

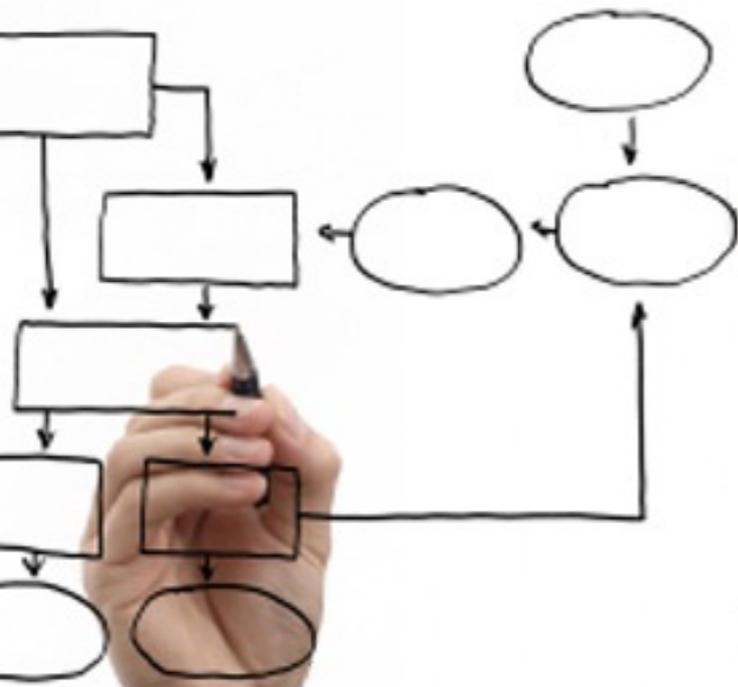
# Business Processes Modelling

## MPB (6 cfu, 295AA)

Roberto Bruni

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

01 - Introduction







Every

**Thursday:**  
16:00-18:00



**Friday:**  
16:00-18:00





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

**Streaming / recording ?**

# Who am I?



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



[bruni@di.unipi.it](mailto:bruni@di.unipi.it)



Office hours: by appointment  
preferably



Wednesday 16:00-18:00

# Who are you?

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

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

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

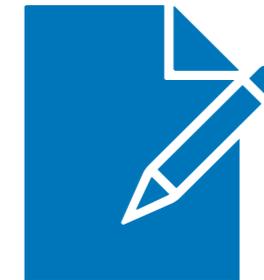
Hi, I'm **Paolo Rossi** from **Italy**

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?

 **Please fill out this form** ×  
A post on Microsoft Forms provided by:  
forms.office.com  
forms.office.com



## Background check (form)

Enrollment number:

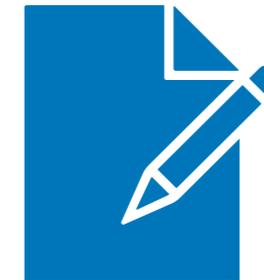
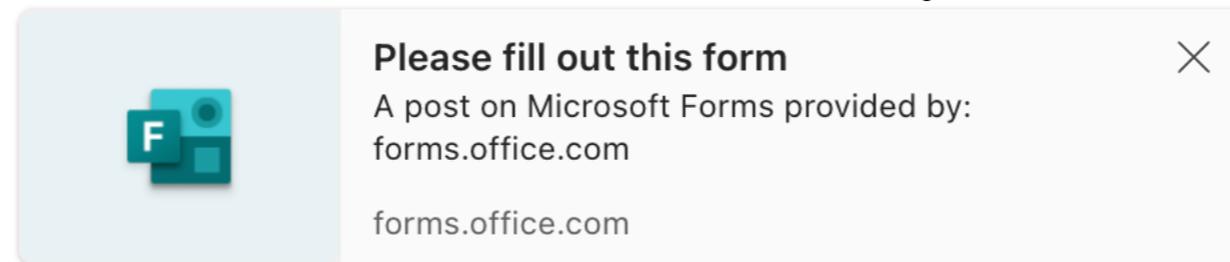
Bachelor degree:

MSc course of enrollment:

Subjects of interest:

.... :

# Who are you?



## Background check (form)

Enrollment number:

Bachelor degree:

MSc course of enrollment:

Subjects of interest:

... :

# The Course

# Some quotes

*All models are wrong, but some are useful*

- George Box

*Subjects are divided in two categories:*

*1) too difficult matters, that CANNOT be studied*

*2) easy matters, that DO NOT NEED to be studied*

- back of a t-shirt

# What is a BP?

Any set of steps aimed to reach some outcome

from opening an account



to processing a custom order

# What is BPM about?

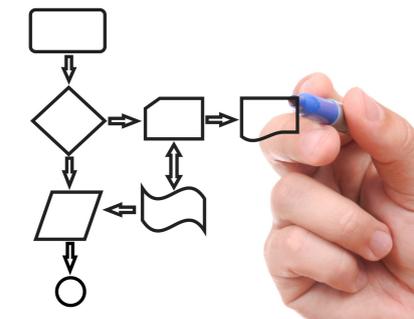


# Course objectives



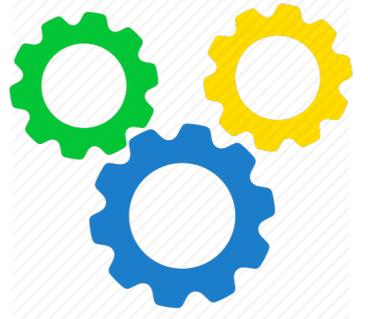
Key issues in Business Process Management (patterns, architectures, methodologies,...)

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,...)

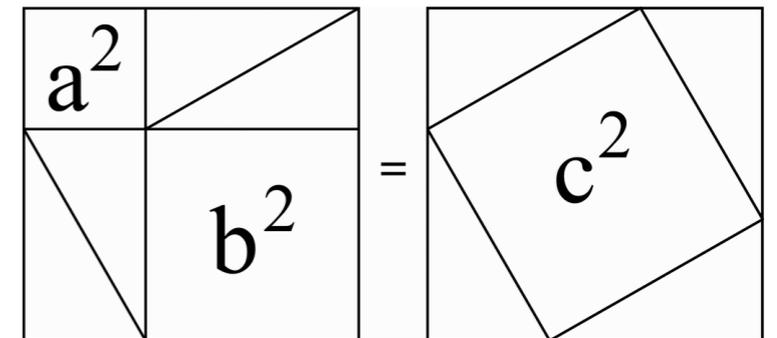


# Course activities



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

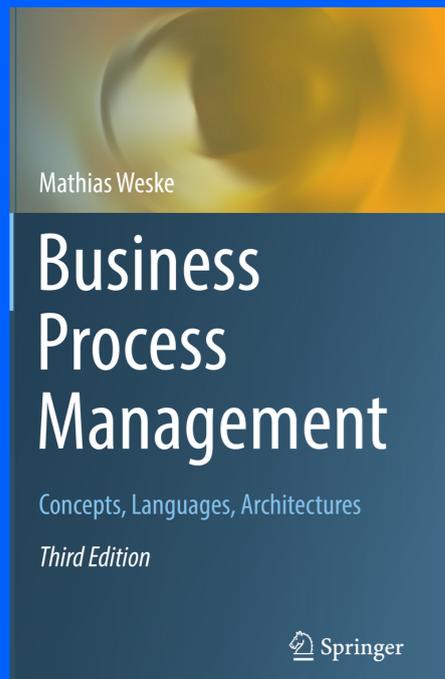


give the exam:  
time for a party!

# Exam

- Project + Oral exam (see [FAQ](#) for more infos)
- Group project
  - at most 2 students for group
  - can be requested any time
  - three-weeks deadline
  - modelling + analysis + short report
  - the validity of the project is 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>



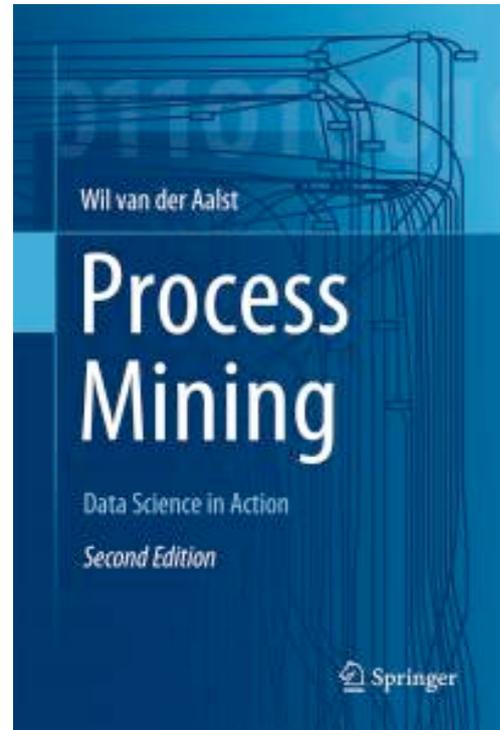
Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo Reijers

Fundamentals of Business Process Management

(2nd ed.) Springer 2018

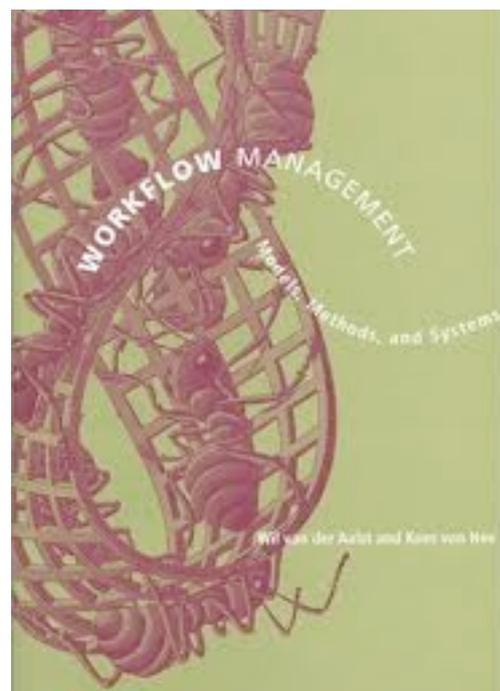
<http://fundamentals-of-bpm.org>

# Other Textbooks



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

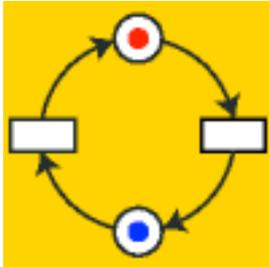
<http://springer.com/978-3-662-49850-7>



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 resources



Petri nets world

<http://www.informatik.uni-hamburg.de/TGI/PetriNets>

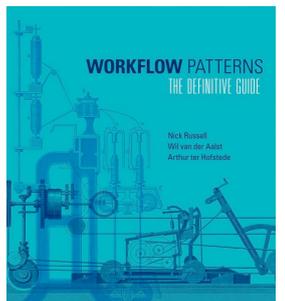


BPMN

<http://www.bpmn.org>

Workflow Patterns

<http://www.workflowpatterns.com>



# Main resources (tools)



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>

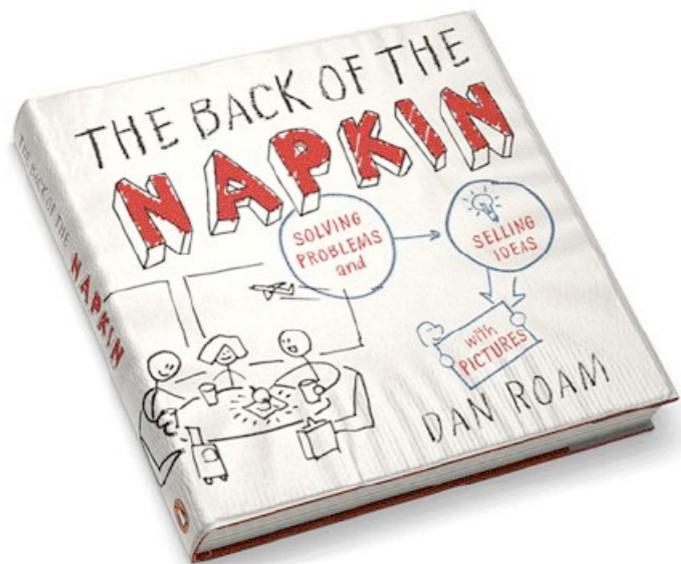
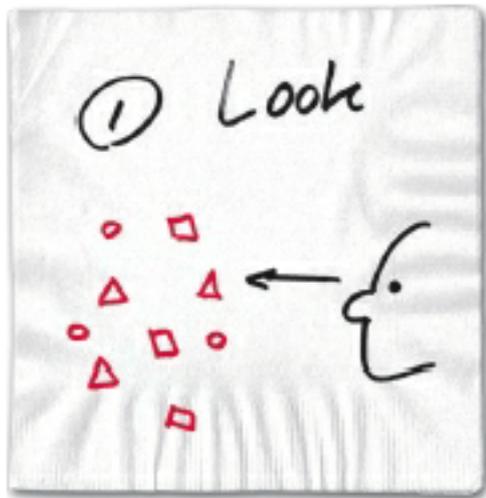
YAWL



<https://yawlfoundation.github.io>

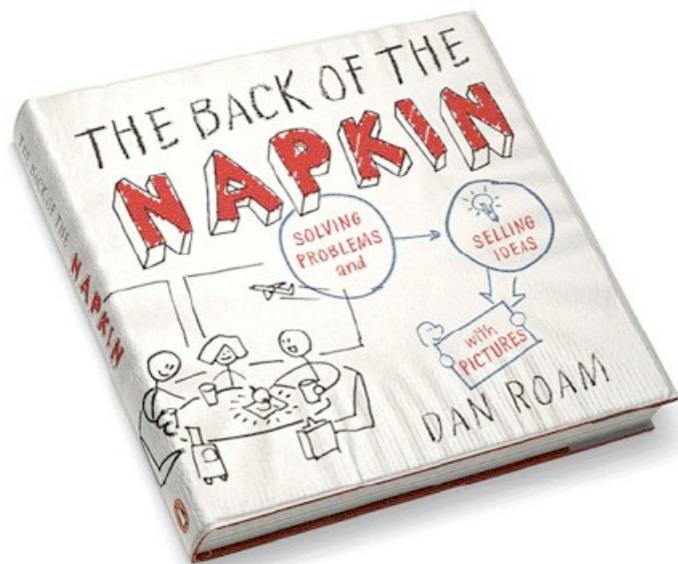
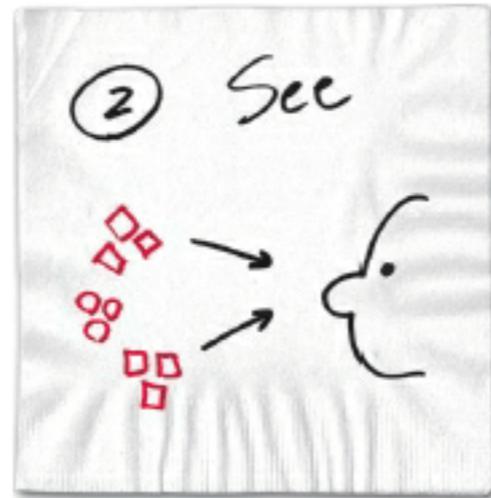
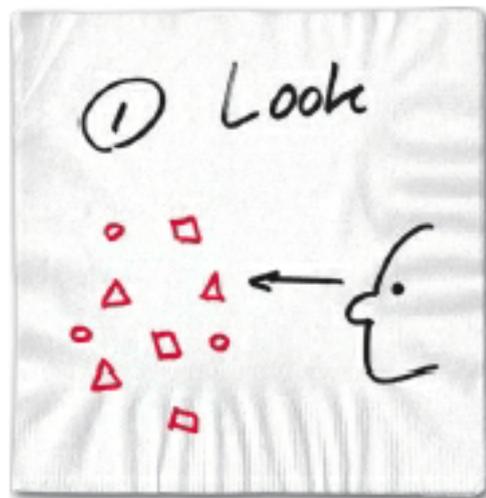
# Modelling

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



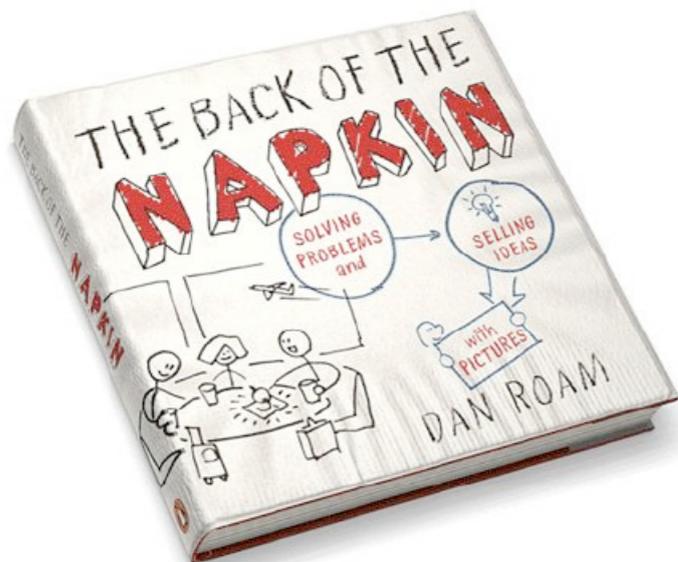
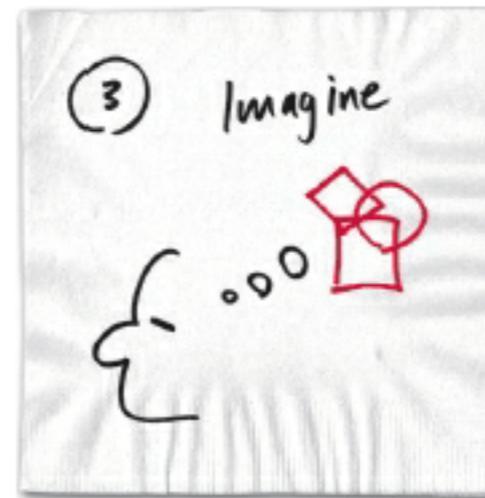
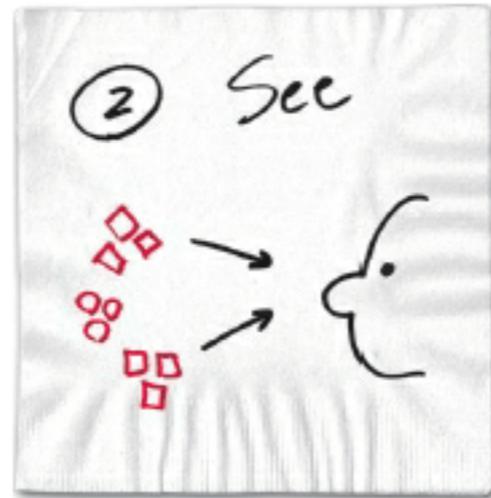
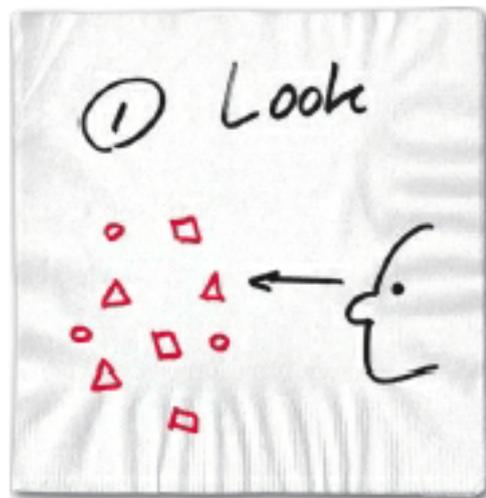
# Modelling

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



# Modelling

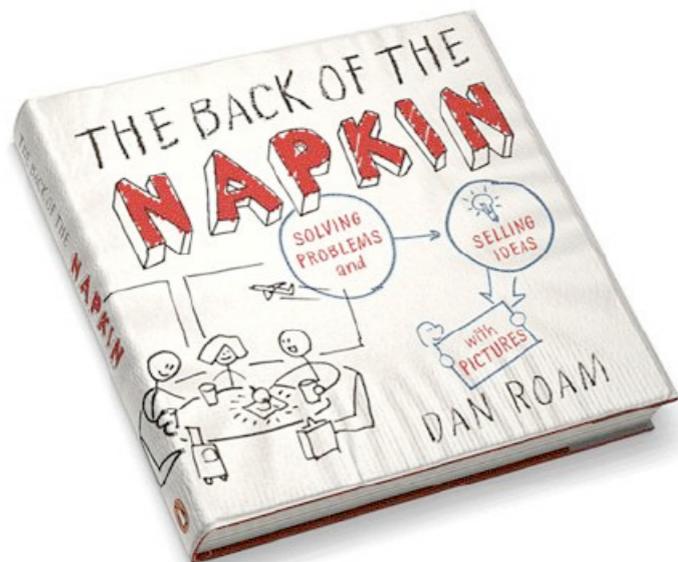
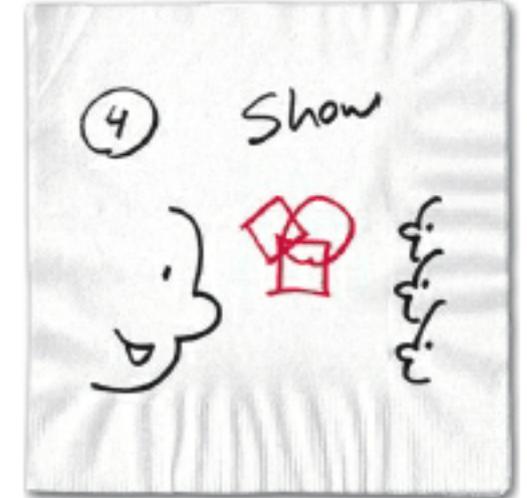
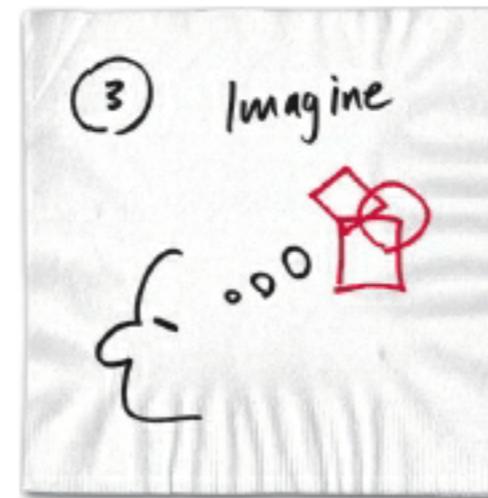
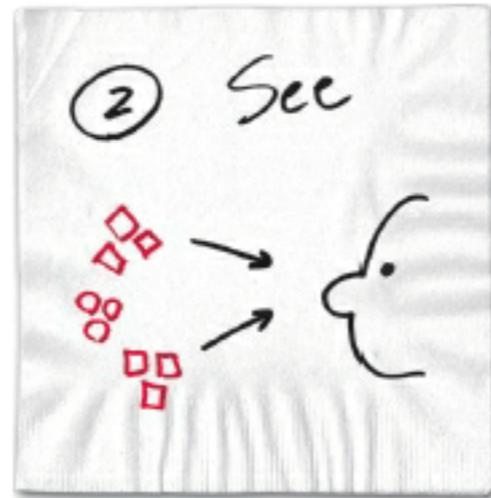
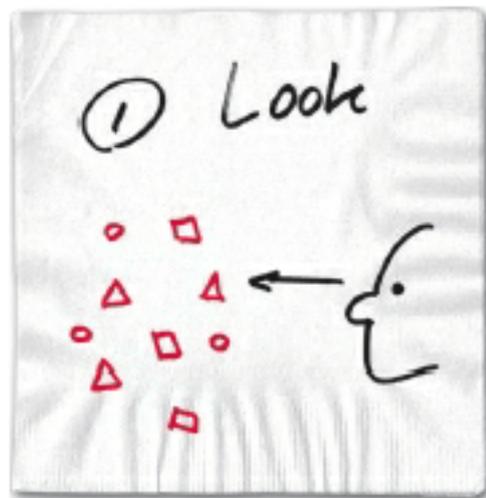
Giving shape to ideas, organizations, processes, collaborations, practices



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

# Quoting Michelangelo

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

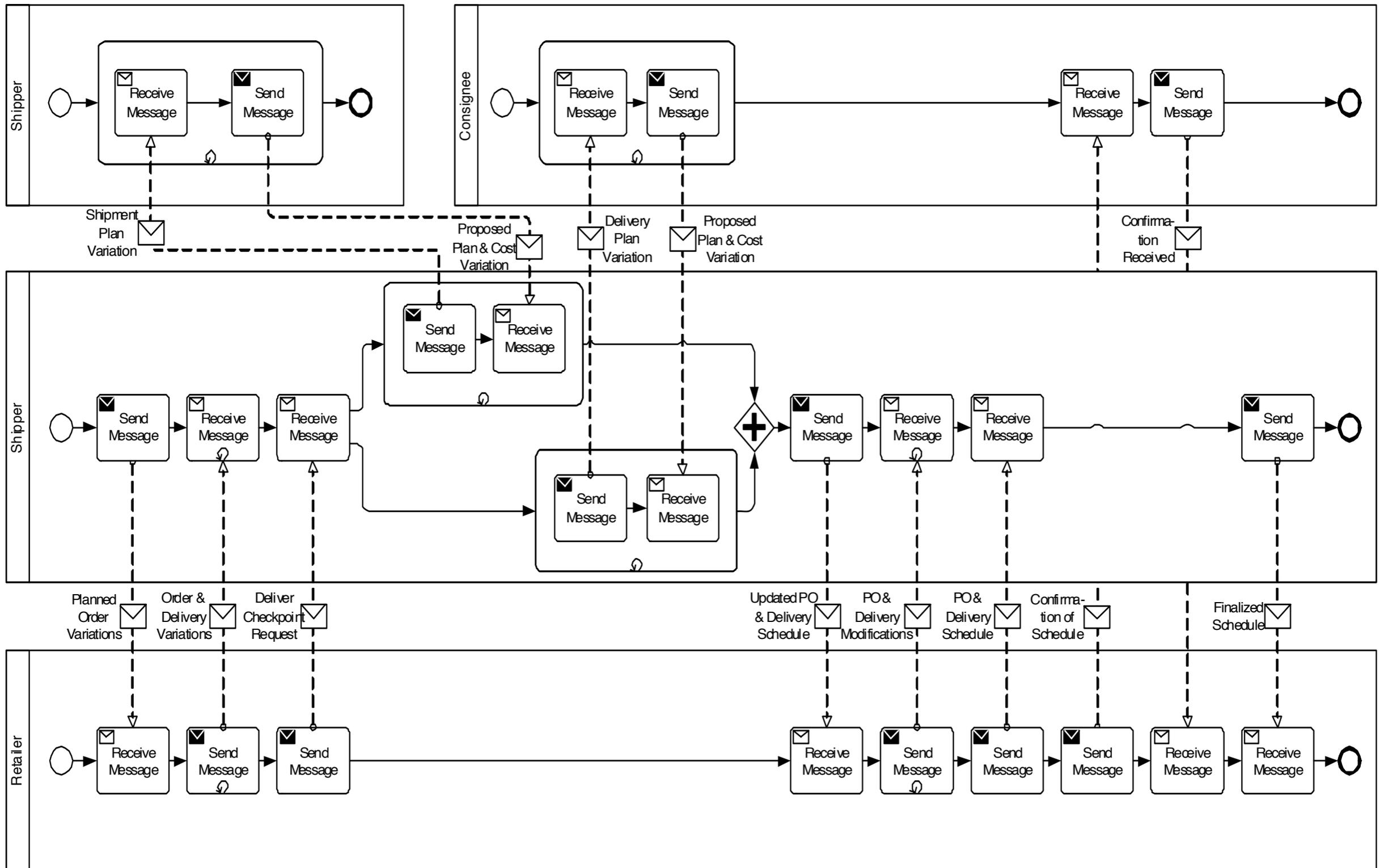


# Quoting Michelangelo

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



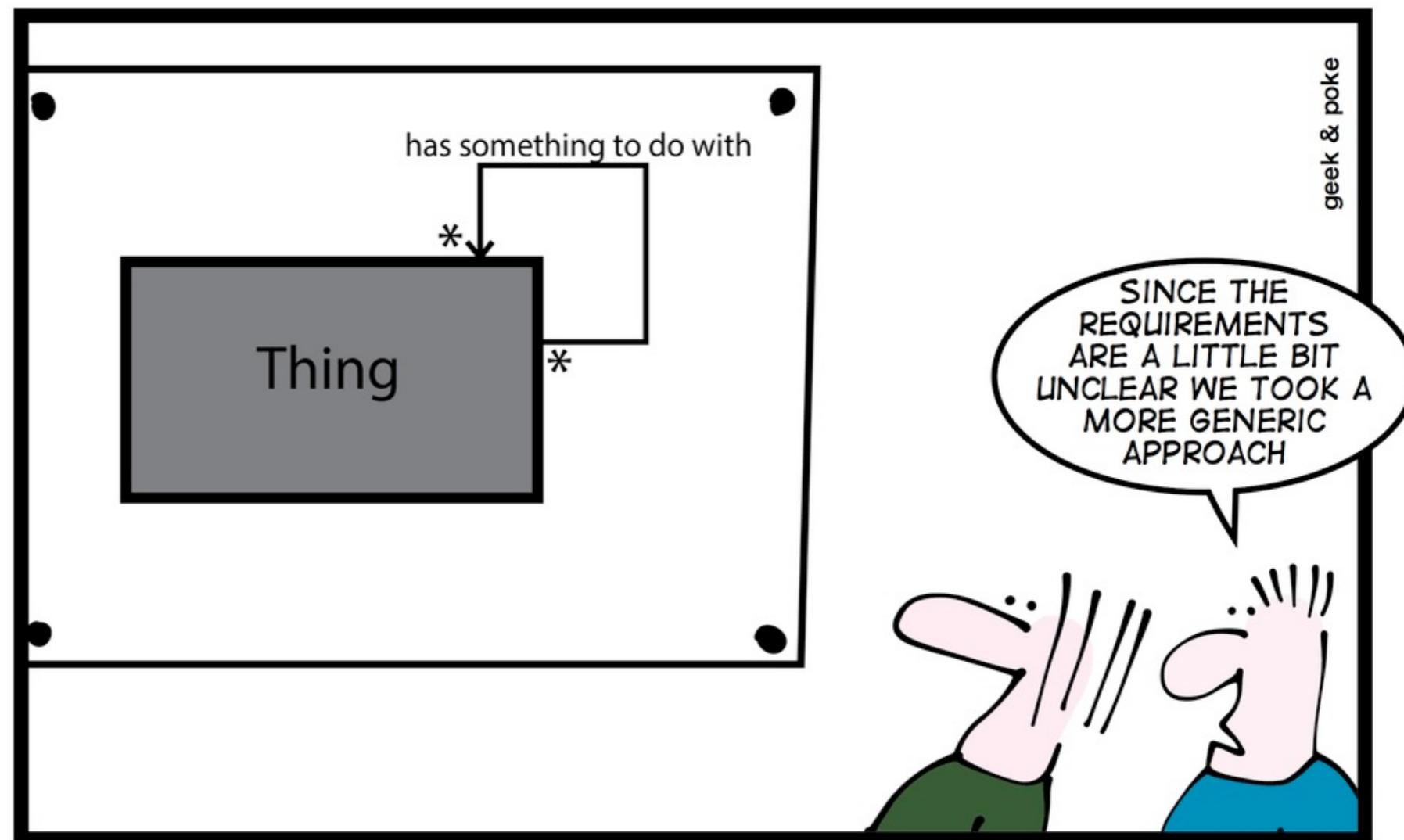
# A taste of BPMN



What

# Data and processes

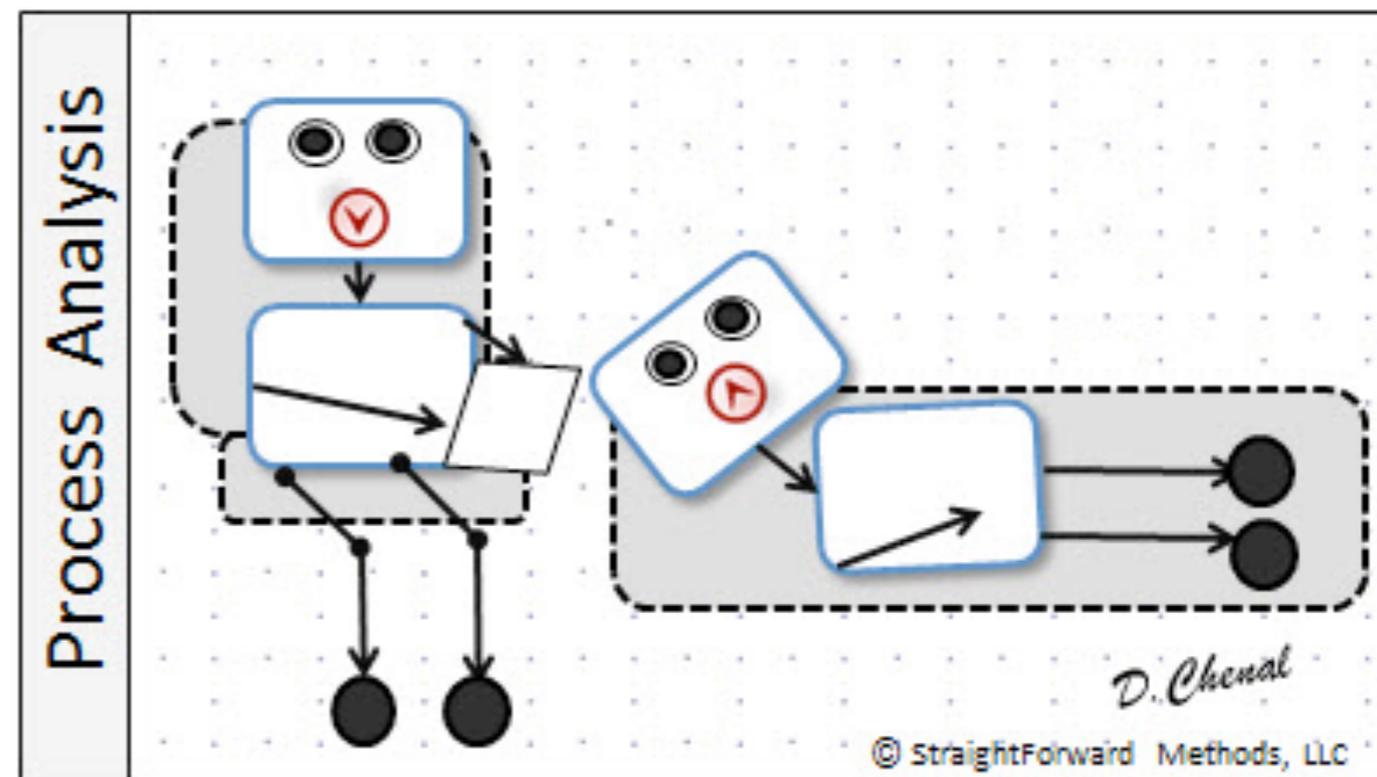
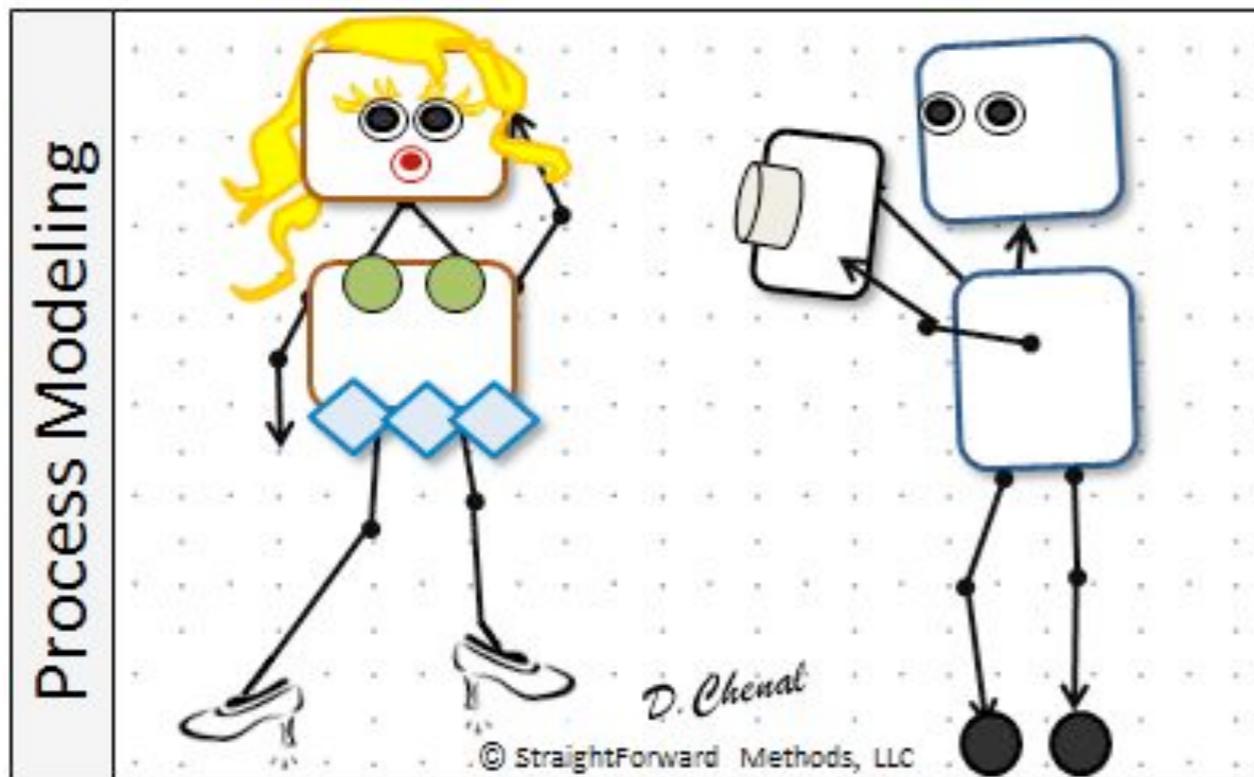
Traditionally, information systems used **information modelling** as a starting point



How

# Data and processes

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

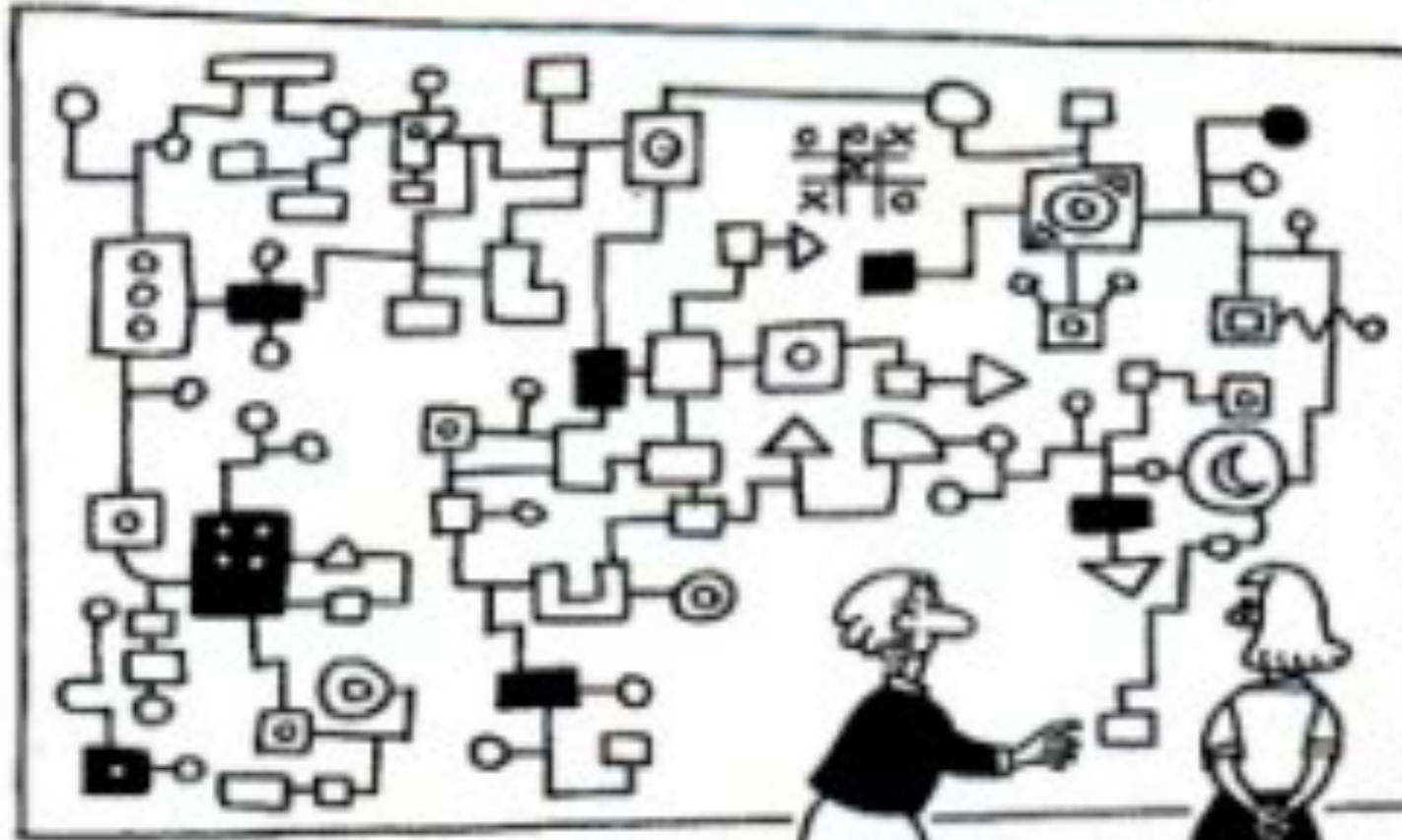


# Motivation

- Each product is the outcome of a number of activities performed
- Because of modern communication facilities:
  - traditional product cycles not suitable for today's dynamic market
- 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 these activities
  - to improve the understanding of their relationships
- IT is an essential support for this aim

# Workflow wave

## WORKFLOW REDESIGN



Geff

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

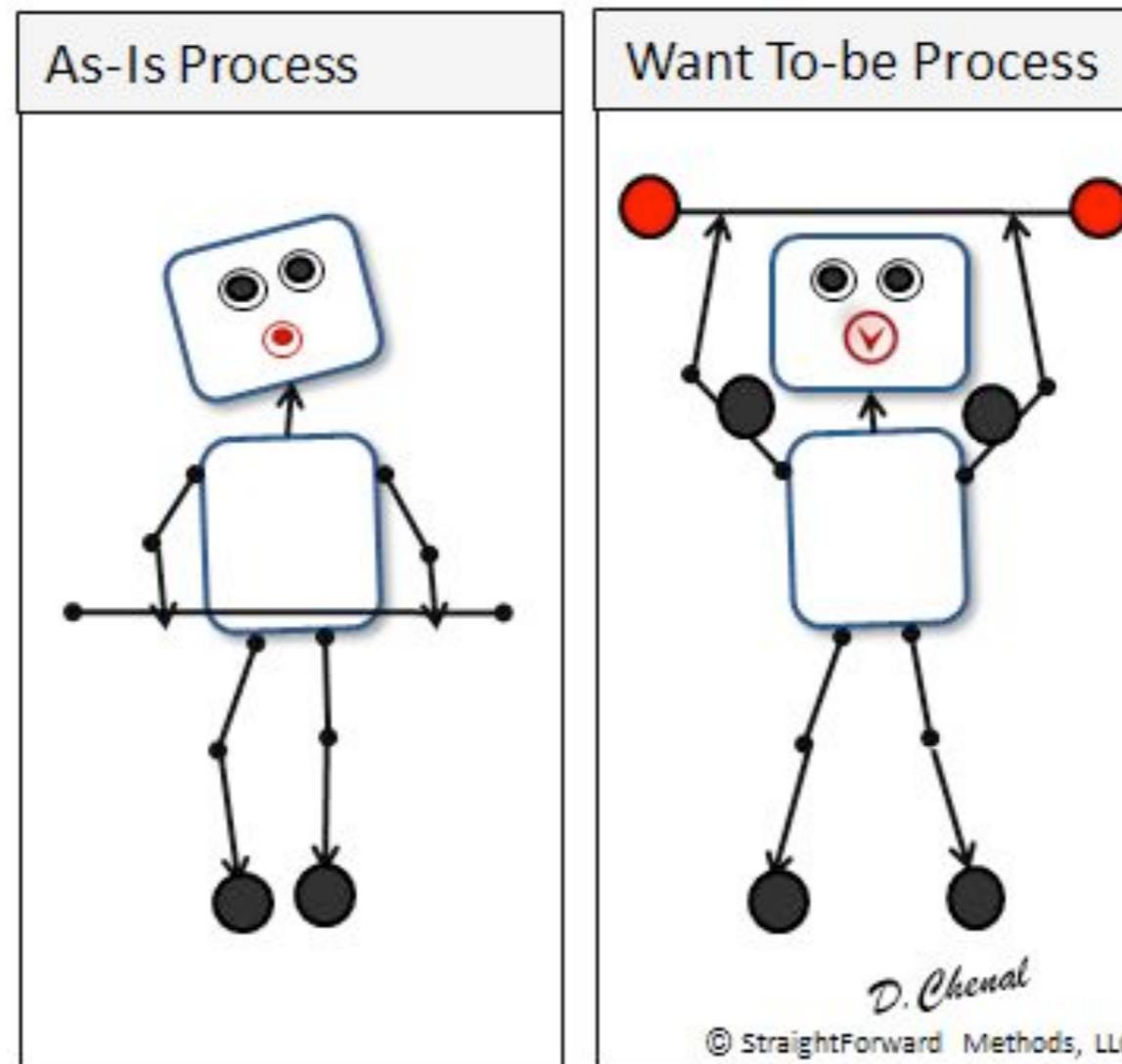
but their application was restricted to only a few application domains

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

# Process awareness

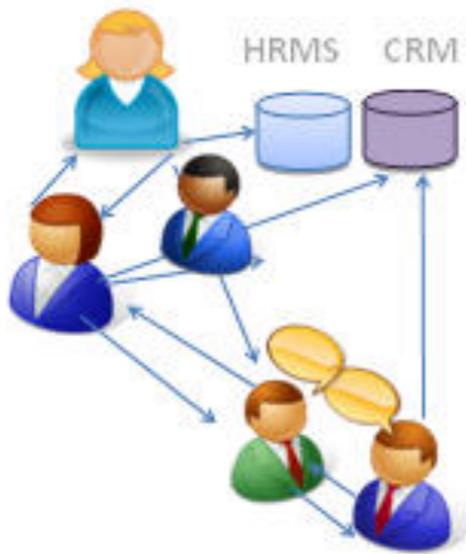
BPM moves from  
workflow management systems  
(intra-organization)

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



# Process awareness

BEFORE BPM

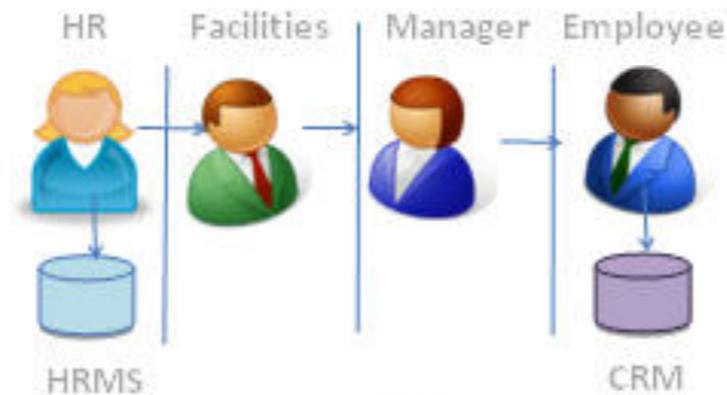


Know end goal

Handled differently every time



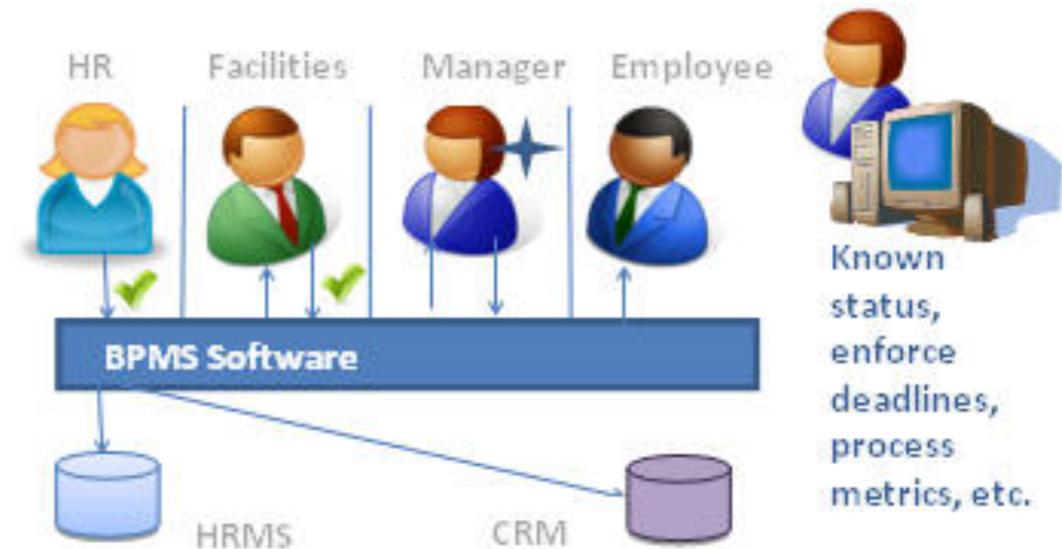
AFTER BPM



Know how to handle each occurrence



AFTER BPMS



# Benefits of BPM

automate workflow and orchestrate processes,  
reduce risk of errors,  
provide metrics,  
real time status,  
enforce deadlines,  
validate data,  
reduce training costs,  
...



# What is the BPM maturity of your organization?

## 5 excellence

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

## 4 managed

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

## 3 defined

BPM is defined. Implementation is yet missing or ongoing.

## 2 awareness

Awareness of BPM exists in the organization. (Planning) activities have started for the definition of the subject.

## 1 initial

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



© 2008 IDS SCHEER

# Why BPM?

Highly relevant for  
practitioners

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

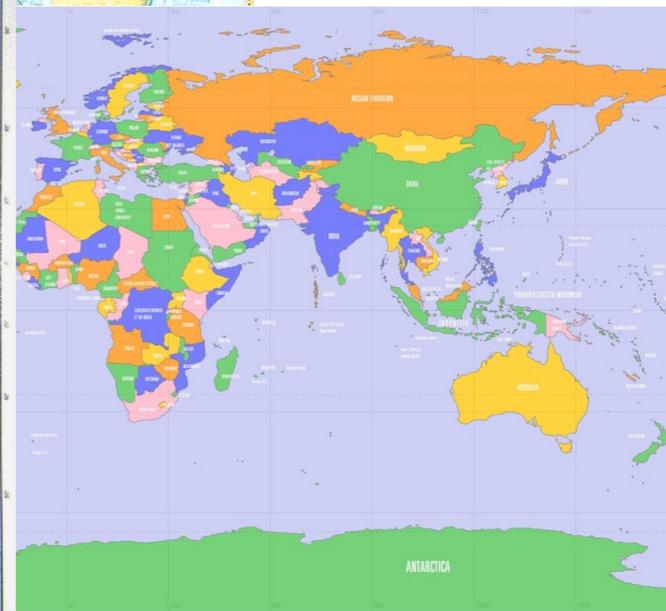
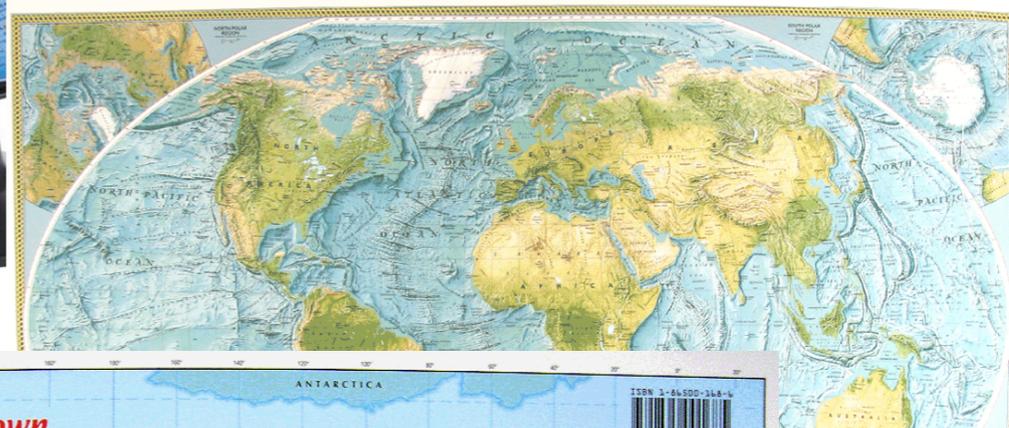
ultimately contributes to the competitive  
advantage of an enterprise

# Abstraction

- 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!

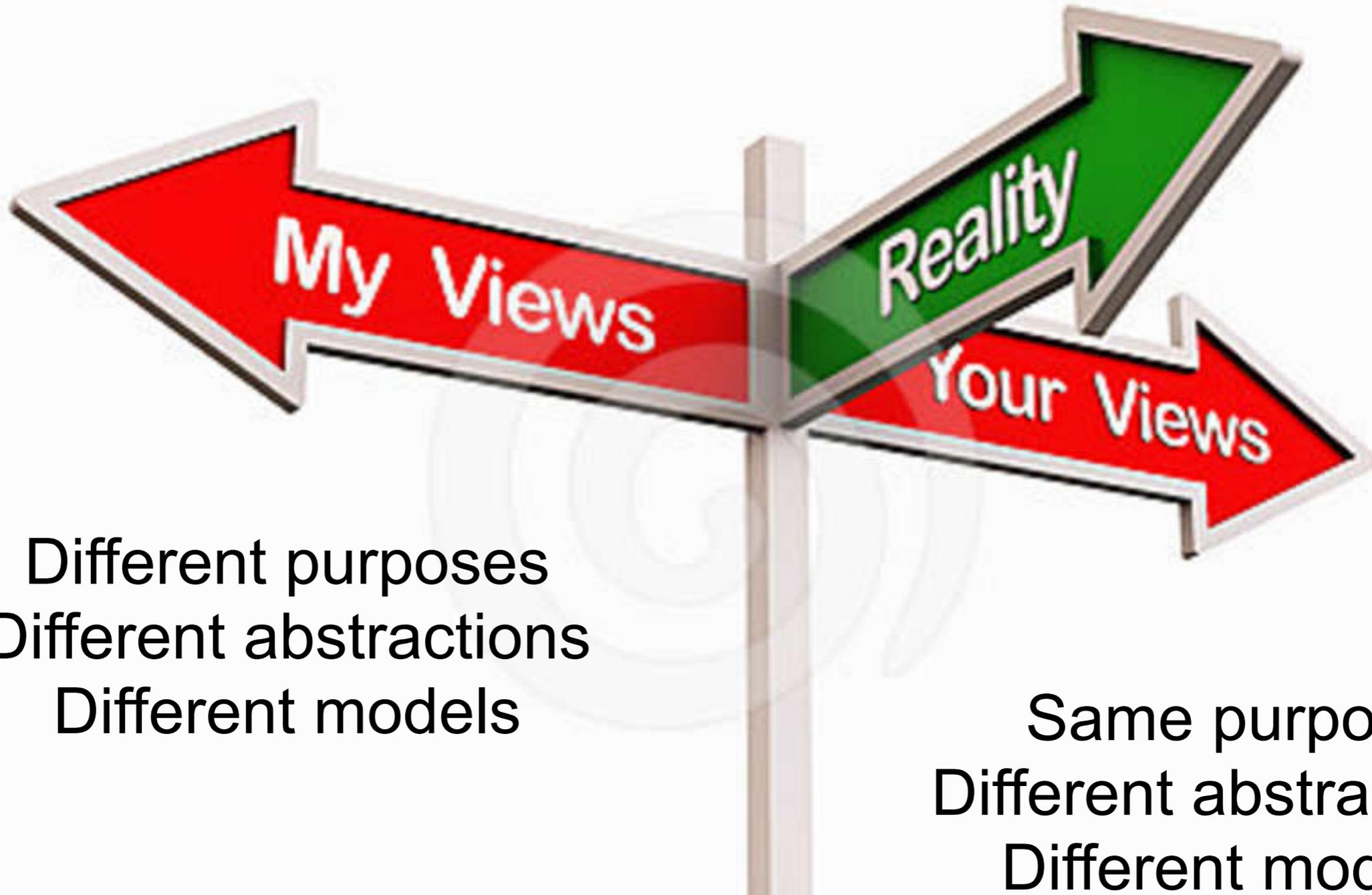
Abstraction as the key to achieve some common understanding, to build a bridge between views...

# Levels of abstractions



One object,  
many views

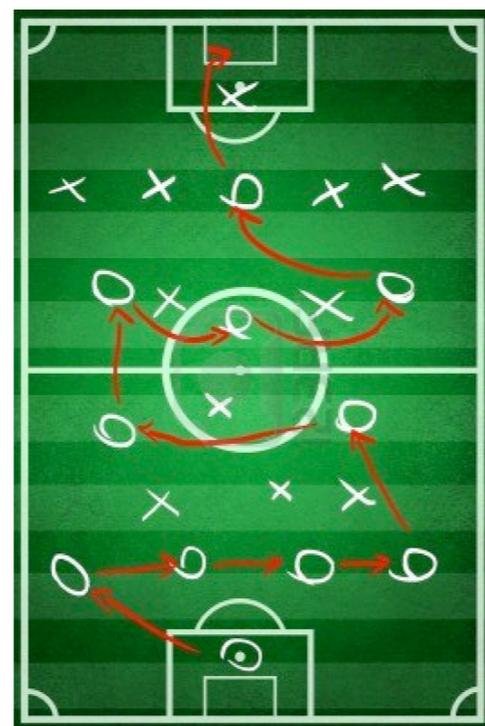
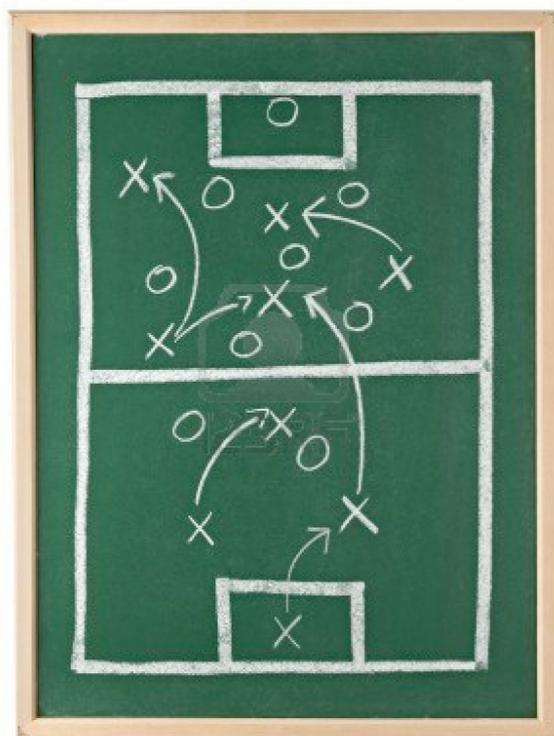
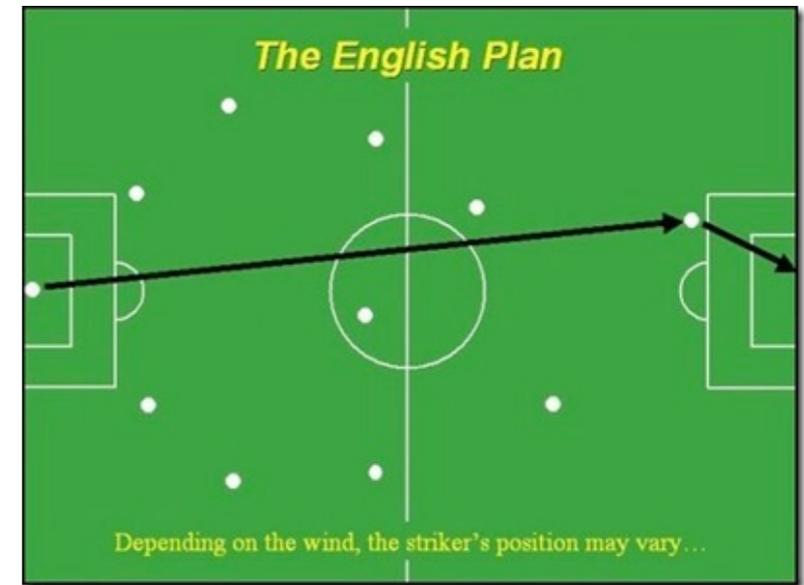
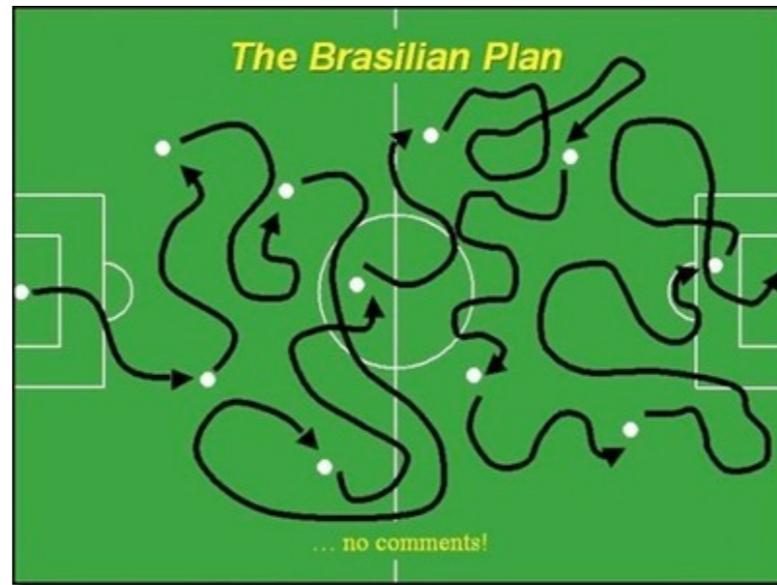
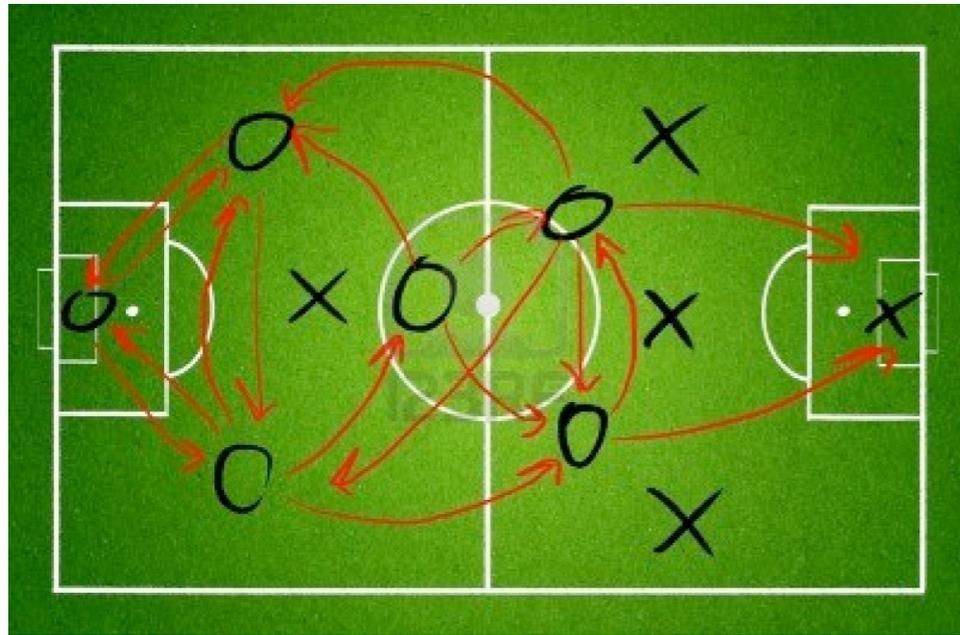
# Different views are common



Different purposes  
Different abstractions  
Different models

Same purpose  
Different abstractions  
Different models

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



# What about the adversaries?

Can we find out their plan?

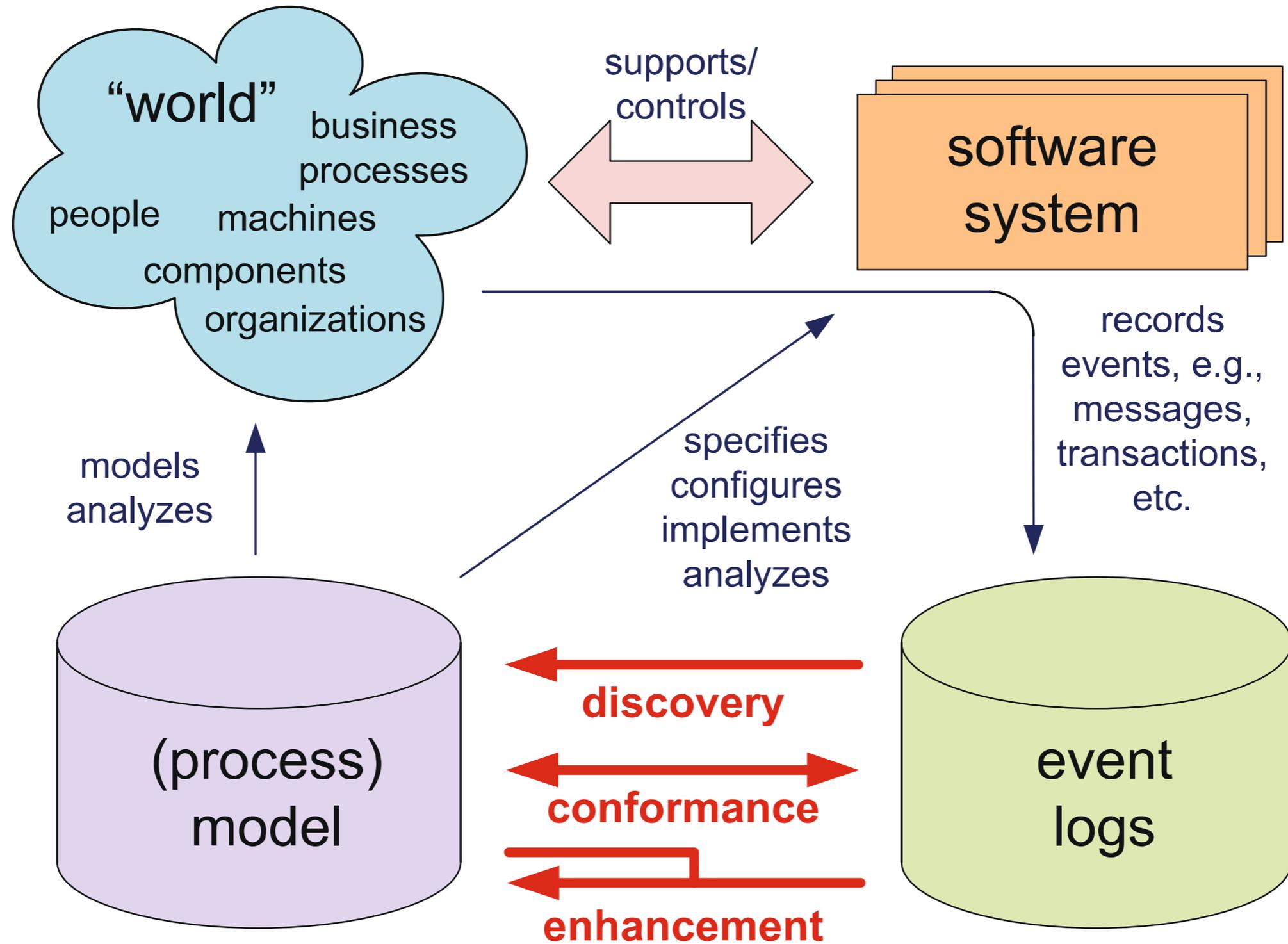


Knowing it would  
be quite helpful

Any idea how to?

(abstractions can be designed but can also be derived)

# A taste of Process Mining

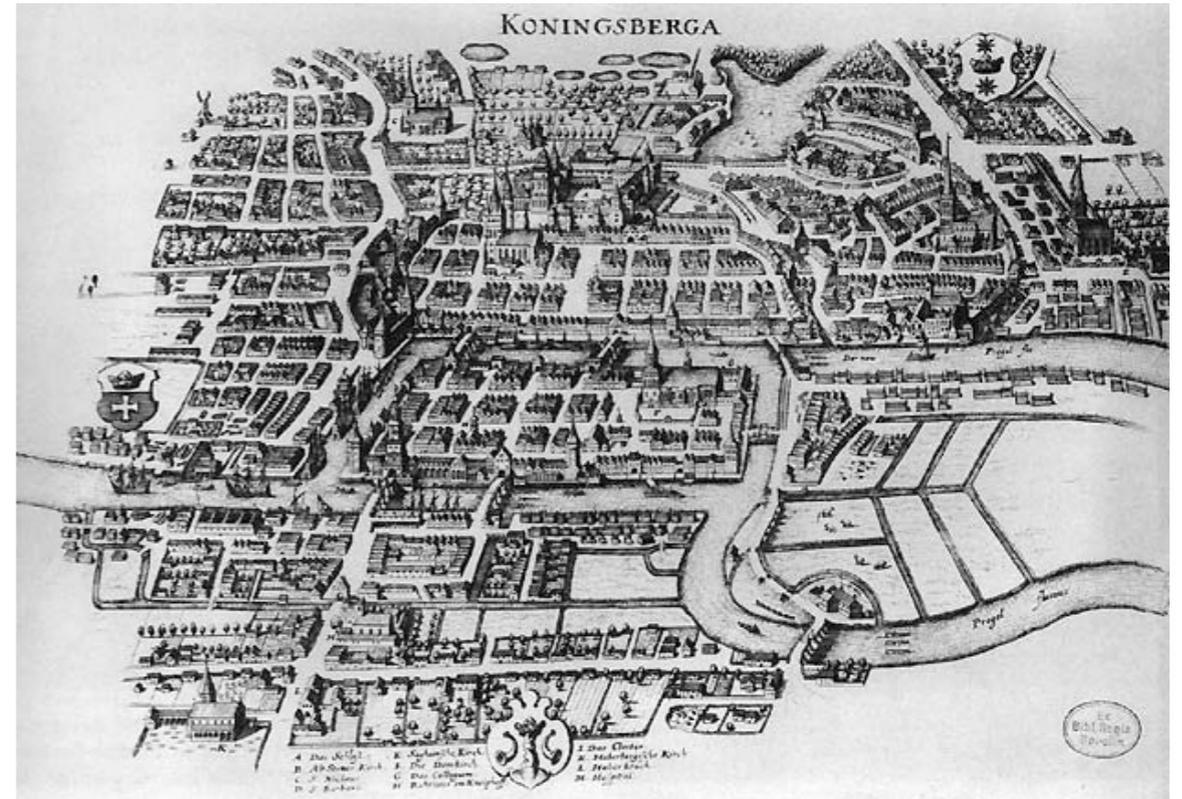


Digression:  
formal modelling  
and the importance of proofs

# Digression...

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

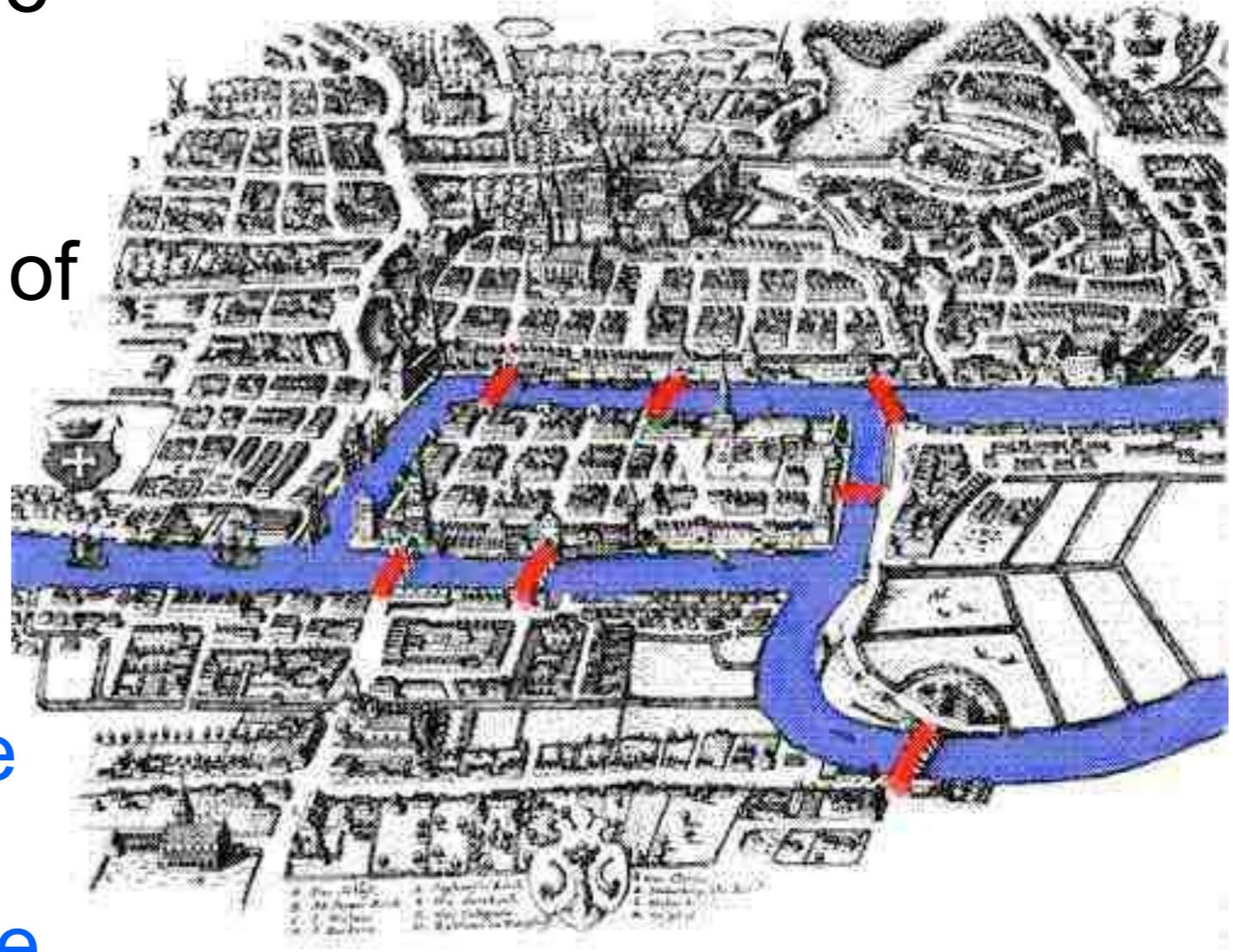
it was thanks to the layout of that city that **Leonhard Euler** answered a puzzle which eventually contributed to the birth of two new areas of maths known as **topology** and **graph theory**.



# Digression...

Königsberg was built on the bank of the river Pregel.  
**Seven bridges** connected two islands and the banks of the river (see map).

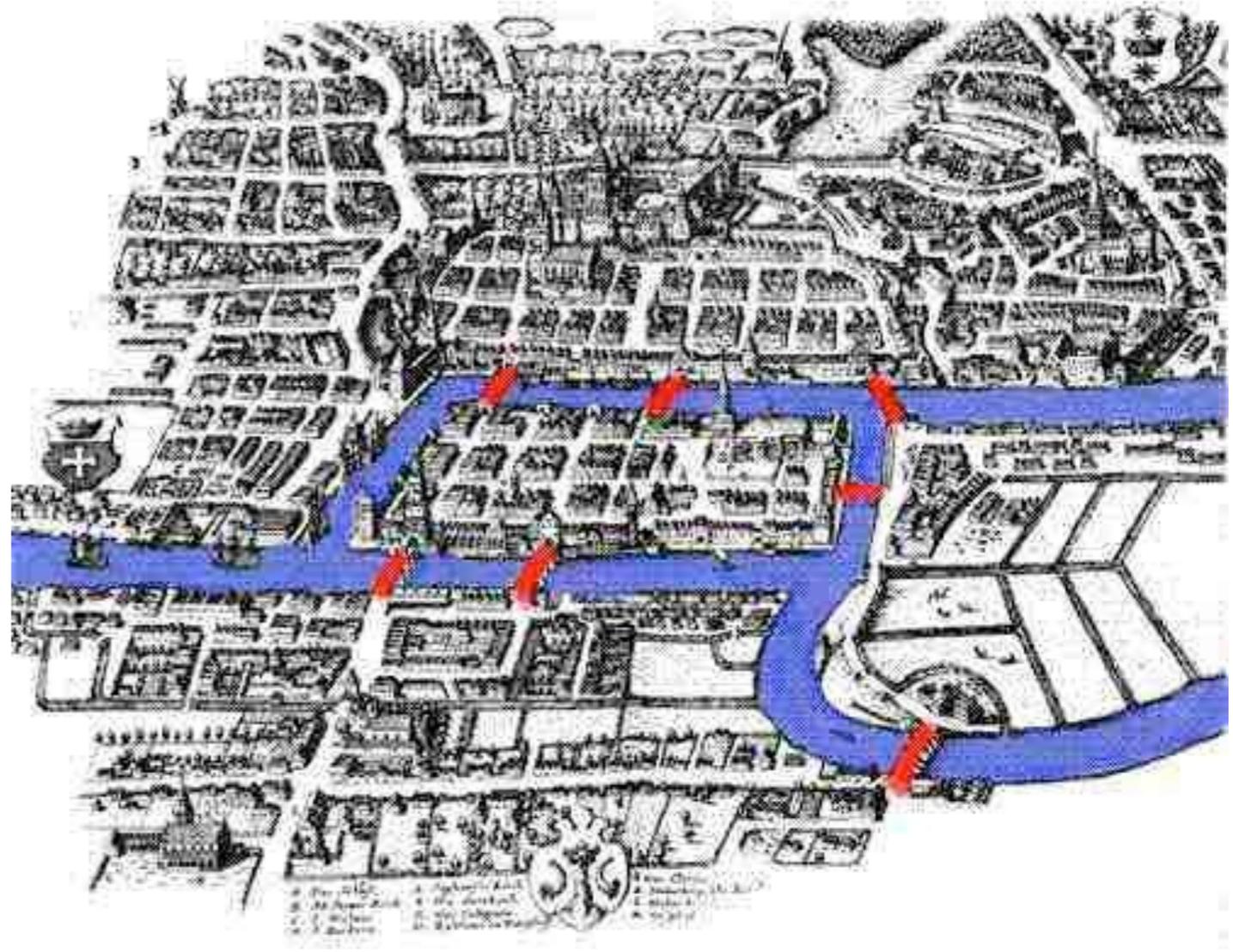
A popular pastime of the residents was to try to **cross all the bridges in one complete circuit** (without crossing any of the bridges more than once).



# Digression...

A seemingly simple task was more than tricky...

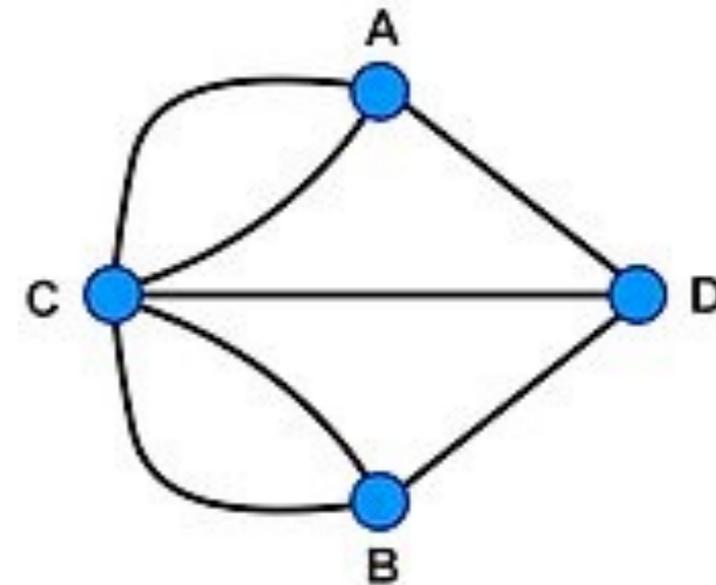
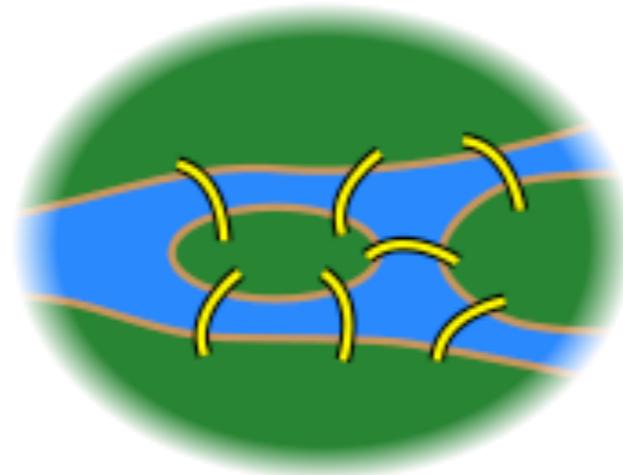
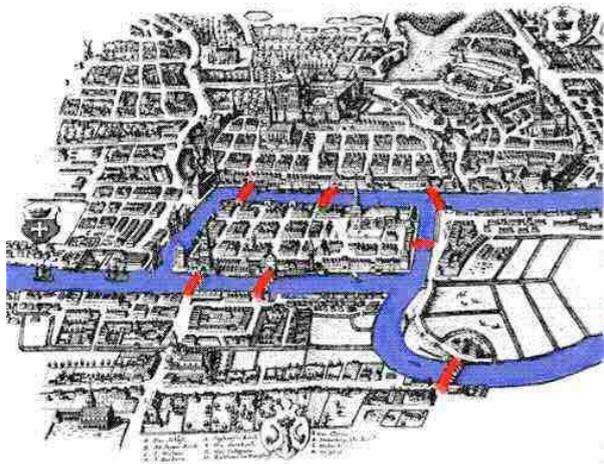
Nobody had been able to find a solution to the puzzle when Euler first heard of it and, intrigued by this, he set about **proving** that **no solution was possible!**



# 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**.

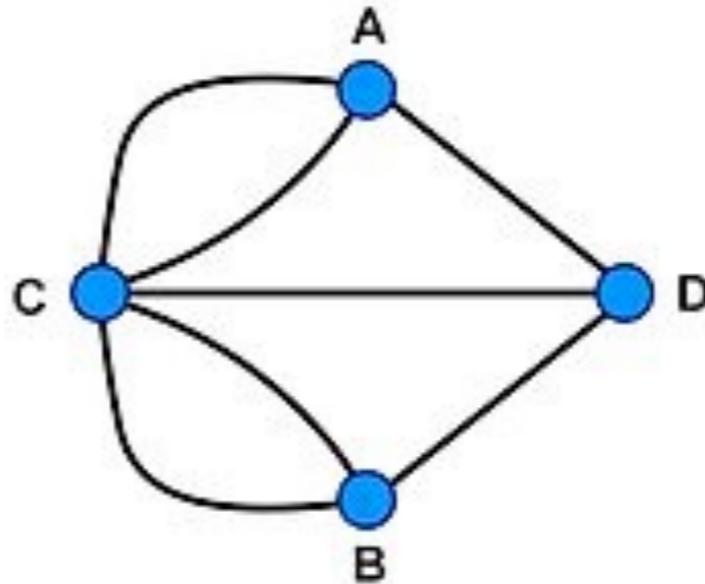
The bridges became **edges** between nodes.

# 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*

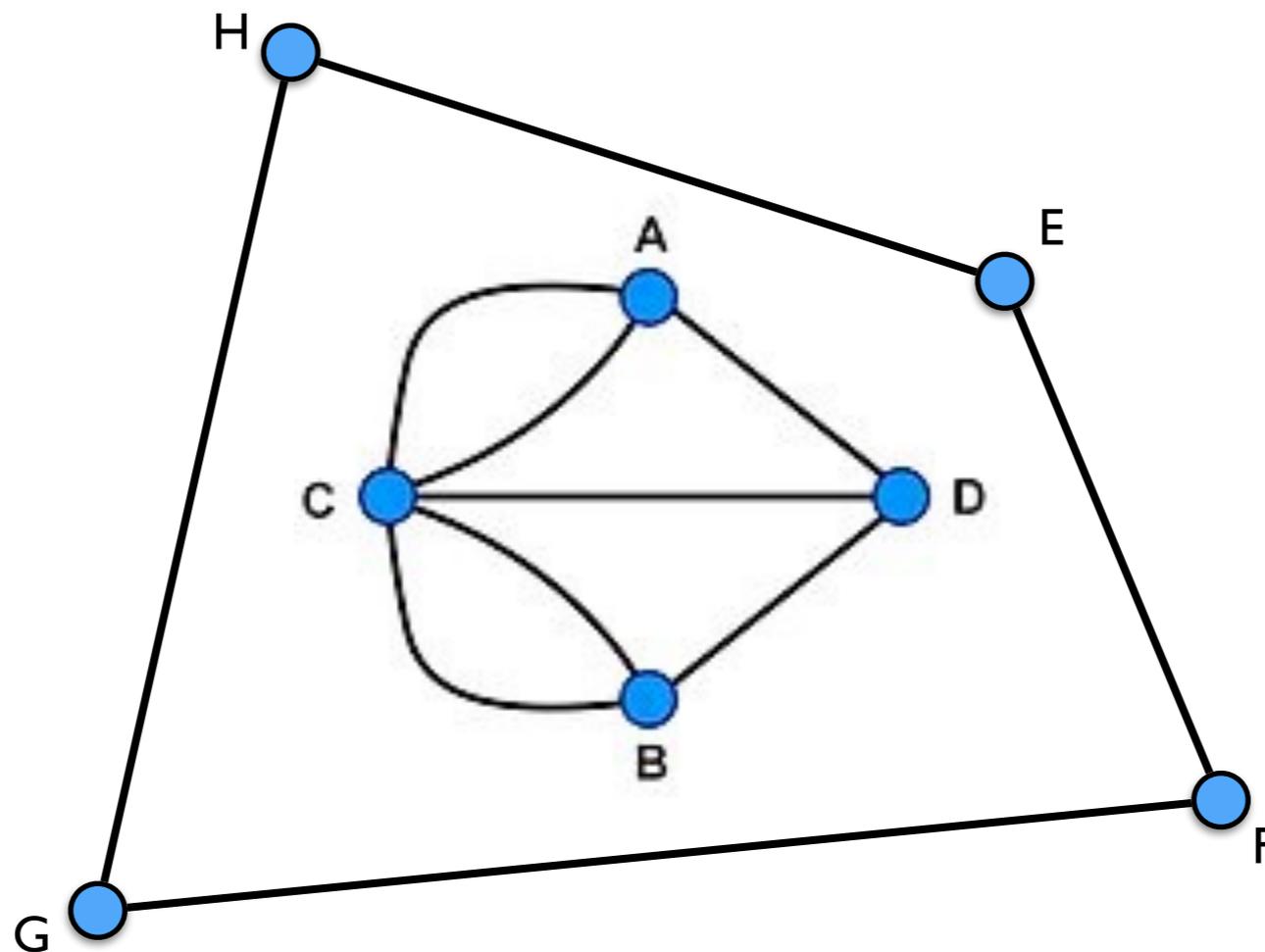
Graph problem: *redrawing this picture without retracing any line and without picking your pencil up off the paper*



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

# Digression...

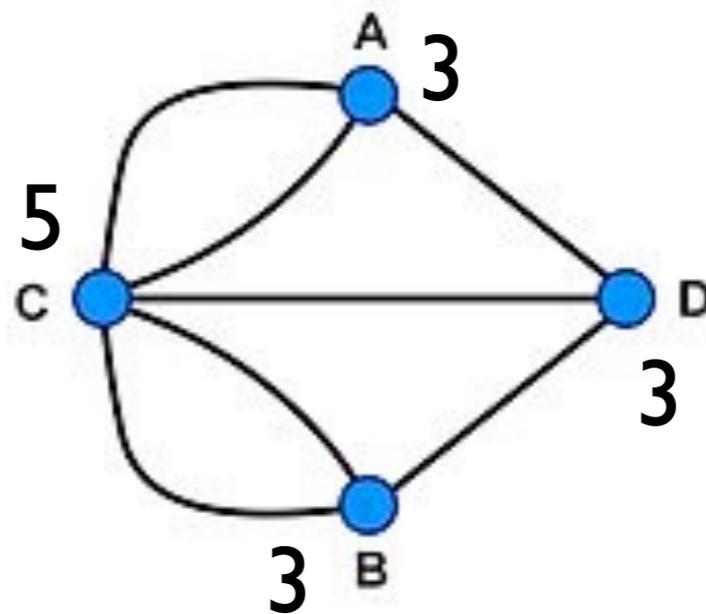
A non-connected graph



# Digression...

Informal reasoning:

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

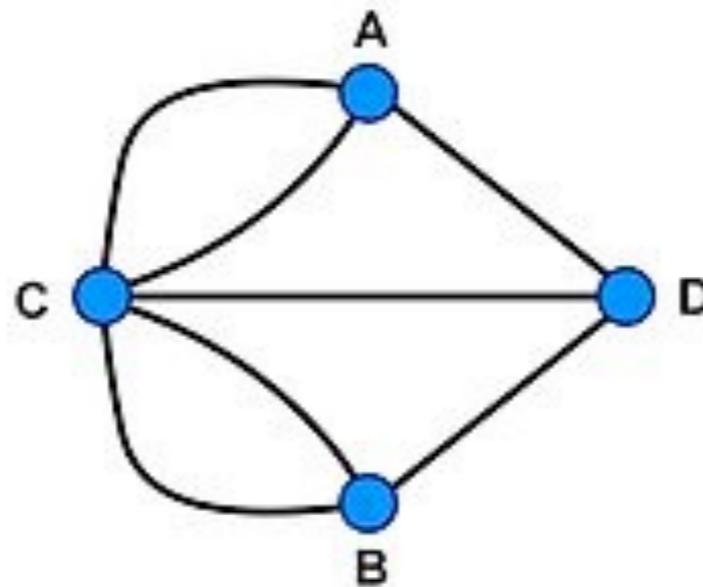


In a circuit every time you enter a node you must be able to leave it: thus, every vertex must be connected to an **even** number of edges!

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:

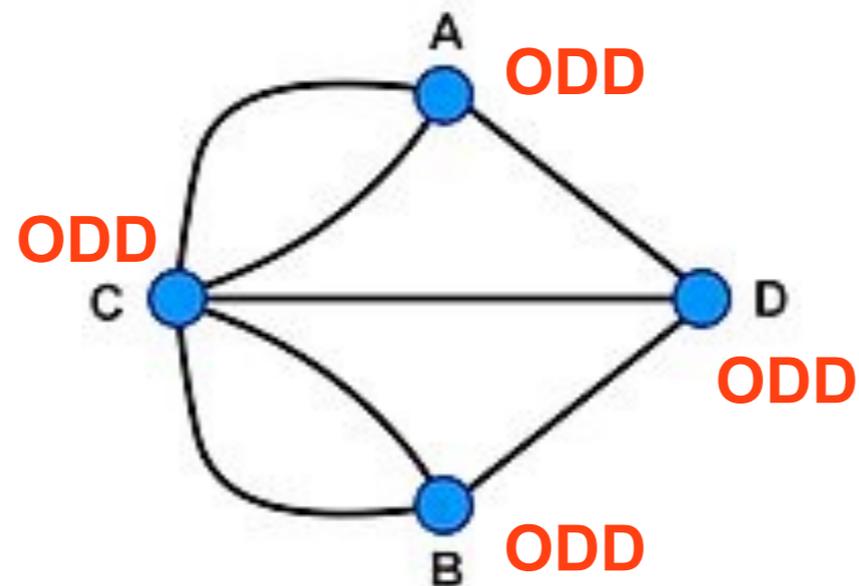
**Definition:** A **path** is a (finite) sequence of contiguous edges. It is a **circuit** if it ends in the same vertex where it starts.

**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.

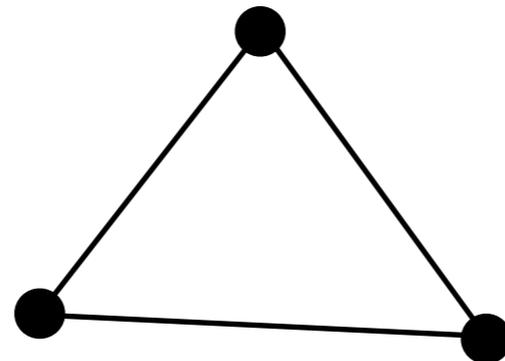
# Digression...

## **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*

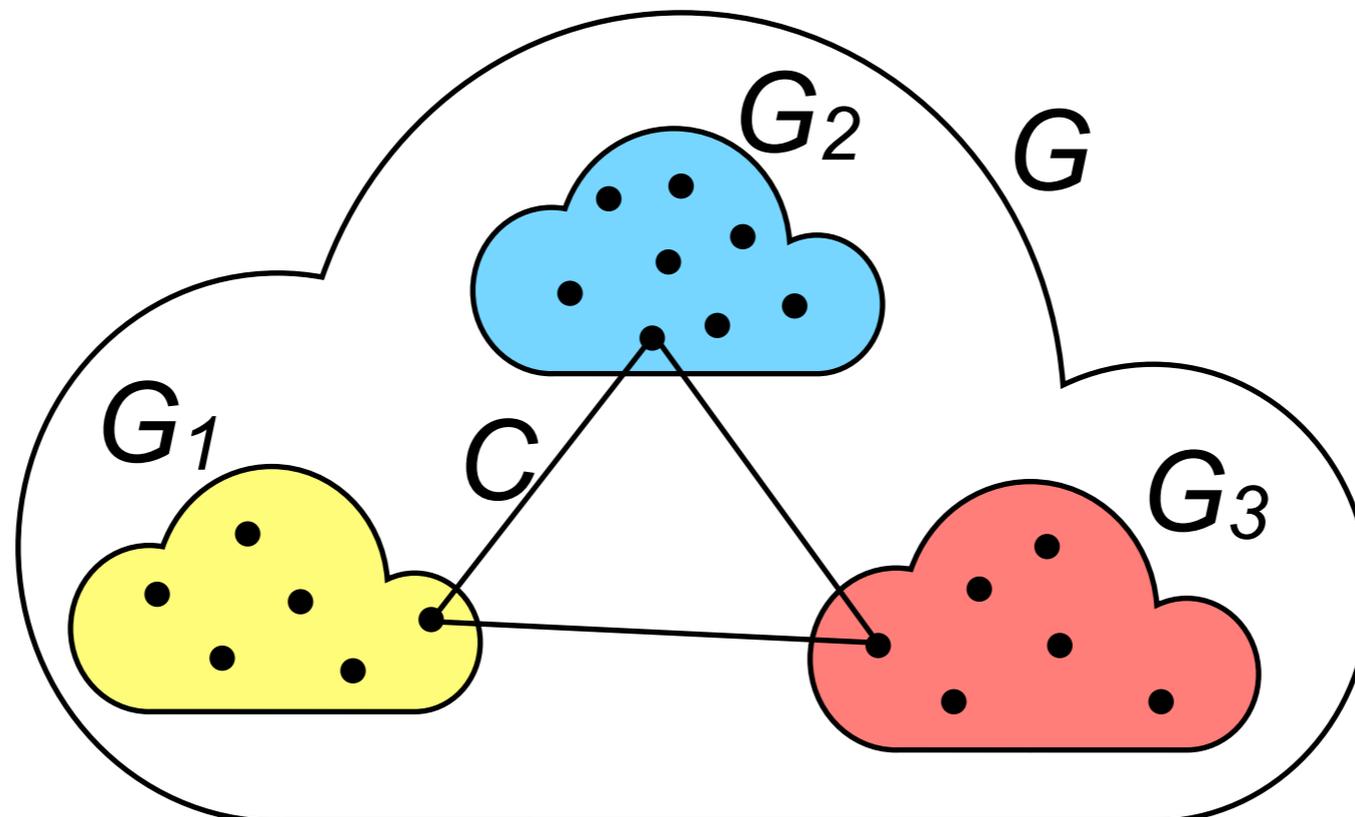
*Since there is no odd vertex,  $G$  cannot be a tree (no leaves). Thus,  $G$  must contain at least one cycle  $C$ .*

...

# 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.*

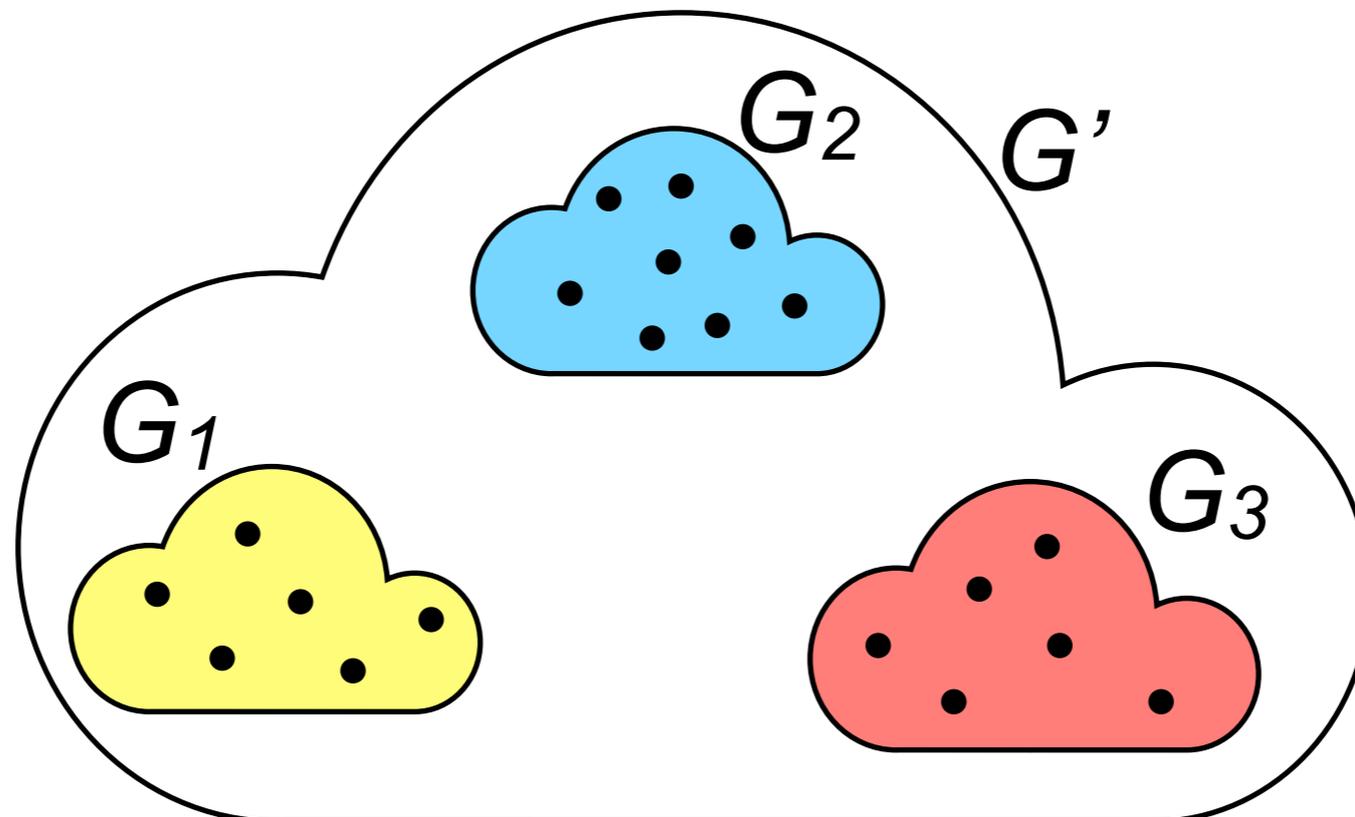


...

# Digression...

**Proof of sufficiency:** (by [induction](#) on the numbers of edges, ctd)  
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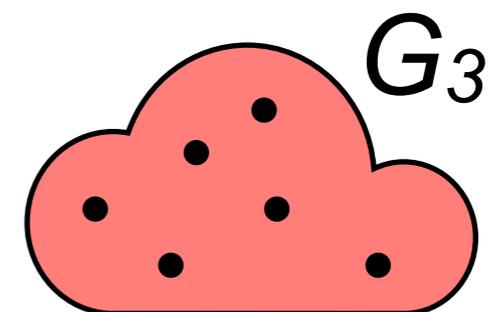
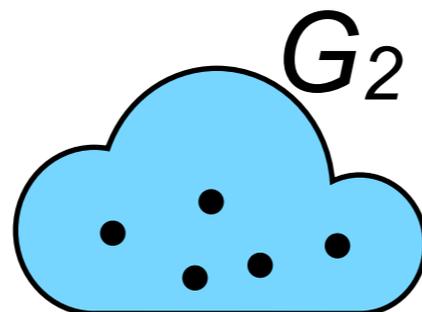
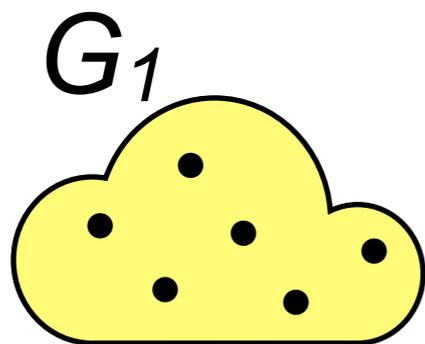
# Digression...

**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...

**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  $C$ .*

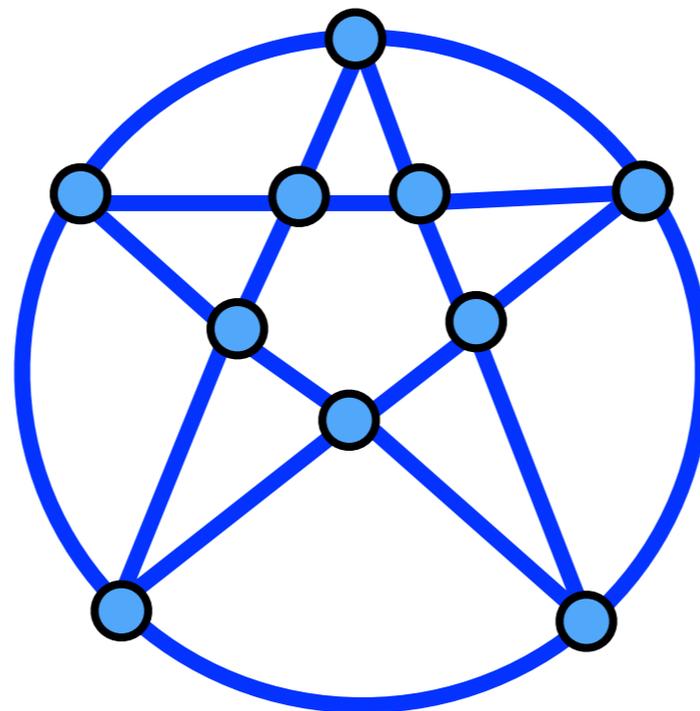
*In the end, we shall return back to the first starting vertex  $v$  of  $C$ , after visiting every edge exactly once. **qed***

# 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.**

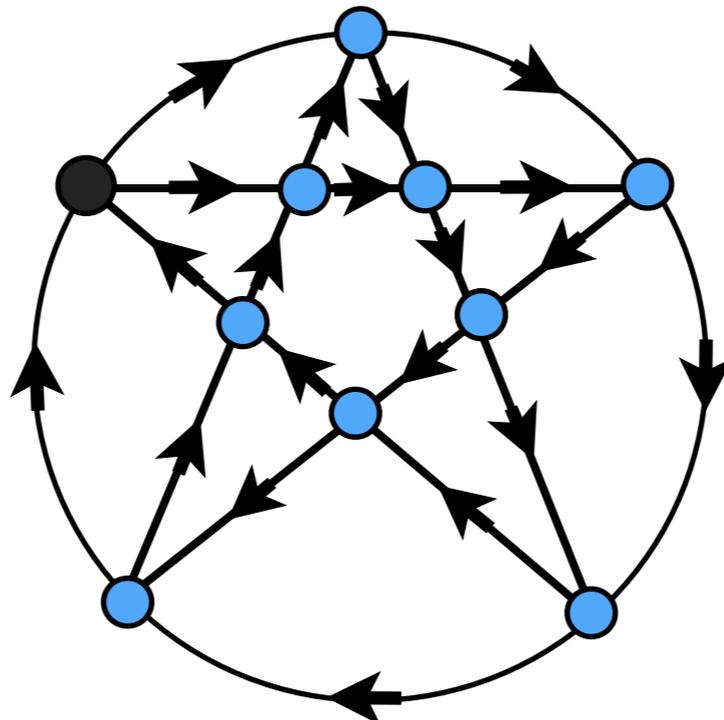


# Digression...

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...

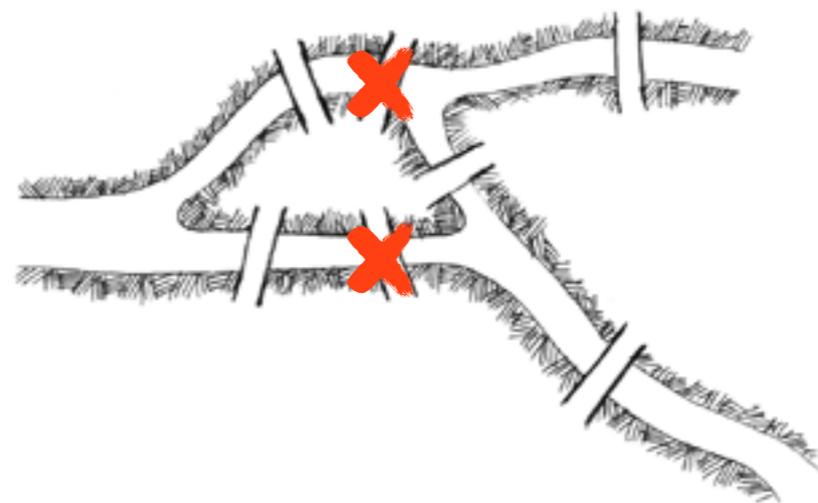
In the late 19th century an eighth bridge was built (see map).  
Was Königsberg Eulerised?

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

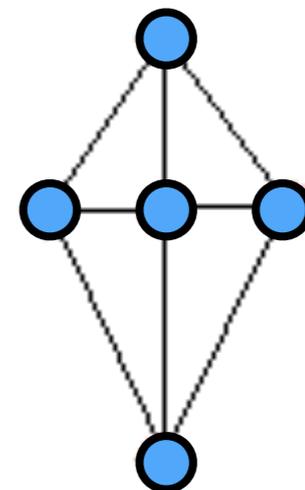
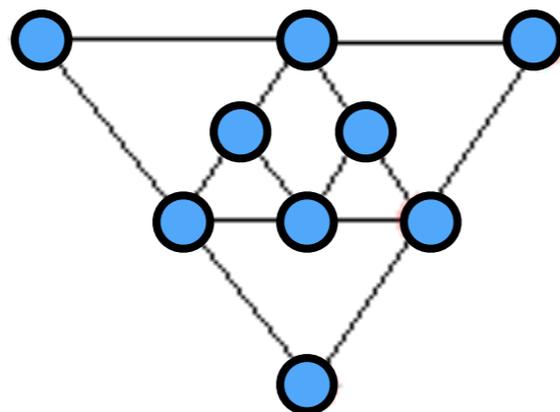
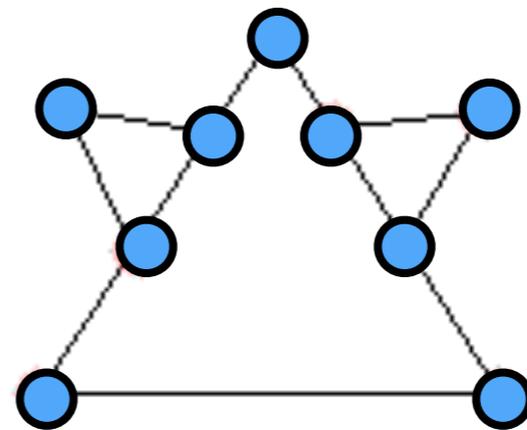
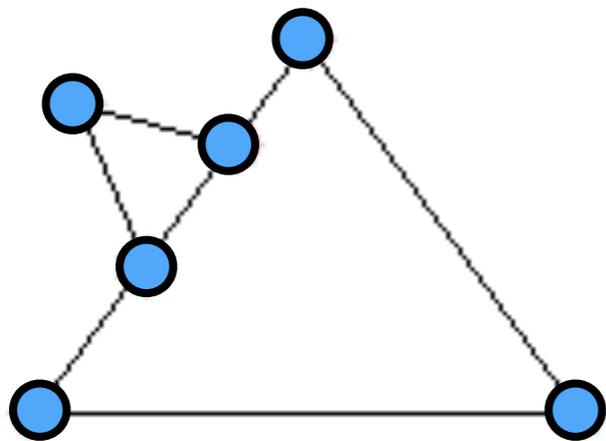


Sadly, in 1944 air raids obliterated most of the bridges. However, five bridges crossing were rebuilt (see map).  
Was the city Eulerised?

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



# 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!

