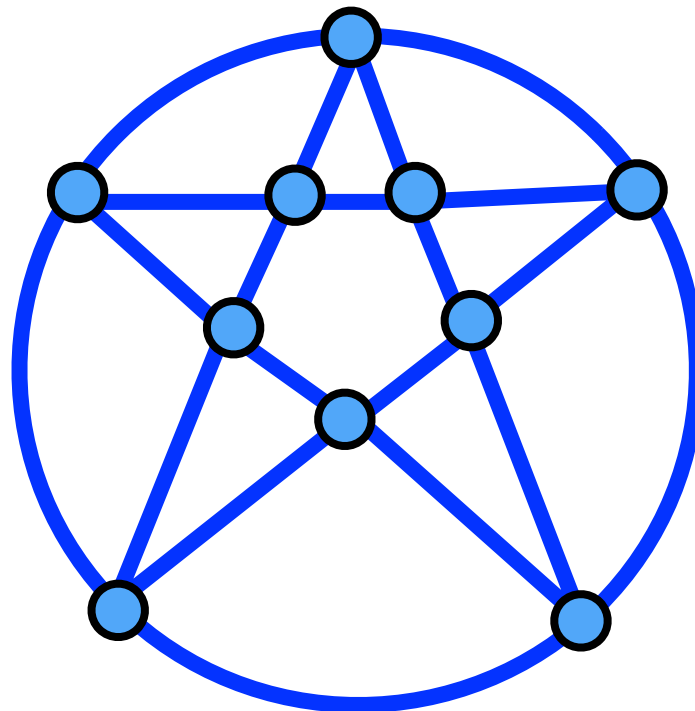
In the end, we shall return back to the first starting vertex v of C , after visiting every edge exactly once. **qed**

Digression...

The theorem, as such, is only an existential statement.

If the necessary and sufficient condition is satisfied, we'd like to find an Eulerian circuit.

The sufficiency proof gives us an algorithm to build Eulerian circuits:
recursively find a cycle, and then remove the edges of the cycle.

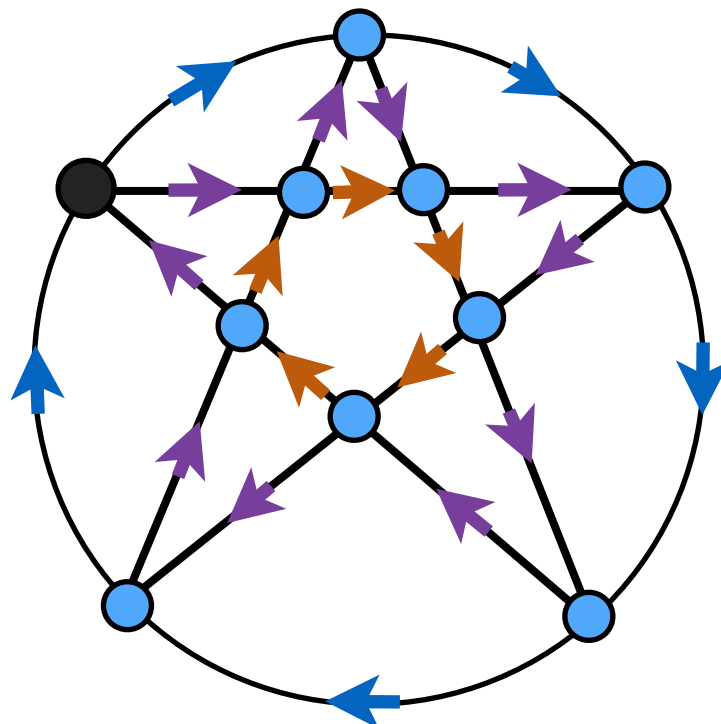


Digression...

The theorem, as such, is only an existential statement.

If the necessary and sufficient condition is satisfied, we wish to find an Eulerian circuit.

The proof naturally gives an algorithm to construct Eulerian circuits:
recursively find a cycle, and then remove the edges of the cycle.



Digression...

Theorem: A graph contains an **Eulerian path** if and only if there are 0 or 2 odd vertices.

Proof. (first part: if G has an Eulerian path then there are 0 or 2 odd vertices)

Suppose a graph G contains an Eulerian path P .

Then, for every vertex v , P must enter and leave v the same number of times, except when it is either the starting vertex or the final vertex of P .

When the starting and final vertices are distinct, there are precisely 2 odd vertices.

When these two vertices coincide, there is no odd vertex.

(second part: if G has 0 or 2 odd vertices, then there is an Eulerian path)

Conversely, suppose G contains 2 odd vertices u and v .

(The case where G has no odd degree vertex is shown in the previous Theorem.)

Then, temporarily add a dummy edge (u, v) to G .

Now the modified graph contains no odd vertex.

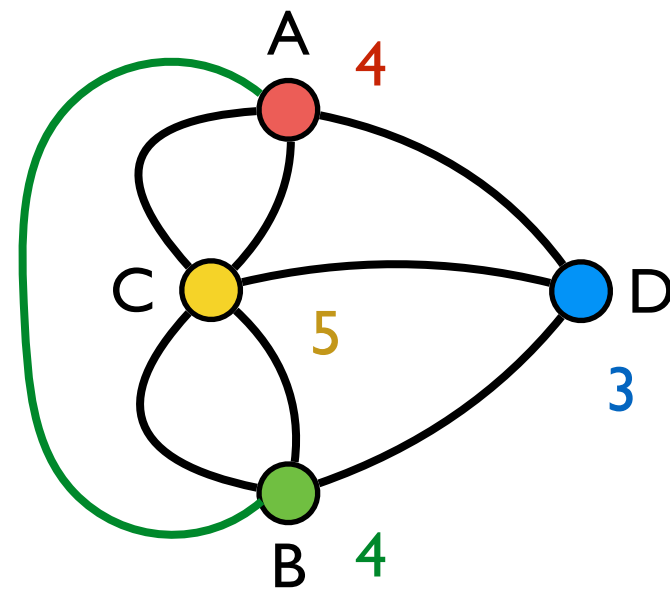
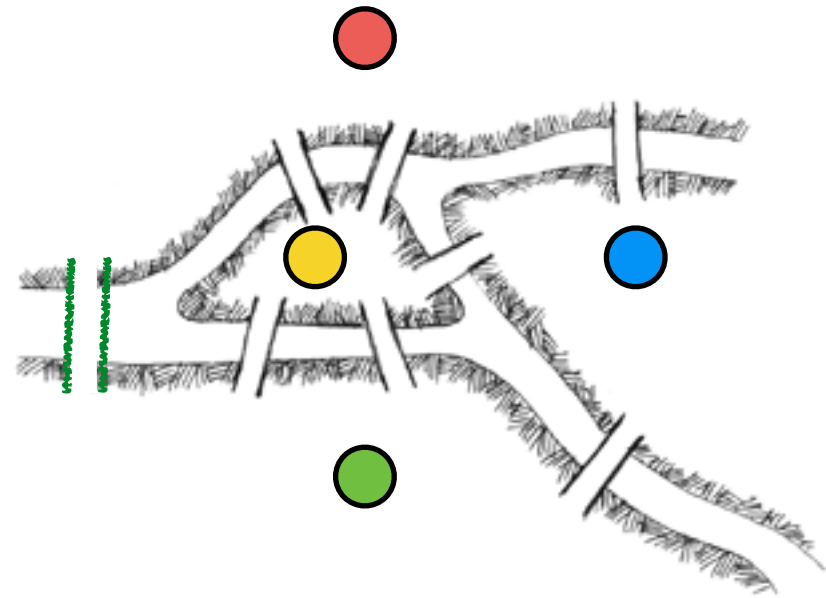
By the previous Theorem, this graph contains an Eulerian circuit C that includes (u, v) .

Remove (u, v) from C , and now we have an Eulerian path where u and v serve as initial and final vertices.

Digression...

In the late 19th century an eighth bridge was built (see map).
Was Königsberg Eulerised?

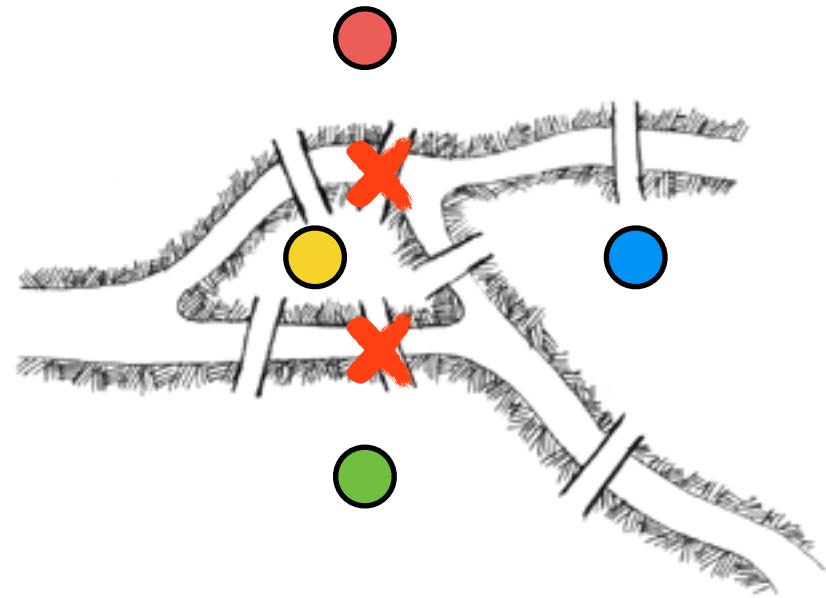
Exercise: prove that an Eulerian **path** can be found **(but not a circuit)**



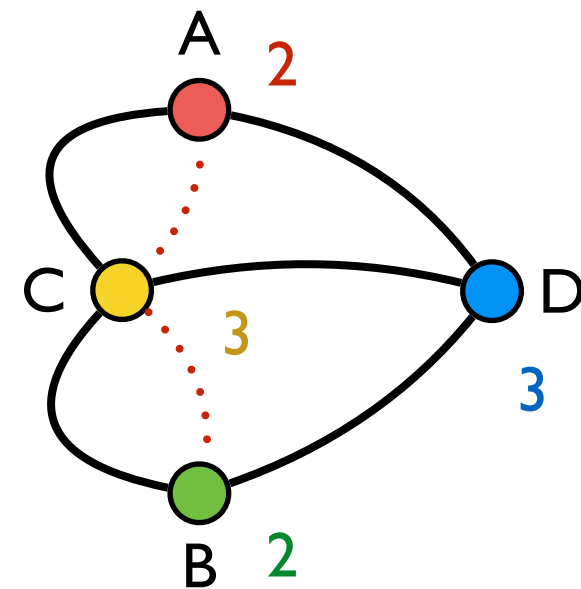
$C \rightarrow D \rightarrow A \rightarrow C \rightarrow A \rightarrow B \rightarrow C \rightarrow B \rightarrow D$

Digression...

Sadly, in 1944 air raids obliterated most of the bridges. However, five bridges crossing were rebuilt (see map). Was the city Eulerised?

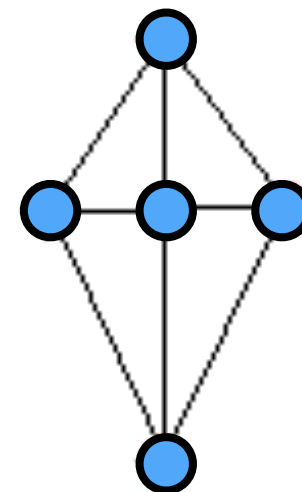
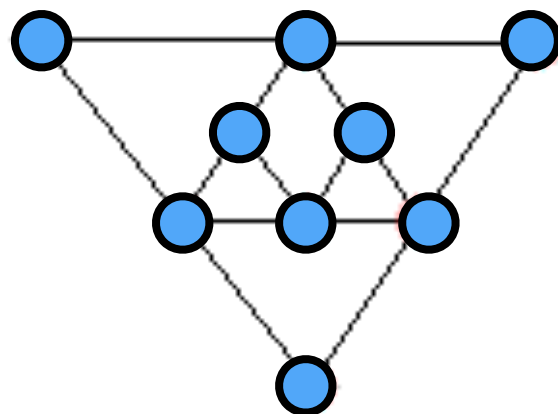
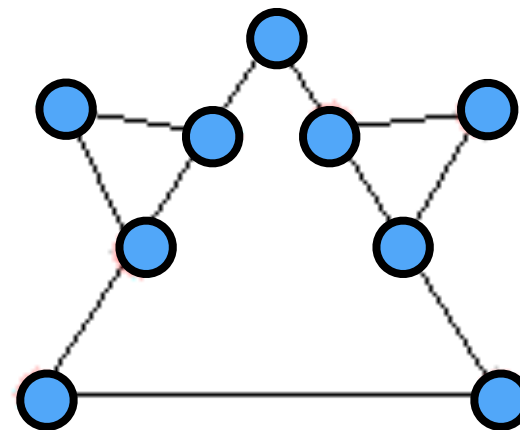
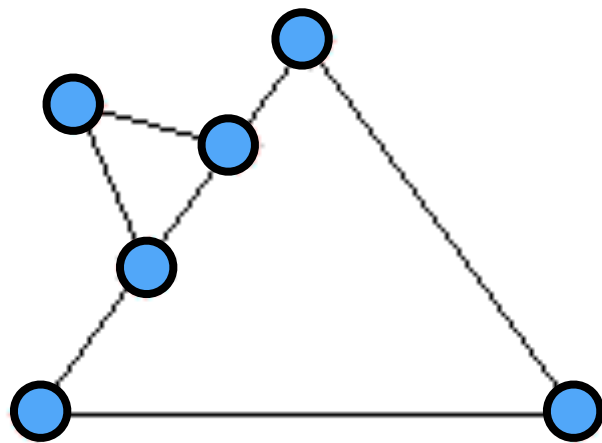


Exercise: prove that an Eulerian path can be found (but not a circuit)



$C \rightarrow D \rightarrow A \rightarrow C \rightarrow B \rightarrow D$

Digression...



Exercises: find Eulerian paths/circuits in the graphs above or prove that they cannot exist.

Recap

Lessons learned

- Start with a concrete instance of the problem
- Abstraction: modeling and generalization, property preserving
- Visual notation: informal, intuitive
- Mathematical notation: rigorous, precise
- Theorems: alternative ways to find answers
- Proofs: construct solutions from formal reasoning
- Implementation: solve any concrete instance of the problem

Yet to learn

- Formal models used in prescriptive manner
- Correctness by design
- Separation of concerns
- Model discovery

Avoid bad designs!

