## Logical Reasoning as Argumentation,

### Or: How Lessons from the Law Are Changing Artificial Intelligence

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**Lecture 1: Argumentation and Artificial Intelligence**
An overview is given of how ideas from argumentation theory have been picked up in artificial intelligence. The focus will be more on general ideas and approaches, and less on formal detail.

**Lecture 2: Argumentation in the law: case-based and rule-based**
In the law, argumentation is central. Two kinds of argument-based reasoning are prominent. In the first kind, precedent cases are followed by analogy; in the second, rules are applied when their conditions are fulfilled.

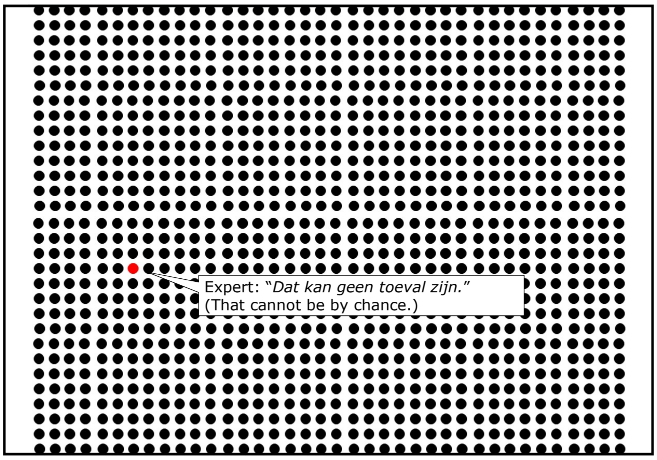
**Lecture 3: Argumentation and evidence: Combining arguments, scenarios and probabilities**
For deciding about the facts in a criminal case, different normative frameworks aiming at the prevention of erroneous reasoning have been proposed: arguments, scenarios and probabilities. The normative frameworks are characterized and their relations investigated, for instance by discussing how arguments and scenarios can be studied using Bayesian networks.

**http://www.ai.rug.nl/~verheij/ssa2016/**


Expert: "The probability is 1 in 342,000,000 that a nurse's shifts coincide with so many unexplained deaths and resuscitations."

Expert: "The probability is 1 in 342,000,000 that a nurse's shifts coincide with so many unexplained deaths and resuscitations."

Expert: "*Dat kan geen toeval zijn.*"
(That cannot be by chance.)

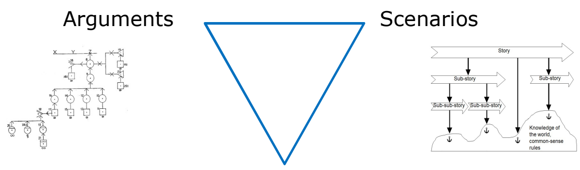



## The problem of proof




geredetwijfel.nl

## Three normative frameworks




Probabilities

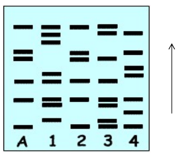
$$\frac{p(H|E)}{p(not-H|E)} = \frac{p(E|H)}{p(E|not-H)} \cdot \frac{p(H)}{p(not-H)}$$

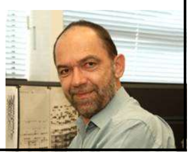
Posterior odds = Likelihood ratio · Prior odds

## DNA profiling

Successful

- High information value
- Scientific foundation
- Precise statistical information (Random Match Probability)



## "The DNA effect"

By the success and nature of DNA the following idea gains momentum:

*Evidence is only valuable when it comes with scientifically supported statistics.*

(Cf. the CSI effect;
http://en.wikipedia.org/wiki/CSI_effect)

## DNA profiling

| DNA Profile | | Allele frequency from database | | | | Genotype frequency for locus | |
|---|---|---|---|---|---|---|---|
| Locus | Alleles | Times allele observed | Size of database | Frequency | | Formula | Number |
| CSF1PO | 10 | 109 | 432 | $p=$ | 0.25 | $2pq$ | 0.16 |
| | 11 | 134 | | $q=$ | 0.31 | | |
| TPOX | 8 | 229 | 432 | $p=$ | 0.53 | $p^2$ | 0.28 |
| | 8 | | | | | | |
| THO1 | 6 | 102 | 428 | $p=$ | 0.24 | $2pq$ | 0.07 |
| | 7 | 64 | | $q=$ | 0.15 | | |
| vWA | 16 | 91 | 428 | $p=$ | 0.21 | $p^2$ | 0.05 |
| | 16 | | | | | | |
| | | | | | **profile frequency=** | | **0.00014** |

Roughly 1 in 7000

Random Match Probability

Charles H. Brenner

## DNA profiling

Assume we find a match between a suspect's DNA and a trace. The estimated profile frequency is 1 in 7000.

What is the probability that the suspect is the source of the trace?

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**With just this information the question has no answer: The prior is needed.**

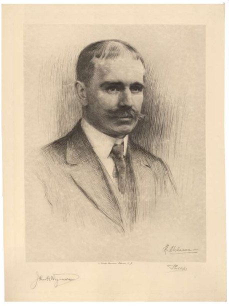
## Probabilities

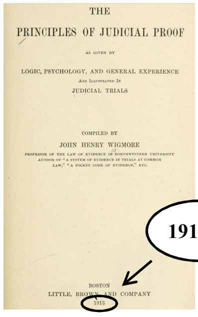
$$\frac{p(H|E)}{p(not\!-\!H|E)} = \frac{p(E|H)}{p(E|not\!-\!H)} \cdot \frac{p(H)}{p(not\!-\!H)}$$

Posterior odds = Likelihood ratio · Prior odds

*H* hypothesis
*E* evidence

## Argumentation




THE

PRINCIPLES OF JUDICIAL PROOF

AS GIVEN BY

LOGIC, PSYCHOLOGY, AND GENERAL EXPERIENCE

AND ILLUSTRATED IN

JUDICIAL TRIALS

COMPILED BY

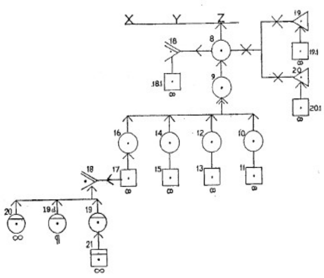
JOHN HENRY WIGMORE

PROFESSOR OF THE LAW OF EVIDENCE IN NORTHWESTERN UNIVERSITY
AUTHOR OF "A SYSTEM OF EVIDENCE IN TRIALS AT COMMON LAW," "A POCKET CODE OF EVIDENCE," ETC.

BOSTON
LITTLE, BROWN, AND COMPANY
1913

1913

## A Wigmore chart

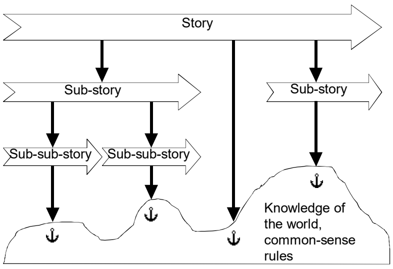


Umilian was accused of murdering Jedrusik.

**KEY LIST**
**Z**: The charge that U killed J.

**8**: Revengeful murderous emotion toward J.
**9**: J's falsely charging U with bigamy, trying to prevent the marriage.
**10**: Letter received by priest stating that U already had a family in the old country.
**11**: Anonymous witnesses to 10.
**12**: J was author of letter (although it was in a fictitious name).
**13**: Anonymous witnesses to 12.
**14**: Letter communicated by priest to U.
**15**: Anonymous witnesses to 14.
**16**: Letter's statements were untrue.
**17**: Anonymous witnesses to 16.
**18**: U's marriage being finally performed, U would not have had a strong feeling of revenge.
**18.1**: Wigmore does not tell us what this represents. Maybe it is witness testimony.
**18(2)**: The witness is biased.
**19**: U and J remaining in daily contact, wound must have rankled.
**19.1**: Witness to daily contact.
**19(2)**: The witness is a discharged employee of U.
**21**: Anonymous witness to 19(2).
**19d**: Discharged employees are apt to have an emotion of hostility.
**20**: Wife remaining there, jealousy between U and J probably continued.
**20.1**: Witness to wife remaining.
**20(2)**: The witness' strong demeanour of bias while on the stand.

## Scenarios



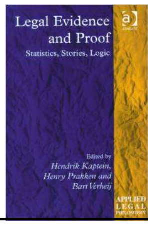

Crombag, H.F.M., van Koppen, P.J., and Wagenaar, W.A. (1992, 1994), *Dubieuze Zaken: De Psychologie van Strafrechtelijk Bewijs. (Dubious Cases. The Psychology of Criminal Evidence.)* (Amsterdam: Contact).

## Three normative frameworks

**Probabilities**
E.g., follow the calculus, don't transpose conditional probabilities, don't forget prior probabilities

**Argumentation**
E.g., take all arguments into account, both pro and con, assess strength and relative strength, avoid fallacies

**Scenarios**
E.g., consider alternative scenarios, assess plausibility, consider which evidence is explained or contradicted




Goal:
promote rational handling of evidence in courts

Tool needed:
a normative framework
**shared** between experts and factfinders

## The two faces of Artificial Intelligence

| | |
|---|---|
| Expert systems | Adaptive systems |
| Business rules | Machine learning |
| Open data | Big data |
| IBM's Deep Blue | IBM's Watson |
| Complex structure | Adaptive structure |
| | |
| **Knowledge tech** | **Data tech** |
| Foundation: | Foundation: |
| logic | probability theory |

# Designing and Understanding Forensic Bayesian Networks with Arguments and Scenarios

www.ai.rug.nl/~verheij/nwofs/

Netherlands Genomics Initiative

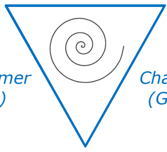
university of groningen

Universiteit Utrecht

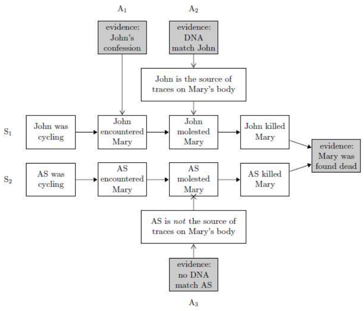
Arguments

Scenarios

Probabilities




## Arguments and scenarios



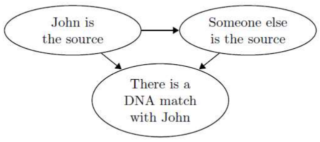




Figure 5: A Bayesian network structure with dependency relations

**John is the source**

| | |
|---|---|
| John is the source = false | 8000/8001 |
| John is the source = true | 1/8001 |

**Someone else is the source**

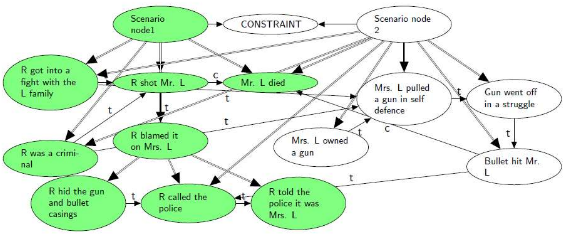
| John is the source | false | true |
|---|---|---|
| Someone else is the source = false | 0 | 1 |
| Someone else is the source = true | 1 | 0 |

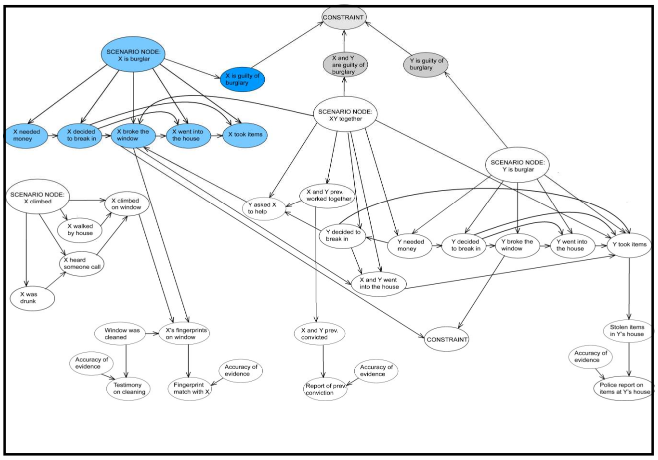
**DNA match**

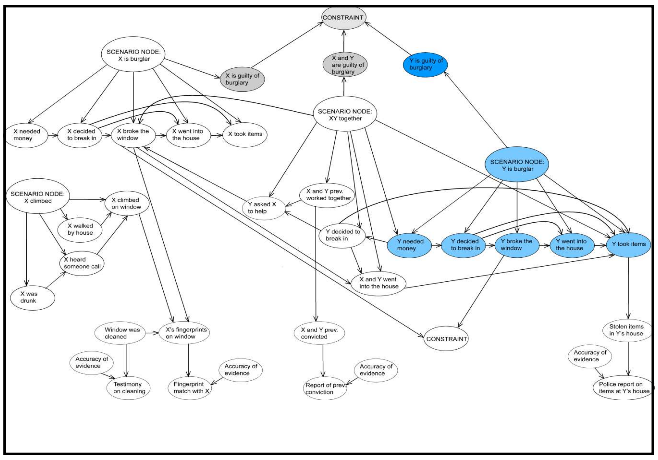
| John is the source | false | | true | |
|---|---|---|---|---|
| Someone else | false | true | false | true |
| DNA match = false | 0.5* | $1 - 0.66 \cdot 10^{-21}$ | 0 | 0.5* |
| DNA match = true | 0.5* | $0.66 \cdot 10^{-21}$ | 1 | 0.5* |

## Scenarios and probabilities

Each scenario is a coherent cluster






## Arguments and probabilities

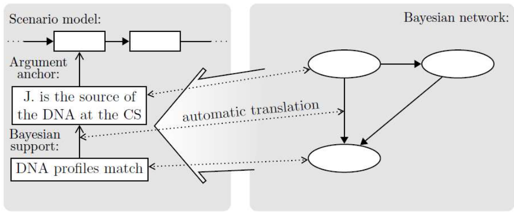
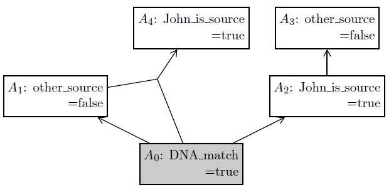



Figure 12: A high-level description of the Bayesian network-Argument translation approach.

## Arguments and probabilities



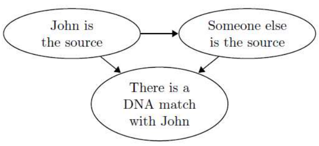

## Project outcomes

**Scenarios**

- **Design method** A method to manually design a Bayesian Network incorporating hypothetical scenarios and the available evidence (Vlek et al 2014)
- **Explanation method** A method to generate a structured explanatory text of a Bayesian Network modeled according to this method (Vlek et al 2016)
- **Case study** A case study testing the design method (Vlek et al 2014)

**Arguments**

- **Explanation method** An algorithm to extract argumentative information from a Bayesian Network modeling hypotheses and evidence (Timmer et al 2015a)
- **Design method** A method to incorporate argument schemes in a Bayesian Network (Timmer et al 2015b)

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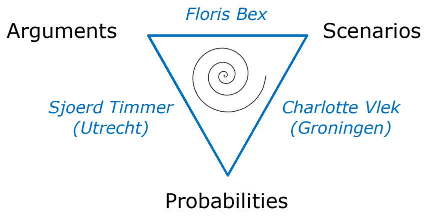
| DNA match = true | 0.5* | $0.66 \cdot 10^{-21}$ | 1 | 0.5* |

## Well-known issues with Bayesian Networks

- A Bayesian Network model typically requires many more numbers than are reasonably available
- The graph model underlying a Bayesian Network is formally well-defined, but there is the risk of misinterpretation, for instance unwarranted causal interpretation



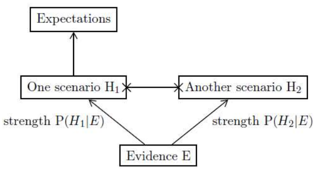

## Idea

Develop a formal theory that connects

presumptive arguments
coherent hypotheses
degrees of uncertainty

using classical logic and standard probability theory

## Arguments, scenarios and probabilities in standard probability and its underlying classical logic

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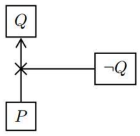
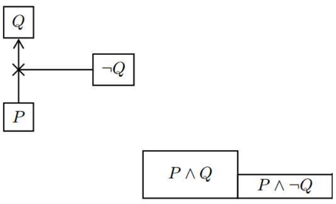
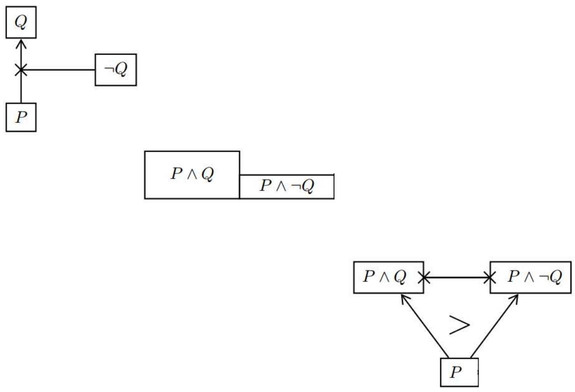


**Definition 1.** A *case model* is a pair $(C, \geq)$ with finite $C \subseteq L$, such that the following hold, for all $\varphi$, $\psi$ and $\chi \in C$:

1. $\not\models \neg\varphi$;
2. If $\not\models \varphi \leftrightarrow \psi$, then $\models \neg(\varphi \wedge \psi)$;
3. If $\models \varphi \leftrightarrow \psi$, then $\varphi = \psi$;
4. $\varphi \geq \psi$ or $\psi \geq \varphi$ ;
5. If $\varphi \geq \psi$ and $\psi \geq \chi$, then $\varphi \geq \chi$.

**Definition 3.** An *argument* is a pair $(\varphi, \psi)$ with $\varphi$ and $\psi \in L$. The sentence $\varphi$ expresses the argument's premises, the sentence $\psi$ its conclusions, and the sentence $\varphi \wedge \psi$ the *case made* by the argument. Generalizing, a sentence $\chi \in L$ is a *premise* of the argument when $\varphi \models \chi$, a *conclusion* when $\psi \models \chi$, and a *position* in the case made by the argument when $\varphi \wedge \psi \models \chi$. An argument $(\varphi, \psi)$ is *(properly) presumptive* when $\varphi \not\models \psi$; otherwise *non-presumptive*. An argument $(\varphi, \psi)$ is an *assumption* when $\models \varphi$, i.e., when its premises are logically tautologous.

# Kinds of argument validity

## Coherent arguments

$(C, \geq) \models (\varphi, \psi)$ if and only if $\exists \omega \in C$: $\omega \models \varphi \wedge \psi$.

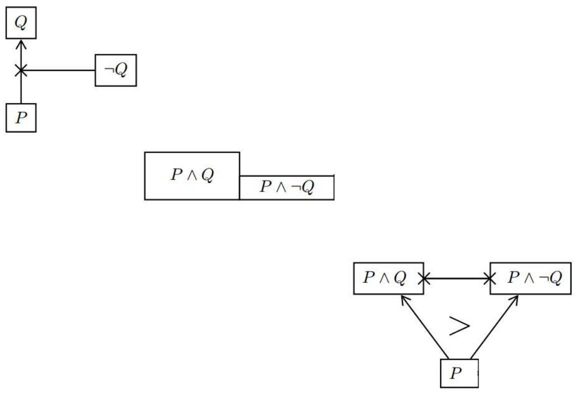
## Conclusive arguments

$(C, \geq) \models \varphi \Rightarrow \psi$ if and only if $\exists \omega \in C$: $\omega \models \varphi \wedge \psi$ and $\forall \omega \in C$: if $\omega \models \varphi$, then $\omega \models \varphi \wedge \psi$.

## Presumptively valid arguments

$(C, \geq) \models \varphi \rightsquigarrow \psi$ if and only if $\exists \omega \in C$:

1. $\omega \models \varphi \wedge \psi$; and
2. $\forall \omega' \in C$ : if $\omega' \models \varphi$, then $\omega \geq \omega'$.

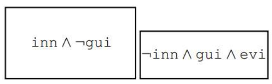



**Proposition 8** *Let $(C, \geq)$ be a case model. For all $\varphi$, $\psi$ and $\chi \in L$:*

*(LE)* If $\varphi \mathrel{|\!\sim} \psi$, $\models \varphi \leftrightarrow \varphi'$ and $\models \psi \leftrightarrow \psi'$, then $\varphi' \mathrel{|\!\sim} \psi'$.
*(Cons)* $\varphi \mathrel{|\!\not\sim} \bot$.
*(Ant)* If $\varphi \mathrel{|\!\sim} \psi$, then $\varphi \mathrel{|\!\sim} \varphi \wedge \psi$.
*(RW)* If $\varphi \mathrel{|\!\sim} \psi \wedge \chi$, then $\varphi \mathrel{|\!\sim} \psi$.
*(CCM)* If $\varphi \mathrel{|\!\sim} \psi \wedge \chi$, then $\varphi \wedge \psi \mathrel{|\!\sim} \chi$.
*(CCT)* If $\varphi \mathrel{|\!\sim} \psi$ and $\varphi \wedge \psi \mathrel{|\!\sim} \chi$, then $\varphi \mathrel{|\!\sim} \psi \wedge \chi$.

**Proposition 13** *Let $(C, \geq)$ be a case model, and $L^* \subseteq L$ the closure of $C$ under negation, conjunction and logical equivalence. Writing $\mathrel{|\!\sim}^*$ for the restriction of $\mathrel{|\!\sim}$ to $L^*$, we have, for all $\varphi$, $\psi$ and $\chi \in L^*$:*

*(Coh)* $\varphi \mathrel{|\!\sim} \varphi$ if and only if $\exists \varphi^* \in L^*$ with $\varphi^* \not\models \bot$ and $\varphi^* \models \varphi$;
*(Ch)* If $\varphi \mathrel{|\!\sim}^* \varphi$ and $\psi \mathrel{|\!\sim}^* \psi$, then $\varphi \vee \psi \mathrel{|\!\sim}^* \neg\varphi \wedge \psi$ or $\varphi \vee \psi \mathrel{|\!\sim}^* \varphi \wedge \psi$ or $\varphi \vee \psi \mathrel{|\!\sim}^* \varphi \wedge \neg\psi$;
*(OC)* If $\varphi \vee \psi \mathrel{|\!\sim}^* \varphi$ and $\psi \vee \chi \mathrel{|\!\sim}^* \psi$, then $\varphi \vee \chi \mathrel{|\!\sim}^* \varphi$.




Two cases, one preferred over the other

| | |
|---|---|
| (inn, ¬gui) | properly presumptive |
| | presumptively valid |
| | conclusive |
| (⊤, inn) | assumption |
| | presumptively valid |
| | properly defeasible |
| (evi, gui) | presumptively valid |
| | conclusive |

inn The suspect is innocent
gui The suspect is guilty
evi There is sufficient evidence for the suspect's guilt

**Definition 14** *Let* $(C, \geq)$ *be a case model, and* $(\varphi, \psi)$ *a presumptively valid argument. Then circumstances* $\chi$ *are* undercutting *when* $(\varphi \wedge \chi, \psi)$ *is not presumptively valid. Undercutting circumstances are* rebutting *when* $(\varphi \wedge \chi, \neg\psi)$ *is presumptively valid; otherwise they are* properly undercutting. *Undercutting circumstances are* excluding *when* $(\varphi \wedge \chi, \psi)$ *is not coherent.*

$\boxed{\texttt{inn} \wedge \neg\texttt{gui}}$ $\boxed{\neg\texttt{inn} \wedge \texttt{gui} \wedge \texttt{evi}}$

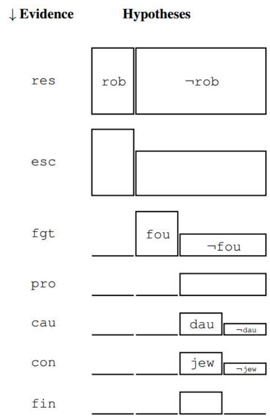
Two cases, one preferred over the other

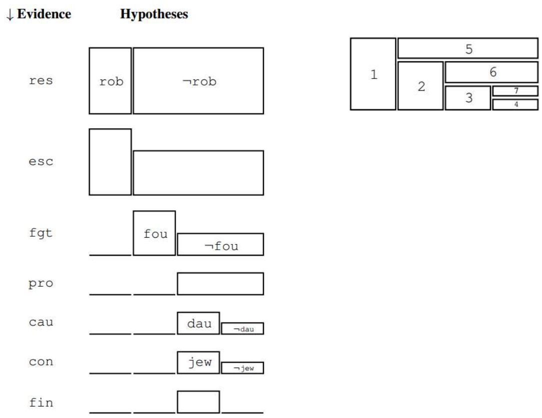
`evi` for (`T`, `inn`) undercutting
rebutting
excluding

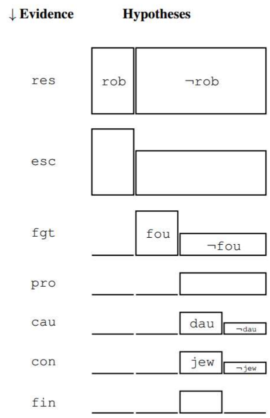
| | |
|---|---|
| `inn` | The suspect is innocent |
| `gui` | The suspect is guilty |
| `evi` | There is sufficient evidence for the suspect's guilt |

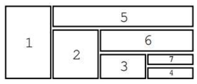





(res ∧ esc, rob)
presumptively valid, not conclusive
(res ∧ esc, ¬rob)
coherent, not presumptively valid
(res ∧ esc ∧ fgt, rob)
incoherent
(dau, jew)
conclusive
(res ∧ … ∧ fin, dau)
conclusive

## Conclusion

- A formal theory has been proposed that connects presumptive arguments, coherent hypotheses and degrees of uncertainty using classical logic and standard probability theory.
- There is no need to specify more numbers than are available. The proposal comes with formal definitions of argument validity.
- The formalism uses ideas from argumentation, rule-based reasoning and case-based reasoning.

## Integrating the three perspectives

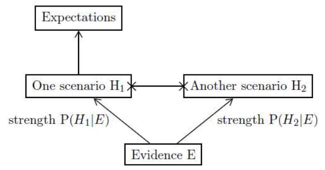
- They are just three different ways of speaking about the same things, each emphasising some specific aspects
- There is no need to idolize any
- There is no need to demonize any

Arguments
for hypothesis development and testing

Scenarios
for coherent, complex hypotheses

Probabilities
for well-founded uncertainty

## Arguments, scenarios and probabilities





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What about Toulmin, Pollock, Dung, nonmonotonic logic?
Claim: more can be done with standard tools than some thought

What about case-based and rule-based reasonin?
Claim: more can be done with standard tools than some thought

What about a choice between arguments, scenarios, probabilities?
Claim: there is less reason to choose than some thought

What next?
- Work on argumentation technology
- Work on formal, computational and empirical foundation
- Work on the grounding of complex knowledge

## The two faces of Artificial Intelligence

| | |
|---|---|
| Expert systems | Adaptive systems |
| Business rules | Machine learning |
| Open data | Big data |
| IBM’s Deep Blue | IBM’s Watson |
| Complex structure | Adaptive structure |
| **Knowledge tech** | **Data tech** |
| Foundation: logic | Foundation: probability theory |

***Far apart***

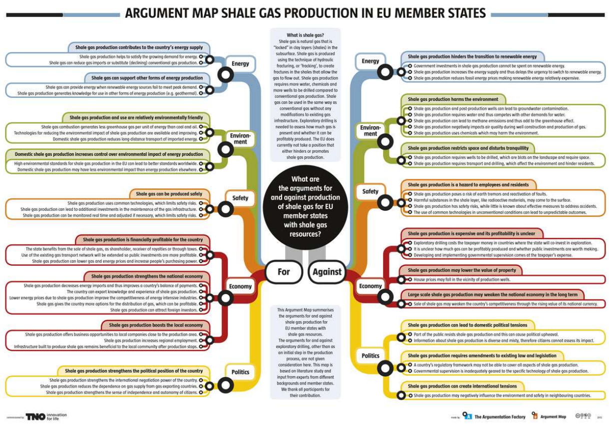
## What is needed to close the gap?

- **Integrating perspective** on adaptive knowledge grounded in data
- **Formal foundations** for the integrating perspective
- **Computational tools** supporting the discovery, testing and selection of adaptive knowledge grounded in data

***Argumentation technology***

# The challenge

**Develop grounded models of our complex world**




Realizing the **dreams** and
countering the **concerns**
connected to AI require the same innovation:

the development of **argumentation technology**

**Lecture 1: Argumentation and Artificial Intelligence**
An overview is given of how ideas from argumentation theory have been picked up in artificial intelligence. The focus will be more on general ideas and approaches, and less on formal detail.

**Lecture 2: Argumentation in the law: case-based and rule-based**
In the law, argumentation is central. Two kinds of argument-based reasoning are prominent. In the first kind, precedent cases are followed by analogy; in the second, rules are applied when their conditions are fulfilled.

**Lecture 3: Argumentation and evidence: Combining arguments, scenarios and probabilities**
For deciding about the facts in a criminal case, different normative frameworks aiming at the prevention of erroneous reasoning have been proposed: arguments, scenarios and probabilities. The normative frameworks are characterized and their relations investigated, for instance by discussing how arguments and scenarios can be studied using Bayesian networks.

**http://www.ai.rug.nl/~verheij/ssa2016/**

# Further reading


**Argumentation in Artificial Intelligence**
Chapter 11 in
van Eemeren, F.H., Garssen, B., Krabbe, E.C.W., Snoeck Henkemans, A.F., Verheij, B., & Wagemans, J.H.M. (2014). *Handbook of Argumentation Theory*. Dordrecht: Springer.

**Project**
Verheij, B., Bex, F.J., Timmer, S., Vlek, C., Meyer, J.J., Renooij, S., & Prakken, H. (2016). Arguments, Scenarios and Probabilities: Connections Between Three Normative Frameworks for Evidential Reasoning. *Law, Probability & Risk* 15 (1), 35-70.

**Integrated perspective**
Verheij, B. (2014). To Catch a Thief With and Without Numbers: Arguments, Scenarios and Probabilities in Evidential Reasoning. *Law, Probability & Risk* 13, 307-325.
http://dx.doi.org/10.1093/lpr/mgu011

Verheij, B. (2016). Correct Grounded Reasoning with Presumptive Arguments. *15th European Conference on Logics in Artificial Intelligence, JELIA 2016.*

## Logical Reasoning as Argumentation,

### Or: How Lessons from the Law Are Changing Artificial Intelligence

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- B. Verheij, ‘Argumentation and rules with exceptions’, in *Computational Models of Argument: Proceedings of COMMA 2010, Desenzano del Garda, Italy, September 8-10, 2010*, eds., B. Baroni, F. Cerutti, M. Giacomin, and G. R. Simari, 455–462, IOS Press, Amsterdam, (2010).
- B. Verheij, ‘Jumping to conclusions. a logico-probabilistic foundation for defeasible rule-based arguments’, in *13th European Conference on Logics in Artificial Intelligence, JELIA 2012. Toulouse, France, September 2012. Proceedings (LNAI 7519)*, eds., L. Farinas del Cerro, A. Herzig, and J. Mengin, 411–423, Springer, Berlin, (2012).
- B. Verheij, ‘Arguments and their strength: Revisiting Pollock’s antiprobabilistic starting points’, in *Computational Models of Argument. Proceedings of COMMA 2014*, eds., S. Parsons, N. Oren, C. Reed, and F. Cerutti, 433–444, IOS Press, Amsterdam, (2014).
- B. Verheij, ‘To catch a thief with and without numbers: Arguments, scenarios and probabilities in evidential reasoning’, *Law, Probability and Risk*, **13**, 307–325, (2014).
- B. Verheij, F. J. Bex, S. T. Timmer, C. S. Vlek, J. J. Meyer, S. Renooij, and H. Prakken, ‘Arguments, scenarios and probabilities: Connections between three normative frameworks for evidential reasoning’, *Law, Probability and Risk*, **15**, 35–70, (2016).
- B. Verheij. ‘Correct Grounded Reasoning with Presumptive Arguments’, in *15th European Conference on Logics in Artificial Intelligence, JELIA 2016,* (2016).