CSE 591 KRR Fall 2011
Introduction to KRR

Joohyung Lee

KRR and AI

- KRR is at the heart of the great challenge of AI: to understand the nature of intelligence and cognition so that computers can be made to exhibit human-like abilities.
- Researchers gained the conviction that AI could be formalized as symbolic reasoning with explicit representations of knowledge, and that the core research challenge is to figure out how to represent knowledge in computers and to use it algorithmically to solve problems

- John McCarthy (2006): “I think the best hope for human-level AI is logical AI, based on the formalizing of commonsense knowledge and reasoning in mathematical logic.”

Advances in KRR

- Researchers have explored general methods of knowledge representation and reasoning, addressing fundamental issues that cut across application domains.
- Researchers have developed specialized methods of knowledge representation and reasoning to handle core domains, such as time, space, causation and action.
- Researchers have tackled important applications of knowledge representation and reasoning, including query answering, planning and the Semantic Web.

What is Knowledge?

Easier question: how do we talk about it?

We say "John knows that ..." and fill the blank with a proposition

- can be true / false, right / wrong

Contrast: "John fears that ..."

- same content, different attitude

Other forms of knowledge:

- know how, who, what, when, ...
- sensorimotor: typing, riding a bicycle
- affective: deep understanding

Belief: not necessarily true and/or held for appropriate reasons

and weaker yet: "John suspects that ..."

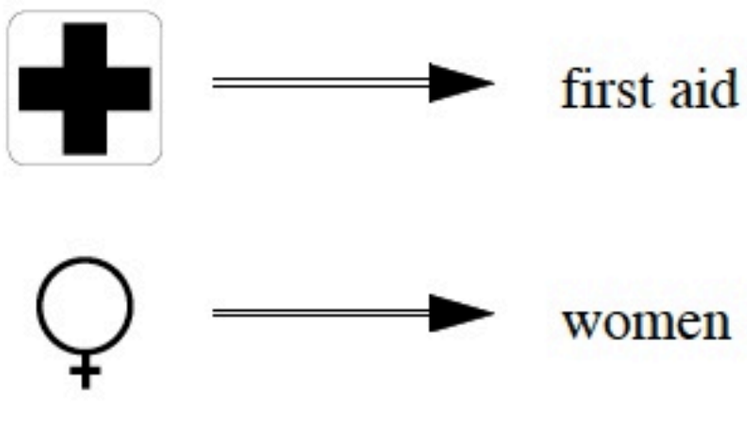
Here: no distinction

the main idea

taking the world to be one way and not another

What is Representation?

Symbols standing for things in the world



Knowledge representation:

symbolic encoding of propositions believed
(by some agent)

What is Reasoning?

- Reasoning is a form of calculation over symbols standing for propositions rather than numbers.
  - If the train arrives late and there are no taxis at the station, then John is late for his meeting. John is not late for his meeting. The train did arrive late.
    - What do you infer?

H: train_late & -taxi -> john_late

-john_late

train_late

T: taxi

Knowledge-Based Techniques

- Can deal with a set of tasks that is *open-ended*.
- Can handle *robust* applications that is not brittle.

KRR Subareas

Commonsense Reasoning

Missionaries and Cannibals

McCarthy's Elaborations

- The boat can carry three.
- Only one missionary and one cannibal can row.
- Three missionaries alone with a cannibal can convert him into a missionary.
- One of the missionaries is Jesus Christ.
- There are four missionaries and four cannibals.

Email to Dr. McCarthy

Date: Sat, 27 Sep 2003 01:00:03 -0500 (CDT)
From: Joohyung Lee <appsmurf@cs.utexas.edu>
To: jmc@cs.stanford.edu
Subject: Elaboration of Missionaries and Cannibals Puzzles

Dear Dr. McCarthy,

In one of the elaborations of Missionaries and Cannibals Puzzles in your paper "Elaboration Tolerance", it says,

"The boat can carry three. Four can cross but not five."

But I think five (pairs) can cross. A solution starts with sending all cannibals to the second bank by moving cannibals only. Then two cannibals are sent back to the first bank. After sending three missionaries to the second bank, send back one missionary and one cannibal together. At this moment, the first bank has three in each group with the boat. Three missionaries move to the second bank, and the rest is to move the remaining cannibals. All these can be done in 11 steps.

I think six can't cross.

McCarthy's Reply

Date: Fri, 26 Sep 2003 23:54:10 -0700 (PDT)
From: John McCarthy <jmc@steam.Stanford.EDU>
Reply-To: jmc@cs.Stanford.EDU
To: appsmurf@cs.utexas.edu
Subject: Re: Elaboration of Missionaries and Cannibals Puzzles

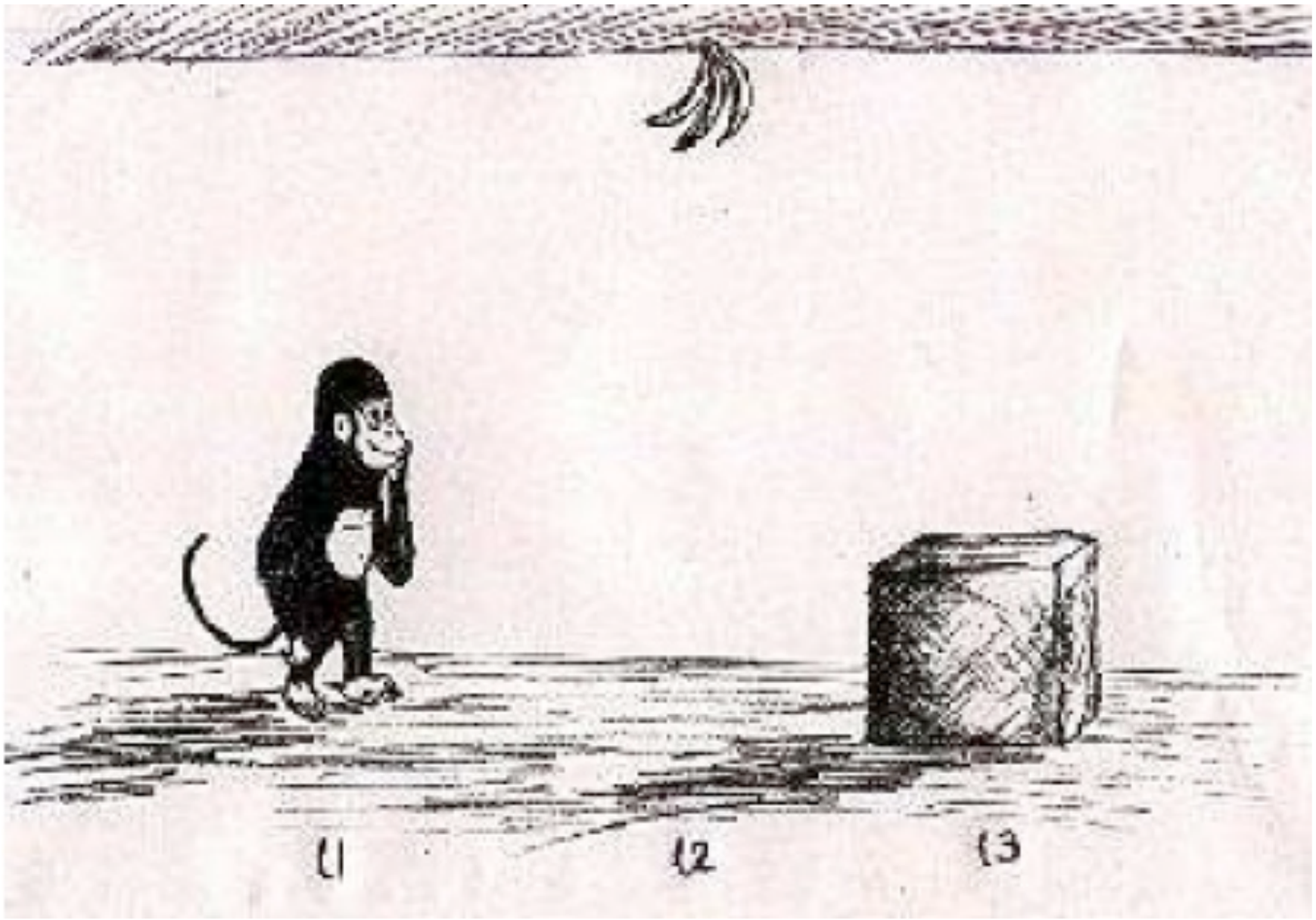
Thanks for the correction. I hope it's ok to add a note to that effect, crediting you.

Correction in the Paper

4. The boat can carry three. Four can cross but not five. If the boat can carry four an arbitrary number can cross. [2003 Sept: This is mistaken. Joohyung Lee showed that if the boat holds three, five can cross.]

[John McCarthy, "Elaboration Tolerance", 1998; updated in 2003]

Monkey and Bananas



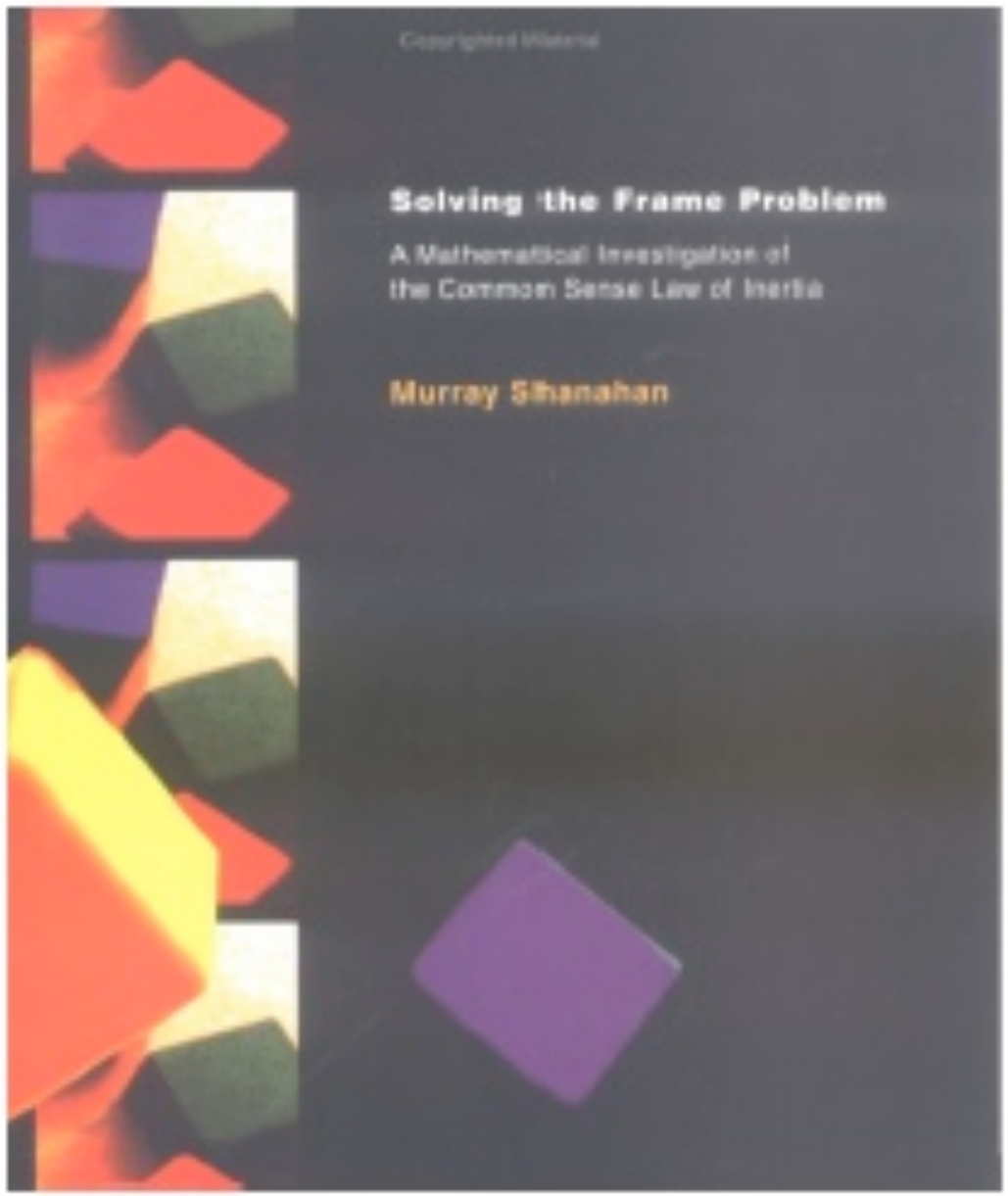
Advice Taker

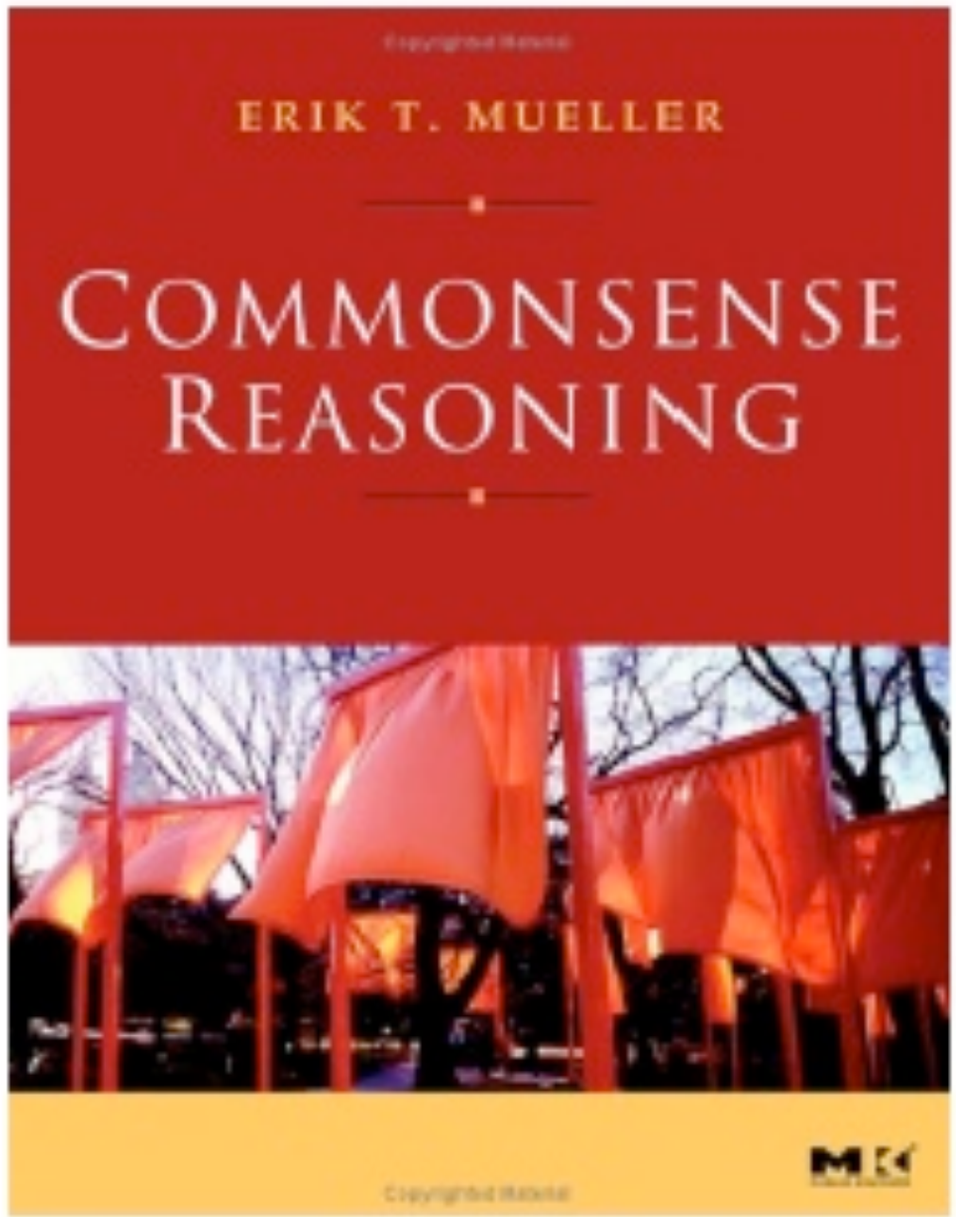
Assume that I am seated at my desk at home and I wish to go to the airport. My car is at my home also. How shall I get to the airport?

Advice Taker: draws a relevant conclusion from the set of formal statements of premises; changes are made by updating the premises, rather than by rewriting the program's internal code [McCarthy, "Programs with common sense," 1959].

The Frame Problem: describing what remains unchanged after executing an action.

Frame Problem





Shanahan, Solving the Frame Problem, 1997, MIT Press.
Mueller, Commonsense Reasoning, 2006, Morgan Kaufmann.

Classical Logic vs. Nonmonotonic Logics

- The needs for defeasible reasoning: conclusions are drawn tentatively and can be retracted in the light of further information
- Classical logic (propositional logic, first-order logic, ...) is monotonic: if $\Gamma \vdash A$ then $\Gamma \cup \Delta \vdash A$
- Nonmonotonic logics: $\Gamma \vdash A$ then $\Gamma \cup \Delta \nvdash A$
  - circumscription [McCarthy, 1980]
  - default logic [Reiter, 1980]
  - nonmonotonic modal logic [McDermott & Doyle, 1980]

Reasoning on the Web

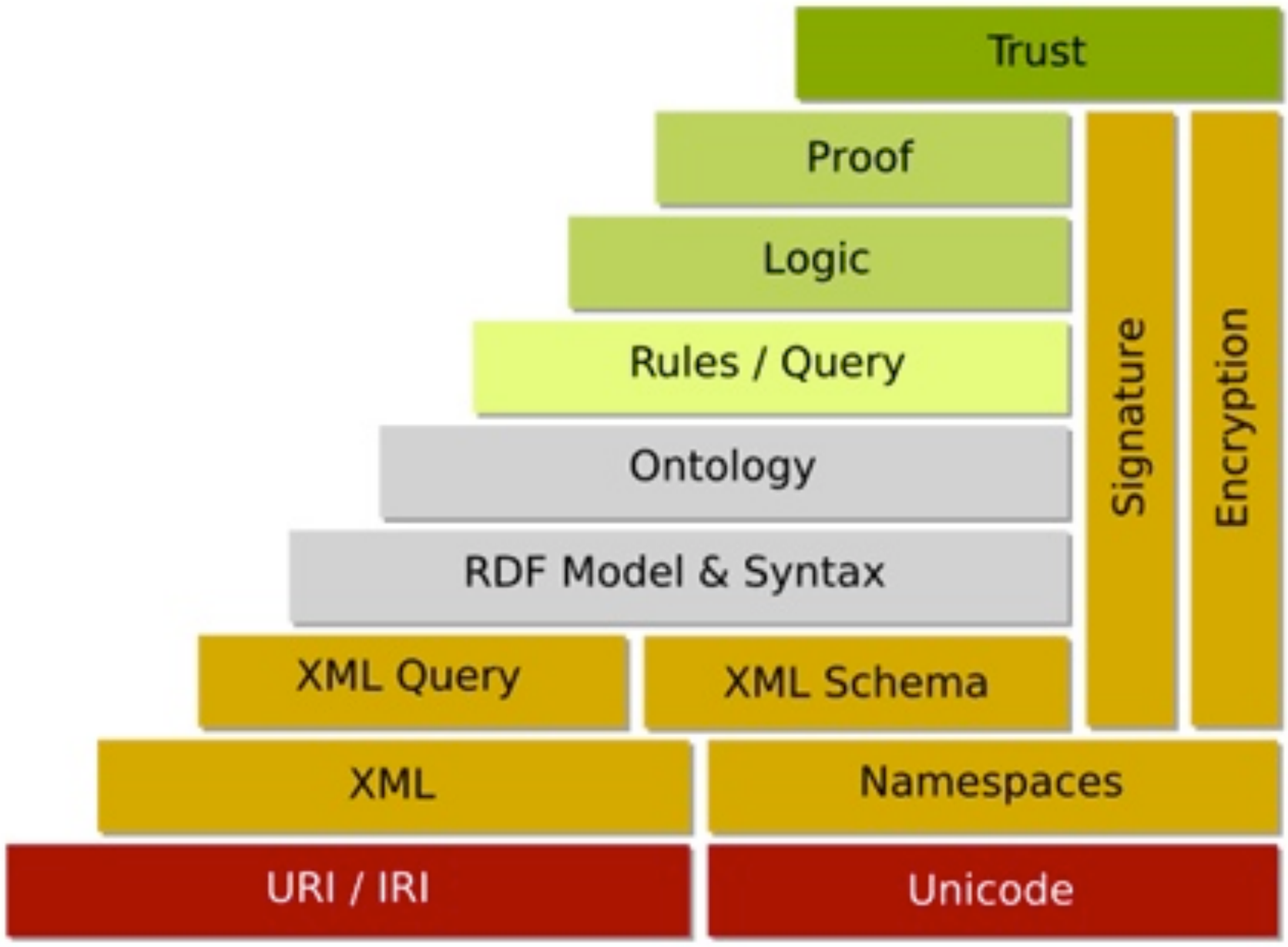
Semantic Web - Idea

- Proposed by Tim Berners-Lee, the inventor of WWW.
- The meaning of current Web Content is not machine accessible.
- The idea of semantic web is to represent Web content in a form that is more easily machine-understandable.
- Web is a HUGE knowledge base.

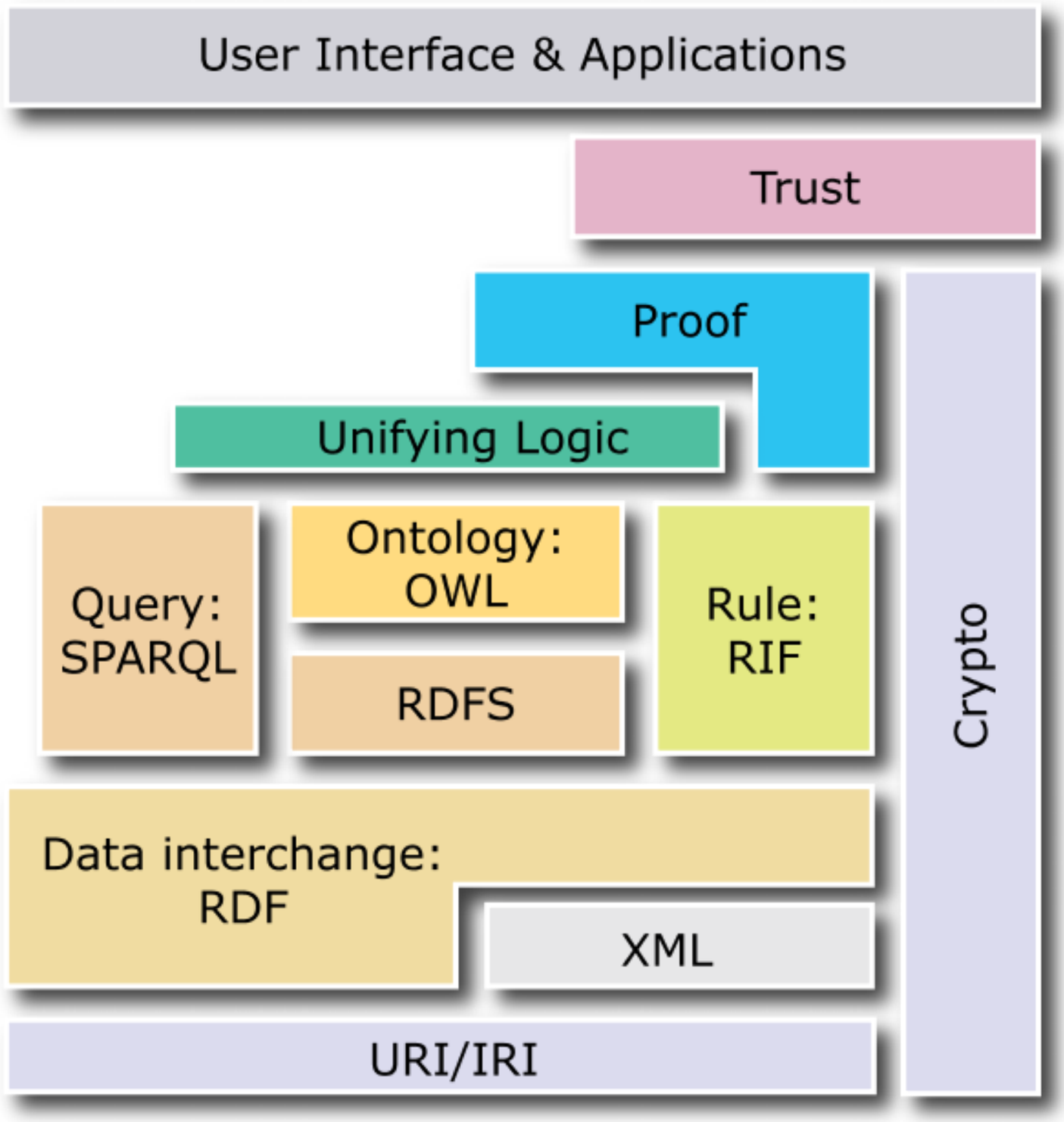
Semantic Web

- Humans are capable of using the Web to carry out tasks such as finding the Irish word for "folder", reserving a library book, and searching for the lowest price for a DVD. However, machines cannot accomplish all of these tasks without human direction, because web pages are designed to be read by people, not machines
- The semantic web is a vision of information that can be readily interpreted by machines, so machines can perform more of the tedious work involved in finding, combining, and acting upon information on the web.

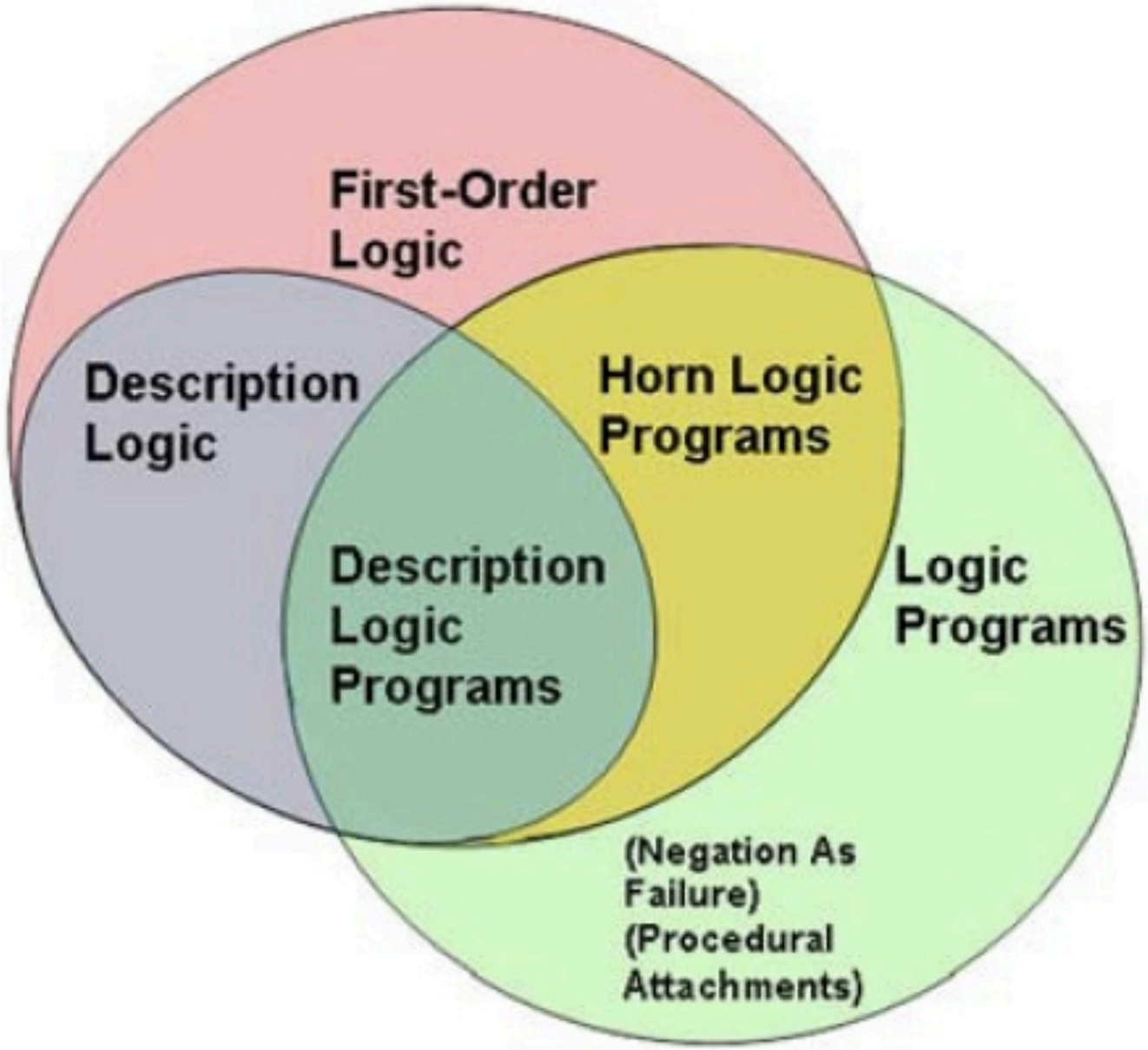
Semantic Web Layer Cake (Traditional)



Semantic Web Layer Cake (Alternative)



Which KR Language for Web?



Ontology Reasoning

Description Logics

- First-order logic in disguise:

$$\text{HappyMan} \equiv \text{Human} \sqcap \neg\text{Female} \sqcap (\exists \text{married}.\text{Doctor}) \sqcap (\forall \text{hasChild}.(\text{Doctor} \sqcup \text{Professor})).$$

$$\text{Doctor} \sqsubseteq \text{Human},$$

- happyMan is subsumed by $\exists \text{married}.\text{Human}$
- $\exists \text{hasChild}.\text{Human} \sqsubseteq \text{Human},$

KM

"All buy events have

- a buyer and a seller (both of type agent)
- an object which is bought
- some money equal to the cost of the object
- two 'give' subevents, in which:
  1. The buyer gives the money to the seller
  2. The seller gives the object to the buyer."

(a) English

```
(every Buy has
  (buyer ((a Agent)))
  (object ((a Thing)))
  (seller ((a Agent)))
  (money ((the cost of (the object of Self))))
  (subevent1 ((a Give with
                (agent ((the buyer of Self)))
                (object ((the money of Self)))
                (rcpt ((the seller of Self))))))
  (subevent2 ((a Give with
                (agent ((the seller of Self)))
                (object ((the object of Self)))
                (rcpt ((the buyer of Self)))))))
```

(b) Axiomatization (KM syntax)

Autonomous Systems and Cognitive Robotics

Cognitive Robotics

- Cognitive robotics is the study of knowledge representation and reasoning problems faced by an autonomous robot. Unlike in traditional knowledge representation and reasoning, knowledge in cognitive robotics is an essential component that is to be acquired and manipulated during the execution because the environment that robots operate in is highly dynamic and incompletely specified.
  - http://ijcai-11.iiia.csic.es/files/videotrack/chen.mov
  - http://krr.sabanciuniv.edu/cogrobo/demos.html
  - http://videolectures.net/aaai07_doherty_ausr/

Combinatorial Search Problems

Wire Routing

- Determine the physical locations of all wires interconnecting the circuit components on a chip.

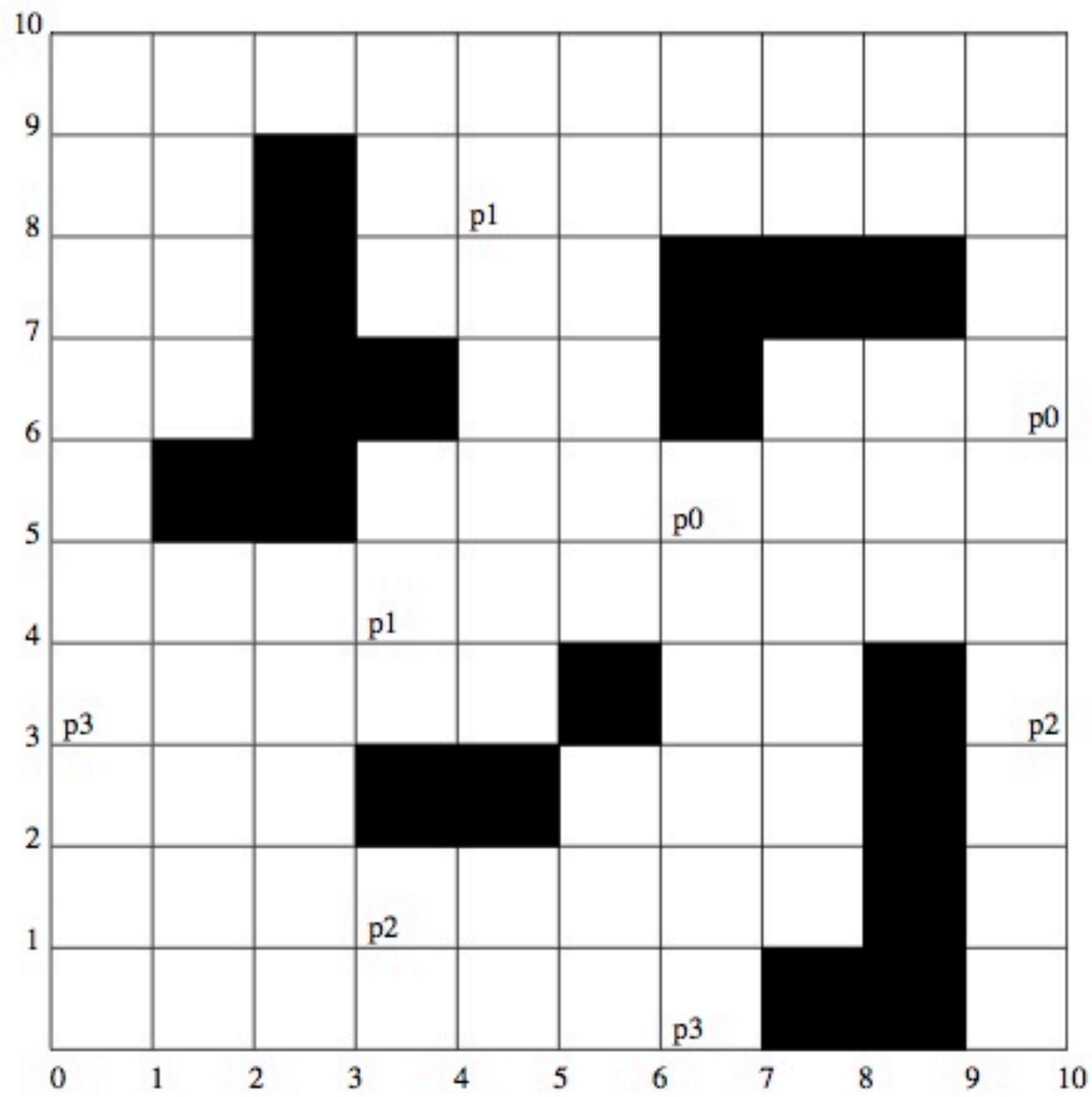


Fig. 1. A routing problem with 4 wires.

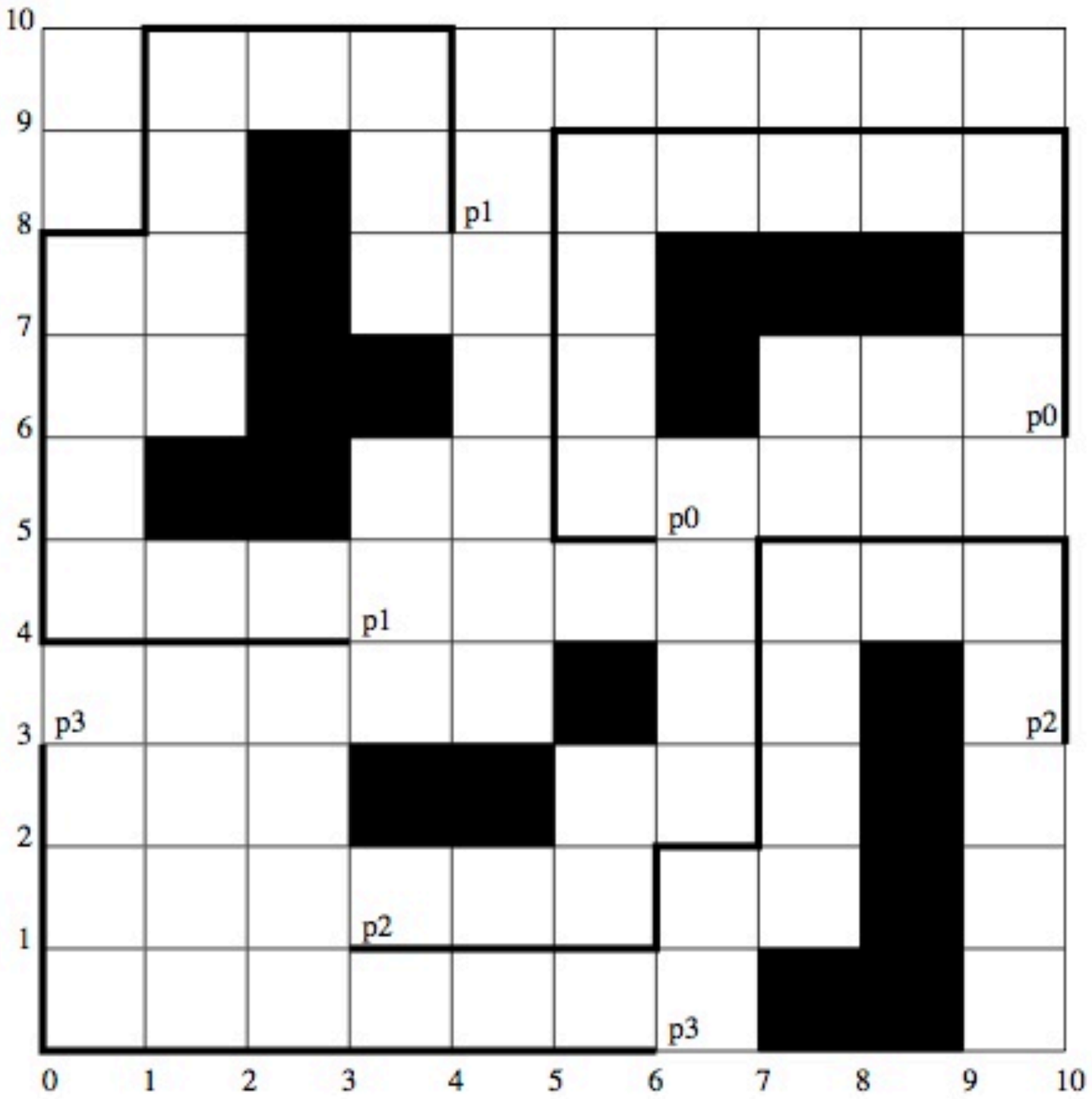


Fig. 2. A solution to the problem from Fig. 1.

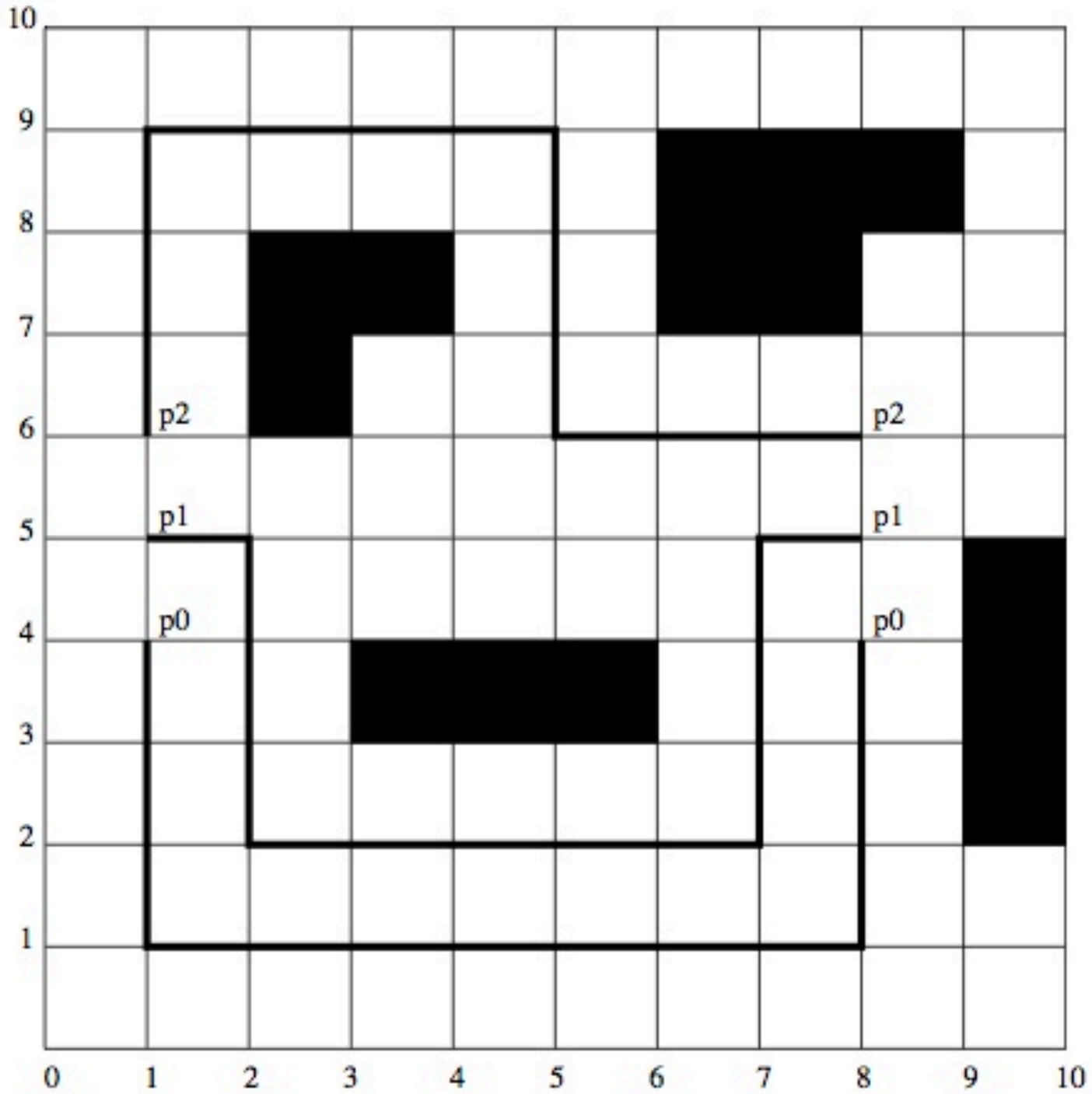


Fig. 5. A bus routing problem. The wires are required to have the same length.

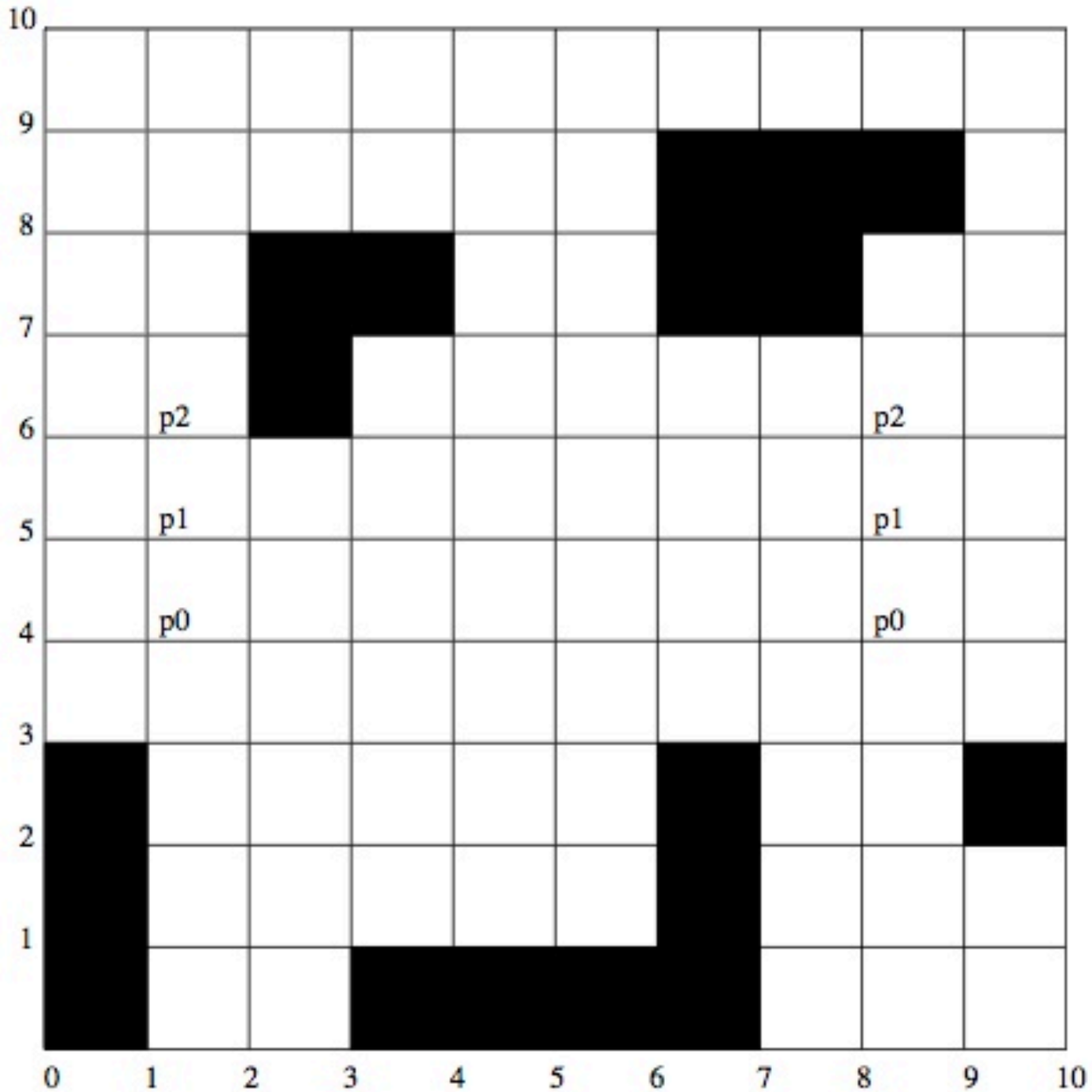


Fig. 7. A bus routing problem that has no precise solution.

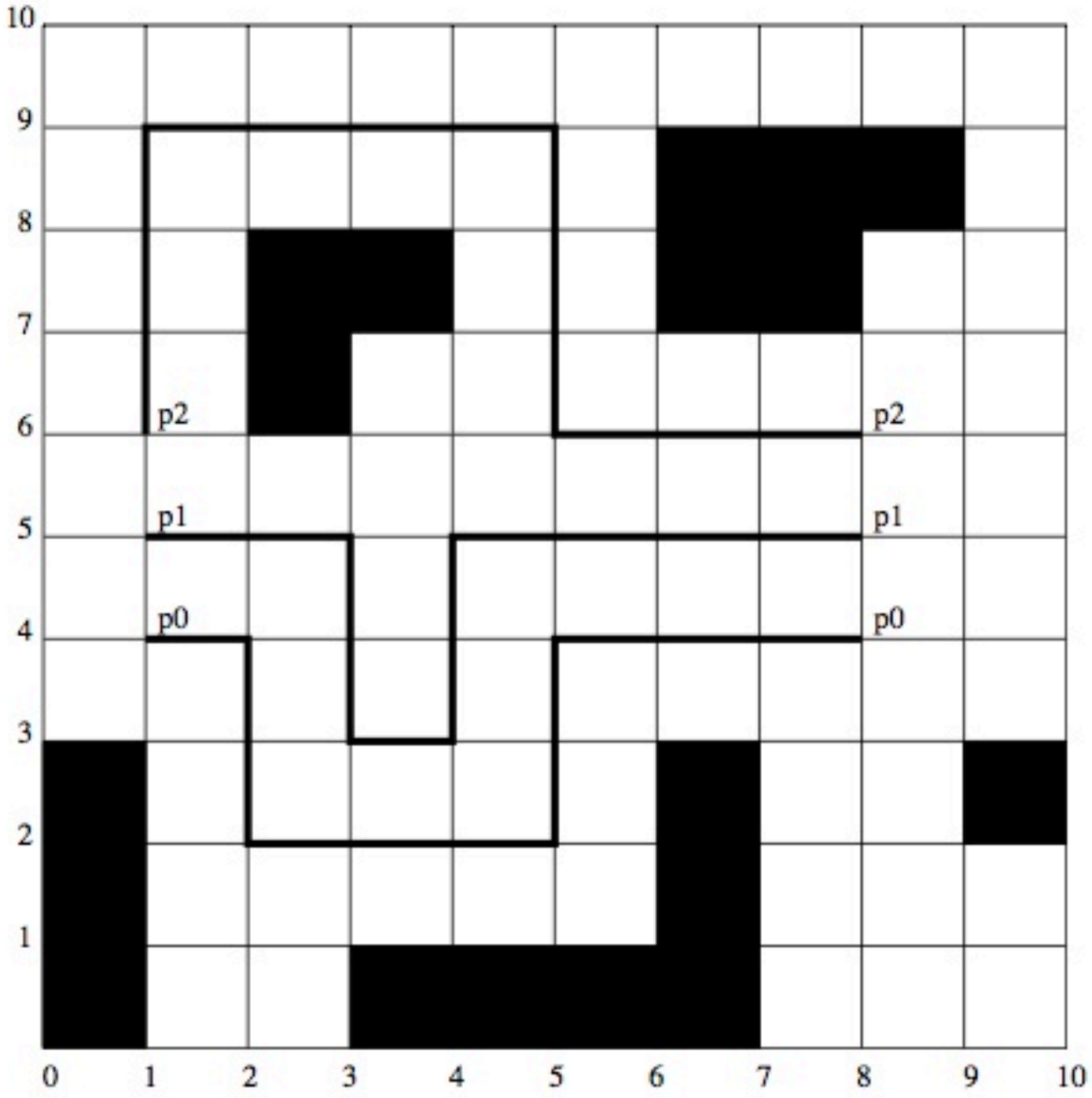


Fig. 8. An approximate solution to the problem from Fig. 7. The differences between the lengths of wires are limited by 2.

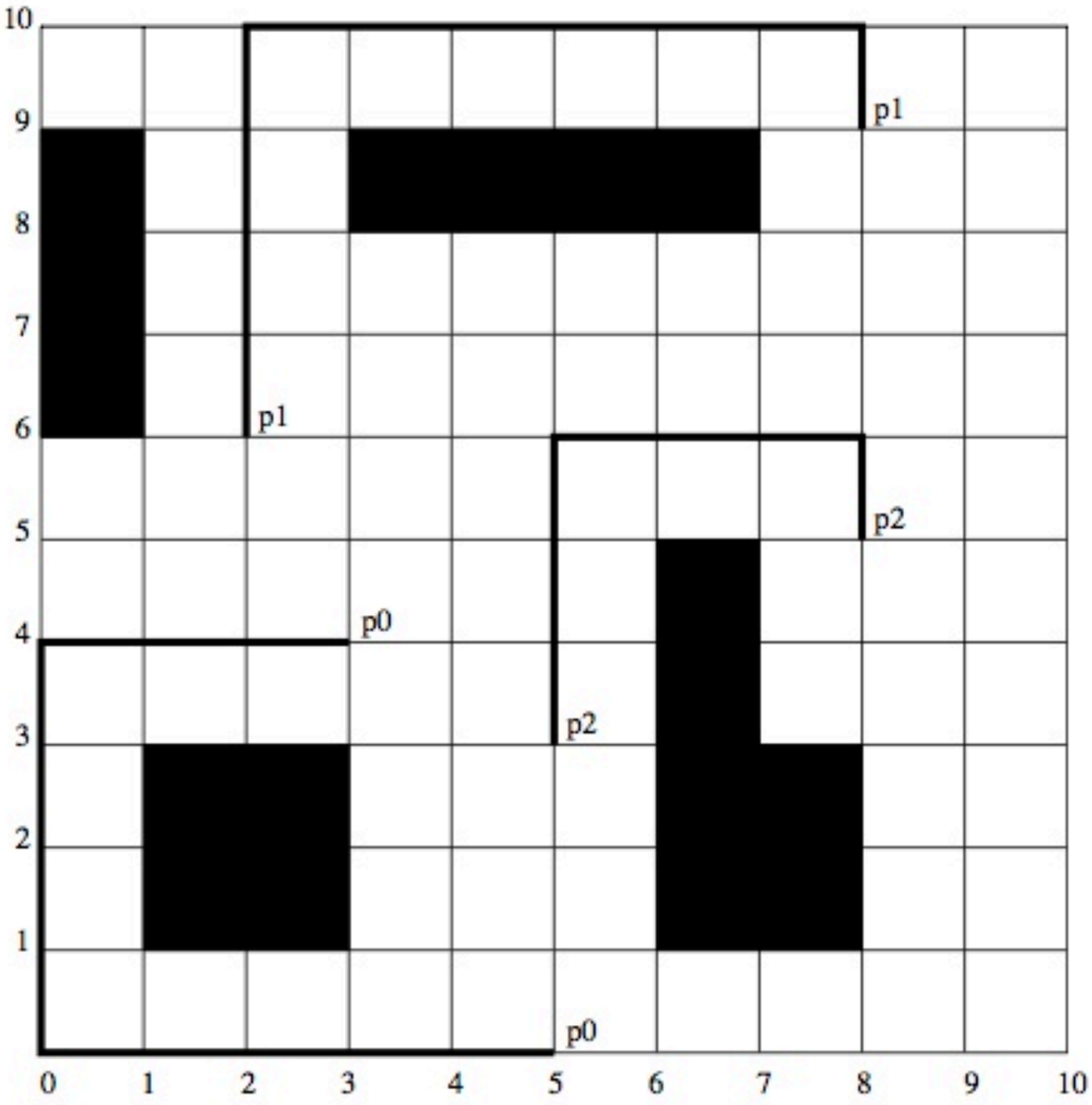
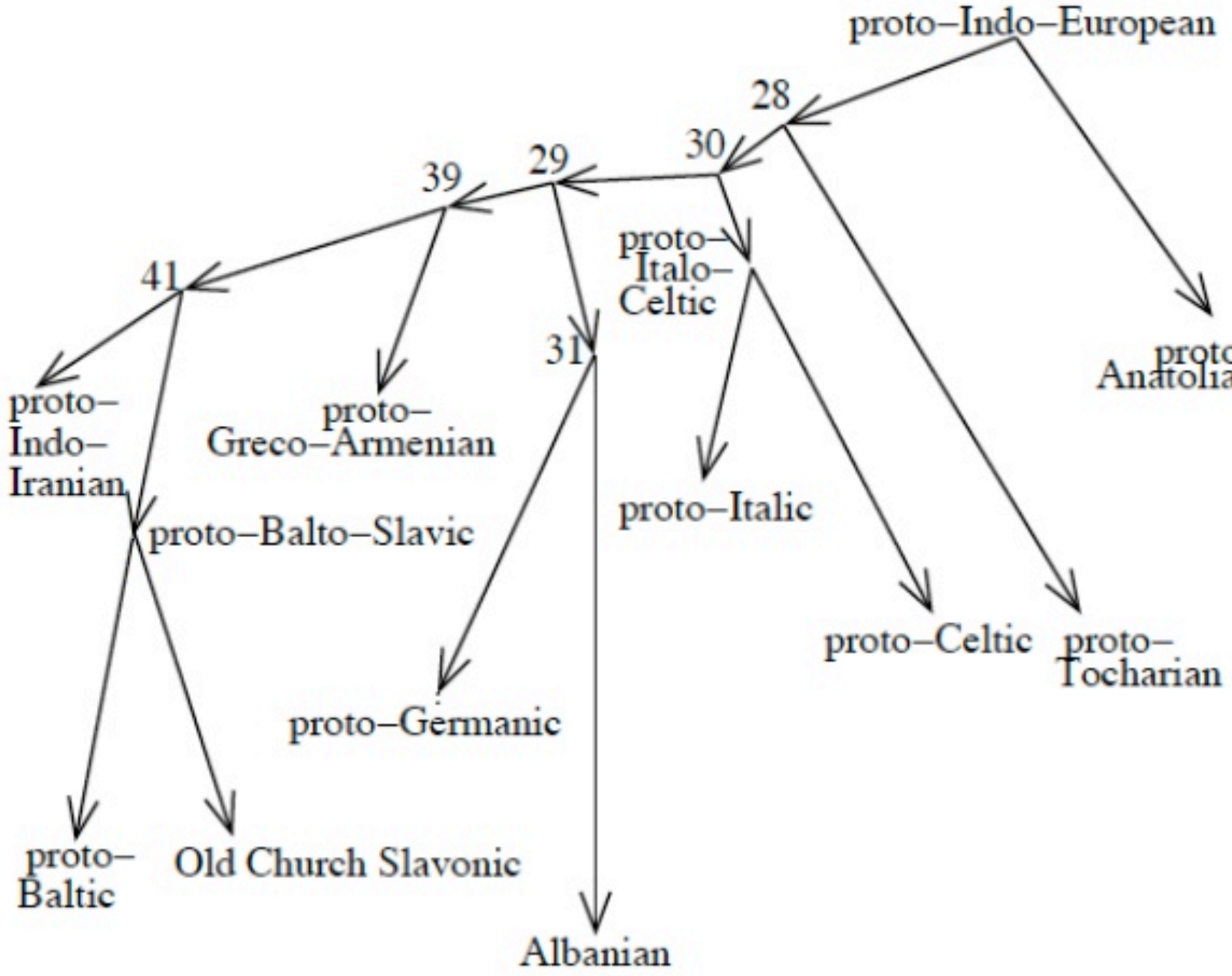


Fig. 12. A solution to a routing problem without adjacent wires.

Inferring Phylogenetic Trees

[Erdem, Lifschitz, Nakhleh, Ringe, "Reconstructing the Evolutionary History of Indo-European Languages Using Answer Set Programming", 2003]

	'one'	'arm'	'beard'	'free'	'pour'	'tear'
proto-Indo-Iranian		5	1			11
proto-Baltic	11	8	5		6	11
Old Church Slavonic			5		6	
proto-Greco-Armenian	2		1	3	3	2
proto-Germanic	11	8	5	10	14	2
Albanian	2		1			
proto-Italic	11		5	3	14	2
proto-Celtic	11			10		2
proto-Tocharian	2	5			3	11
proto-Anatolian			1			


proto–Indo–European
28
30
29
39
41
31
proto–
Italo–
Celtic
proto–
Anatolian
proto–
Indo–
Iranian
proto–
Greco–Armenian
proto–Balto–Slavic
proto–Italic
proto–Celtic
proto–
Tocharian
proto–Germanic
proto–
Baltic
Old Church Slavonic
Albanian

KRR and Security

Access Control Policies

- Policies are declarative specifications about the desired behaviors of a complex adaptive system.
  - Widely used in network and system management, privacy and security, business rules, ...
- Policy-based computing helps to handle complex system properties by separating policies from system implementation.
- The increasing complexity of policy-based computing demands strong support of automated reasoning techniques.

Access Control Policies

- An access control policy is about authorizing a group of users to perform a set of actions on a set of resources.
- XACML (eXtensible Access Control Markup Language):
  - An XML-based access control policy description language.
  - Widely adopted standard to specify access control policies for various web applications.
  - Well supported by Organization for the Advancement of Structured Information Standards (OASIS) whose members include IBM, Microsoft and ORACLE.

Access Control Policies

- Semantics of XACML is semi-formal
- Automated analysis services?
  - Assuring correctness
  - Identifying inconsistencies/conflicts
  - Policy comparison
  - Checking redundancies
  - ....

Example

- The global policy of the entire company:
  - employees can read and change codes during working hours (8:00 - 17:00), and
  - nobody can change codes during non-working hours.
- The local policy of a development department:
  - developers can read codes during non-working hours,
  - testers cannot read codes during non-working hours, and
  - testers and developers cannot change codes during non-working hours.

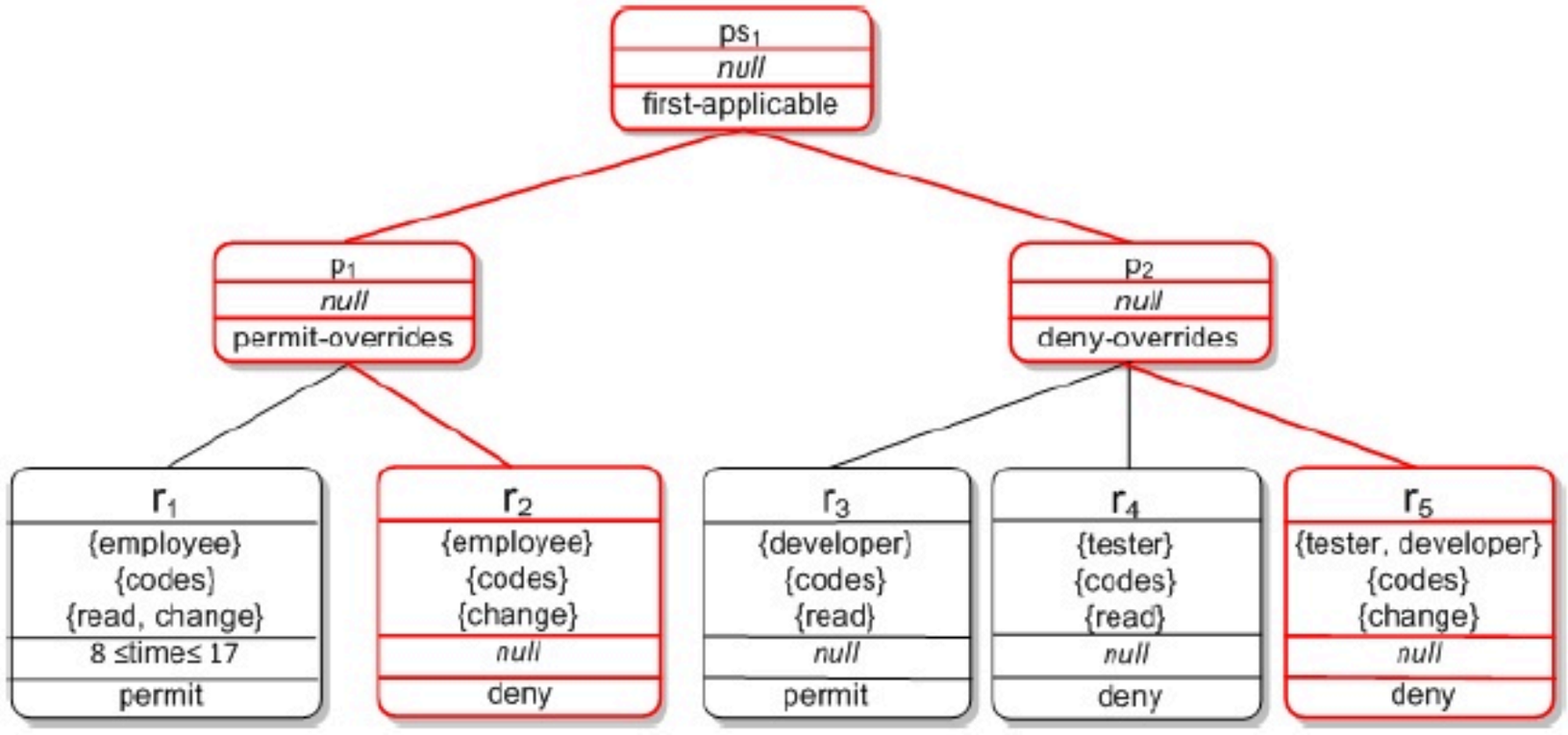
The global policy supersedes the local policy.

Example XACML Codes

```
<PolicySet PolicySetId="ps1" PolicyCombiningAlgId="first-applicable">
  <Target/>
  <Policy PolicyId="p1" RuleCombiningAlgId="permit-overrides">
    <Target/>
    <Rule RuleId="r1" Effect="permit">
      <Target>
        <Subjects><Subject>     employee   </Subject></Subjects>
        <Resources><Resource>   codes      </Resource></Resources>
        <Actions><Action>         read     </Action>
                 <Action>         change   </Action></Actions>
      </Target>
      <Condition>              8 ≤ time ≤ 17          </Condition>
    </Rule>
    <Rule RuleId="r2" Effect="deny">
      <Target>
        <Subjects><Subject>     employee   </Subject></Subjects>
        <Resources><Resource>   codes      </Resource></Resources>
        <Actions><Action>       change     </Action></Actions>
      </Target>
    </Rule>
  </Policy>
```

Property Verification

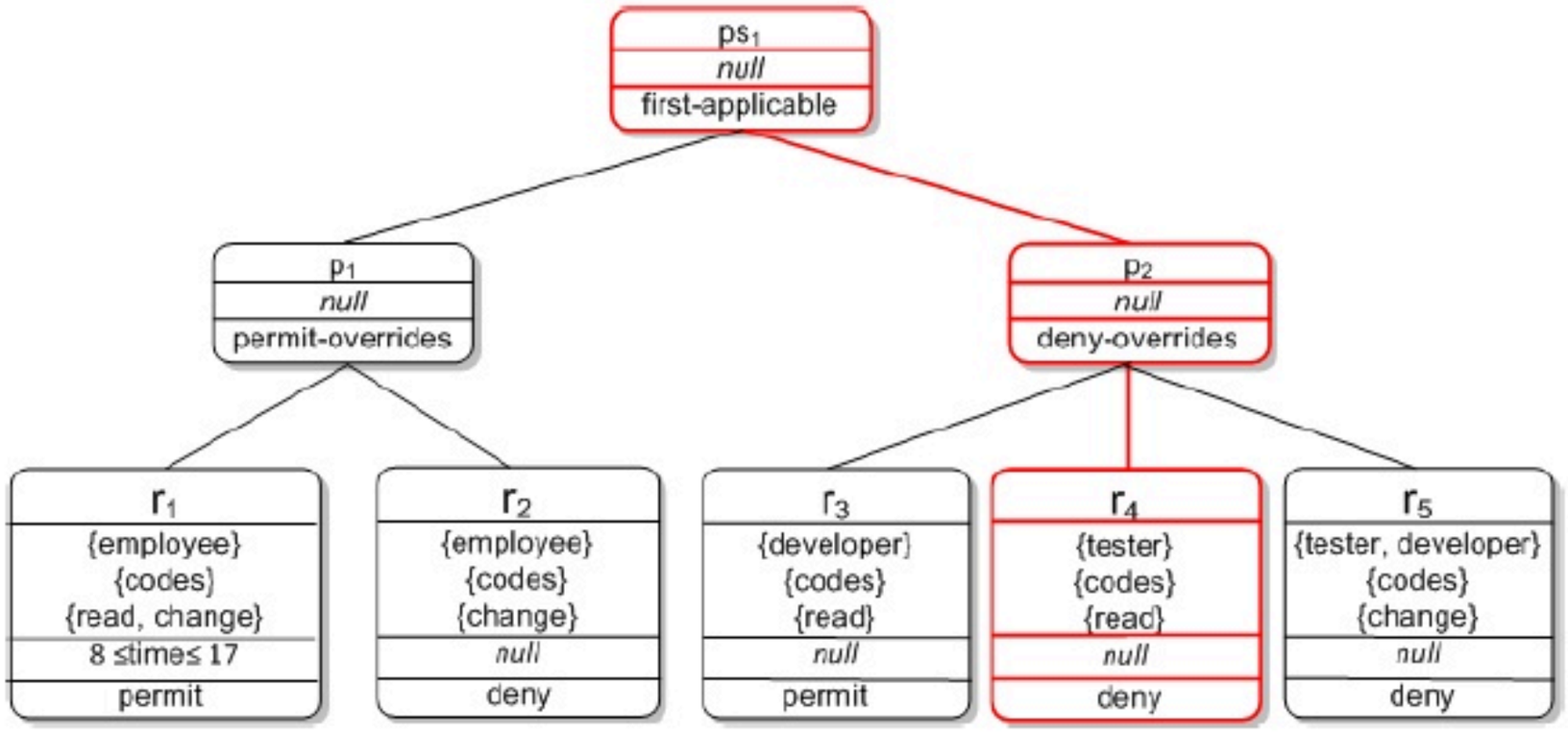
- Is the request by the developer to read the code during non-working hours always permitted?



A: No, if the request also contains changing the codes:

$$Answer\ Set : \{subject(developer)\ subject(employee)\ action(read)\ action(change)\ resource(codes)\ \ldots\}.$$

- Okay, let’s say no two requests at the same time.
- Same question: Is the request by the developer to read the code during non-working hours always permitted?



A: Still no, if the developer is also a tester:

$$Answer\ Set : \{subject(developer)\ subject(tester)\ subject(employee)\ action(read)\ resource(codes)\ \ldots\}.$$

Security Protocol Analysis

Protocol Analysis

Consider a simple (flawed) one-way authentication protocol (personal communication, Alessandro Armando).

$$(1)\ Alice \rightarrow Bob : Alice, \{N\}Kab$$
$$(2)\ Bob \rightarrow Alice : \{f(N)\}Kab$$

where N is a nonce generated by Alice, Kab is a symmetric key, f is a function known to Alice and Bob only, and $\{x\}k$ denotes the result of encrypting text x with key k. Since only Bob could have formed the appropriate response to the message issued in (1), Alice may assume that she has been talking with Bob.

Protocol Analysis

$$
\begin{aligned}
&(1.1)\ Alice \rightarrow Ivory : Alice, \{N\}Kab \\
&(2.1)\ Ivory \rightarrow Alice : Bob, \{N\}Kab \\
&(2.2)\ Alice \rightarrow Ivory : \{f(N)\}Kab \\
&(1.2)\ Ivory \rightarrow Alice : \{f(N)\}Kab.
\end{aligned}
\tag{7.1}
$$

Alice starts a session by sending a message. Ivory intercepts it and starts the second session by sending back the received message. Assuming that it was sent by Bob, Alice replies to this message. The reply is exactly the message that Alice was waiting for in the first session. Ivory just send this message back to Alice. Alice believes that she was talking with Bob, but it is wrong.

Question Answering Biomedical Ontologies

Querying Biomedical Ontologies

- Biomedical data is stored in various structured forms and at different locations.
- With the current Web technologies, reasoning over these data is limited to answering simple queries by keyword search and by some direction of humans.
- Vital research, like drug discovery, requires high-level reasoning.

A Simple Query

What are the genes targeted by the drug Epinephrine?

Search DrugBank for: epinephrine Search Reset

☑ Common Name ☑ Synonym and Brand Name ☐ All Text Fields

A Simple Query

What are the genes targeted by the drug Epinephrine?

DrugBank

Home | Browse | PharmaBrowse | ChemQuery | Text Query | SeqSearch | Data Extractor | Download and Stats

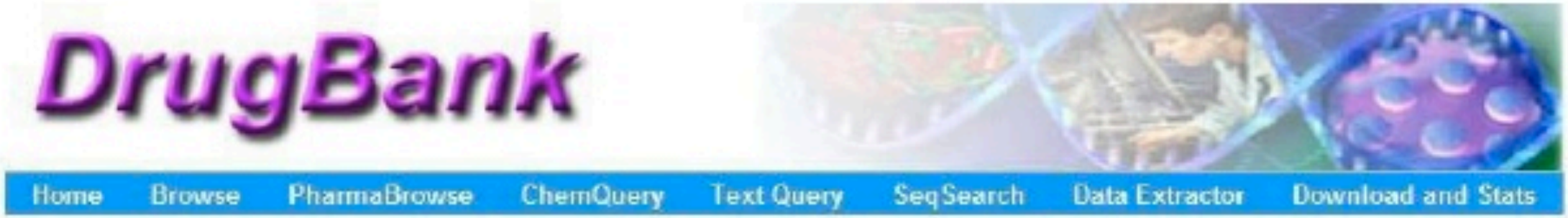
Search DrugBank for: epinephrine Search Reset

☑ Common Name ☑ Synonym and Brand Name ☐ All Text Fields

Drug Target 1	
Drug Target 1 Name	Alpha-1A adrenergic receptor
Drug Target 1 Synonyms	1. Alpha 1A-adrenoceptor 2. Alpha 1A- adrenoreceptor 3. Alpha-1C adrenergic receptor 4. Alpha adrenergic receptor 1c
Drug Target 1 Gene Name	ADRA1A

A Simple Query

What are the genes targeted by the drug Epinephrine?



Search DrugBank for: epinephrine Search Reset

☑ Common Name ☑ Synonym and Brand Name ☐ All Text Fields

Drug Target 2	
Drug Target 2 Name	Beta-1 adrenergic receptor
Drug Target 2 Synonyms	1. Beta-1 adrenoceptor 2. Beta-1 adrenoreceptor
Drug Target 2 Gene Name	ADRB1

A Simple Query

What are the genes targeted by the drug Epinephrine?

DrugBank

Home | Browse | PharmaBrowse | ChemQuery | Text Query | SeqSearch | Data Extractor | Download and Stats

Search DrugBank for: epinephrine Search Reset

☑ Common Name ☑ Synonym and Brand Name ☐ All Text Fields

Drug Target 3	
Drug Target 3 Name	Beta-2 adrenergic receptor
Drug Target 3 Synonyms	1. Beta-2 adrenoceptor 2. Beta-2 adrenoreceptor
Drug Target 3 Gene Name	ADRB2

Another Simple Query

What are the genes related to the disease Asthma?

PharmGKB
The Pharmacogenetics and Pharmacogenomics Knowledge Base

Home | Search | Submit | Help | PGRN | Contributors | Sign In | Feedback

Search PharmGKB: ?

asthma Go

e.g. a gene ("NOS3"), drug ("ace inhibitors") or disease ("ALL")

Database Search | Website Search

view legend

Results 1 - 20 of 478

Disease: Asthma
Alternate names: Asthma, Bronchial, Asthmas, Asthmas, Bronchial, Bronchial Asthma, Bronchial Asthmas

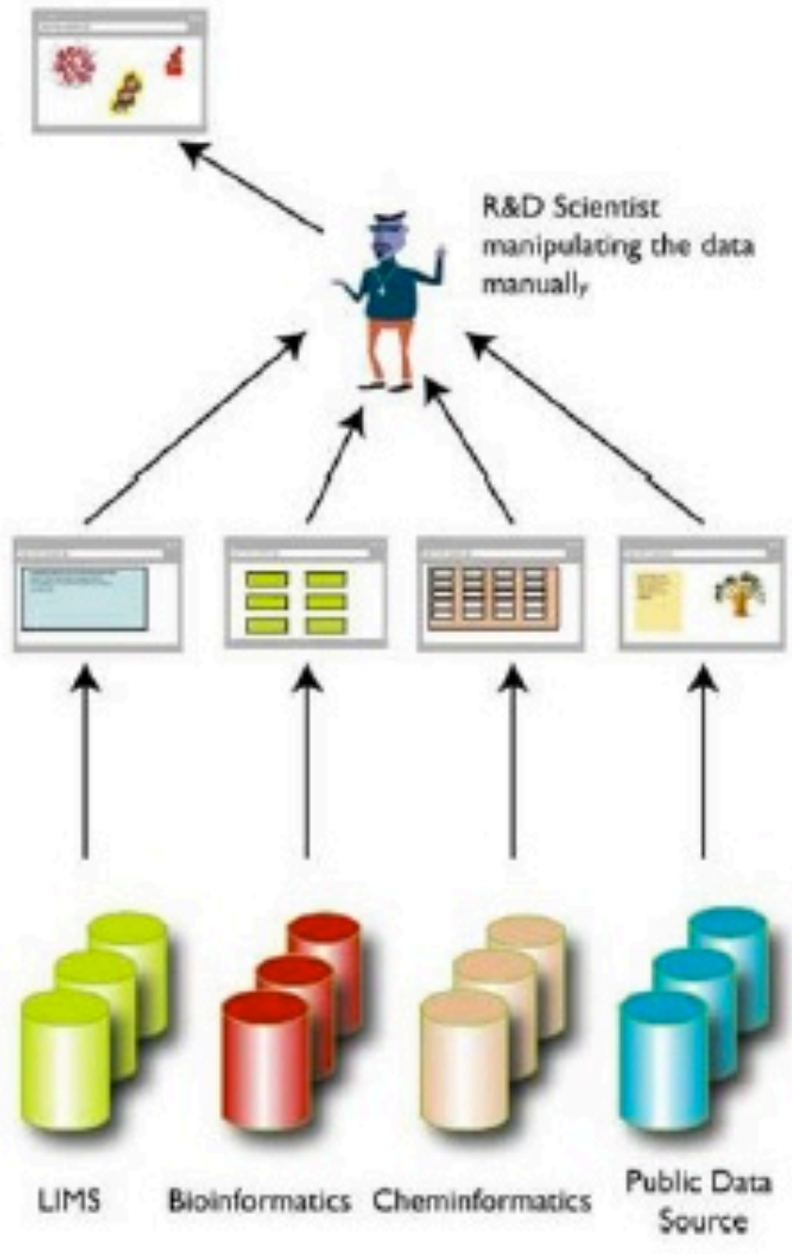
Disease: Asthma, Exercise-Induced
Alternate names: Asthma, Exercise Induced, Asthmas, Exercise-Induced, Bronchospasm, Exercise Induced, Bronchospasm, Exercise-Induced, Bronchospasms, Exercise-Induced, Exercise Induced Asthma, Exercise Induced Bronchospasm...

Publication: Pharmacogenetics of asthma

Disease: Dyspnea, Paroxysmal
Alternate names: Asthma, Cardiac, Cardiac Asthma, Dyspnea, Paroxysmal Nocturnal, Dyspneas, Paroxysmal, Dyspneas, Paroxysmal Nocturnal, Nocturnal Dyspnea, Paroxysmal, Nocturnal Dyspneas, Paroxysmal, Paroxysmal Dyspnea, Paroxysmal Dyspneas...

Complex Query

What are the genes related to Asthma and targeted by Epinephrine?



Challenges

- Too many biomedical ontologies and databases, and in different formats.
- Biomedical ontologies are incomplete, and biomedical knowledge has exceptions.
- Reasoning over biomedical ontologies requires recursive definitions, aggregates, constraints, preferences, etc.

QA Systems

QA System

Text:

John and Mike took a plane from Paris to Baghdad.
John took his laptop on the plane with him.

Questions:

- Where is John at the end of the trip?
- Where is Mike at the end of the trip?
- Where is John's laptop at the end of the trip?

Text:

John and Mike took a plane from Paris to Baghdad. John took his laptop on the plane with him. On the way, the plane stopped in Rome, where John was arrested.

Questions:

- Where is John at the end of the trip?
- Where is Mike at the end of the trip?
- Where is John's laptop at the end of the trip?

"John and Mike took a plane from Paris to Baghdad."

LCC logical form obtained from the text:

```
john_NN(x1) & _other_human_NE(x1)
& mike_NN(x2) & _other_human_NE(x2)
& and_CC(x6,x1,x2) & take_VB_4(e1,x6,x3)
& plane_NN(x3) &_vehicle_NE(x3) & ...
```

AnsProlog knowledge base (part):

```
h(at(Agent,Loc),T+1)
    :- o(move(Agent,Loc),T), not ab(Agent,Loc,T).

h(at(Agent,Loc),T+1)
    :- h(at(Agent,Loc),T), not ¬h(at(Agent,Loc),T+1).
```

Automated Music Composition

Automated Music Composition

- Anton is an automatic composition tool that can compose melodic and harmonic music in the style of the "Palestrina Rules" for Renaissance music. It uses an answer set solver as it's core computational engine, Csound for synthesis and can optionally output to Lilypond.

```
%% At every time step the note must change
%% It changes by stepping (moving one note in the scale) or
%% leaping (moving more than one note)
%% These can either be upwards or downwards
1 { stepAt(P,T), leapAt(P,T) } 1 :- T != t.
1 { downAt(P,T),   upAt(P,T) } 1 :- T != t.

stepDown(P,T) :- stepAt(P,T), downAt(P,T).
stepUp(P,T)   :- stepAt(P,T),   upAt(P,T).

leapDown(P,T) :- leapAt(P,T), downAt(P,T).
leapUp(P,T)   :- leapAt(P,T),   upAt(P,T).
```

Many KRR formalisms

- General methods
  - SAT, description logics, constraint programming, conceptual graphs, nonmonotonic logics, answer set programming, belief revision, ...
- Specialized methods: time, space, causation, action
  - temporal reasoning, knowledge and belief, action formalisms
- Applications
  - query answering, semantic web, planning, cognitive robotics, multiagent systems

Tentative Schedule

- Introduction (0.5 wk)
- Review of classical logic (1 wk)
- Nonmonotonic Causal Logic and C+ (3 wk)
- Cognitive robotics (1.5 wk)
- Description logics and semantic Web KR (3wk)
- Logic Programming (3 wk)
- KRR and Security (2 wk)
- Project Presentation (1wk)

Role of Logic in KRR

(Handbook, Ch1)

Role of Logic

- Logic is the study of reasoning
- FOL is a starting point, but not universal for all KR problems.
  - Yale Shooting Problem
  - …
- Many KRR formalisms

Anti-Logicist Arguments and Response

- Deductive Reasoning isn't enough
- Deductive reasoning is too expensive
- Writing down all the knowledge (the right way) is infeasible
- Other approaches do it better and/or cheaper

Argument: Deductive reasoning isn't enough

- Bar-Hillel's argument
- Need for nonmonotonic reasoning
- $\forall x(Bird(x) \rightarrow Flies(x))$
- $\forall x(Bird(x) \wedge \neg Ab(x) \rightarrow Flies(x))$

  $\forall x(Penguin(x) \rightarrow Ab(x))$

  $\forall x(Brokenwinged(x) \rightarrow Ab(x))$

Argument: Deductive reasoning is too expensive

- Efficient theorem proving methods
- Special-purpose reasoning techniques
  - Cyc, Description Logics, logic programming
  -

Argument: Writing down all the knowledge is infeasible

- Many successes in writing down knowledge correctly
  - theories of causation and temporal reasoning
  - theories of knowledge and belief
  - spatial reasoning
  - physical reasoning

Argument: Other approaches do it better and/or cheaper

- Statistical learning systems are becoming popular.
- But they can only go so far. E.g.,
  - performed well for text-retrieval competitions (TREC)
  - not for message-understanding competitions (MUC)
- Most successful applications should make use of both approaches

300 Years Ago by Gottfried Wilhelm Leibniz

‘when a controversy arises, there will be as much need for discussion between two philosophers as there is between two calculators. It will be sufficient to seize one’s pen, sit down at a table and say to each other: Let us calculate!’