Semantic web policy languages

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Main goals of this talk

- Introducing semantic web policies based on
  - Decription logics
  - Logic programs
- Comparing semantic web policy languages w.r.t.
  - Expressiveness
  - Complexity
  - Maturity
- Show the need for a formal clean-up of a savagely proliferating area

Privacy and confidentiality policies

- In their simplest form constrain
  - Access to information / knowledge (server's view)
  - Disclosure of information / knowledge (user's view)
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  - The nature of the current transaction / operation
  - Contextual properties (time, place, etc.)
- Expressiveness needs for policy languages
  - Complex conditions
  - Over all sorts of knowledge and data

Policies for semantic web & social networks

- Access control & information disclosure depend on **metadata** such as:
  - User profiles
  - Relationships between users
    - Friendship
    - Reputation
  - Content classification
  - etc...
- Such metadata are encoded with KR languages
  - RDF / Description logics
  - Rules
  - In perspective, combinations thereof

Policies for enterprise data

- Recent initiatives aimed at applying the LOD paradigm to organization data / knowledge management
- Increasing use of RDF and OWL

Policies *languages* for semantic web, social networks etc

- KR languages are a natural choice
  - Uniform representation of usage constraints & support knowledge
- Existing DL-based proposals
  - KAoS
  - Rei
- Existing rule-based proposal
  - Cassandra (Datalog + constraints)
  - RT family
  - PeerTrust (distributed Datalog)
  - TrustBuilder
  - Protune (Datalog + O.O. syntactic sugar + metalanguage)

Orienteering

- Need for a formal framework for assessing and comparing these policy languages and more
- Exploiting multidisciplinary expertise to highlight strengths and (sometimes serious) weaknesses

Outline

- Description logics (DLs): basics
  - I assume that the basics on logic programs are known
- Some considerations on expressiveness
- Some considerations on reasoning mechanisms
- Conclusions & further needs

- No time for usability, usage control, disclosure minimization and other evolving topics

Description logics

Syntax

- First-order logic in disguise
  - Hidden logical variables
  - 2-variable fragment + slight extensions
    - Transitivity
    - Counting (generalized quantifiers)
  - Decidable
- Second-order features
  - Transitive closures

Syntax

Inclusions (constitute *TBoxes*)

- Human $\sqsubseteq$ Animal
  - Humans are animals
  - $\forall x.$ Human(x) $\rightarrow$ Animal(x)
- Animal $\sqsubseteq$ $\exists$ parent.Animal
  - Animals have a parent that is an animal
  - $\forall x.$ Human(x) $\rightarrow \exists$ y. parent(x,y) $\wedge$ Animal(y)
- {Piero} $\sqsubseteq$ Professor $\sqcap$ Italian
  - Piero is a professor *and* italian

Syntax

Assertions (constitute *ABoxes*)

- Human(John)
- ∃parent.Animal(Fido)
- Professor ⊓ Italian(Piero)
- parent(Piero,Paolo)

Syntax

- Further constructs include:
  - All boolean operators over concepts (like Human) and roles (like parent)
  - Inverse roles
  - Transitive role closure
  - Generalized quantifiers
    - ($\geq n$ child)
    - ($\leq n$ child)
  - …

Reasoning

- Subsumption
  - KB $\models$ C $\sqsubseteq$ D
- Instance checking
  - KB $\models$ C(x)
- Concept consistency
  - Is there a model where C is nonempty?
- They can be reduced to each other in sufficiently rich DLs

Standards

- OWL and RDF provide XML syntax for DL inclusions and assertions
  - With some restrictions

Description logics as policy languages

Approach 1

- Permission as roles
- read(Ann,'/tmp')
  - Ann can read /tmp
  - to be *asserted* (policy authoring) or *checked* (access control)
- Friends $\sqsubseteq$ $\exists$ download.Pictures
  - Every friend can download some picture
- Friends $\sqsubseteq$ $\forall$ ¬download.¬Pictures
  - Friends can download all pictures
- ($\leq$ 5 update.Proj1_Files)(Bob)
  - Bob can update at most 5 objects in Proj1_Files

Approach 2

- Policies as sets of permitted/denied requests
- Policy *P* represented by *Permit-P* and *Deny-P*
- $\exists$subj.Staff $\sqcap$ $\exists$op.{read,write} $\sqcap$ $\exists$obj.Internal $\sqsubseteq$ Permit-P
- $\exists$subj.$\neg$Staff $\sqcap$ $\exists$obj.Internal $\sqsubseteq$ Deny-P
- Access control as subsumption:
  - Does CurrentReq $\sqsubseteq$ Permit-P hold?

Sample policy *rules*

FAF (Flexible Authorization Framework)

- cando(staff, +read, '/src')
- cando(mary, -read, '/src')
- dercando(Subj, Op, Obj) :-
  member(Subj,Grp), cando(Grp, Op, Obj)
- do(Subj, +Op, Obj) :-
  dercando(Subj, +Op, Obj),
  not dercando(Subj, -Op, Obj)
- do(Subj, -Op, Obj) :-
  dercando(Subj, -Op, Obj)

FAF (Flexible Authorization Framework)

- FAF can encode all the major policy models
  - Mandatory
  - Role-based
  - Chinese Walls
  - …
- All the major default policies
  - Open, closed, and mixed
- And all the major conflict resolution policies
  - Denials take precedence
  - Most specific takes precedence
  - Most specific along a path takes precedence
  - Prioritized authorizations (including Orion's strong/weak)

Policy language expressiveness

What is a policy in the simplest case?

- In abstract terms, just a mapping...
  - From *contexts*
    - Database tables, RDF triples, XML documents...
    - Essentially, finite structures (potentially large!)
  - To *authorizations*,
  - that can be represented in relational forms
    - Access control matrices *et similia*
    - <subject, object, action,...> tuples

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- Essentially a **query**

Descriptive complexity

- A well understood way of measuring the expressiveness of query languages
  - A good candidate for policy languages ...
- Expressiveness of a language:
  - The class of mappings it can express
  - It frequently coincides with a complexity class
  - Example:
    - if the descriptive complexity of L1 is PSPACE
    - and the descriptive complexity of L2 is EXPTIME
    - then L1 is “less expressive” than L2

Descriptive complexity

- Many results for rule-based languages
  - When the context is a set of facts...
- Missing results:
  - Descriptive complexity of DLs
- We can't use descriptive complexity to compare DL-based policy languages right away
  - A nice motivation for further work on Dls...
- However some preliminary observations are possible

Easy observations on DL

- DL typically enjoy tree- or forest-model properties
  - Every consistent theory has a forest-shaped model
- Therefore DL cannot uniformly express cyclic patterns
  - There exist simple PTIME-computable policies that cannot be expressed with DL
  - We will make an effort to identify *practically relevant* such policies
- Difficulties also with conditions involving 3 or more individuals
  - Basic DLs are fragments of 2-variable logic
  - Only partially relaxed by additional constructs such as generalized quantifiers

Simple policies for complex DL

- Allow access if:
  - medical_record(R), patient(R,P), cures(Doctor,P)
  - user(U), picture_of(Pic,Owner), friend(Owner,U)
  - id(ID), credit_card(CC), owner(ID,User), owner(CC,User)

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- Ternary formulas! Partial workaround for DLs:
  - Reification: represent context as an individual with 3 attributes
  - $\exists$id $\sqcap$ $\exists$credit_card $\sqcap$ $\exists$user

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=

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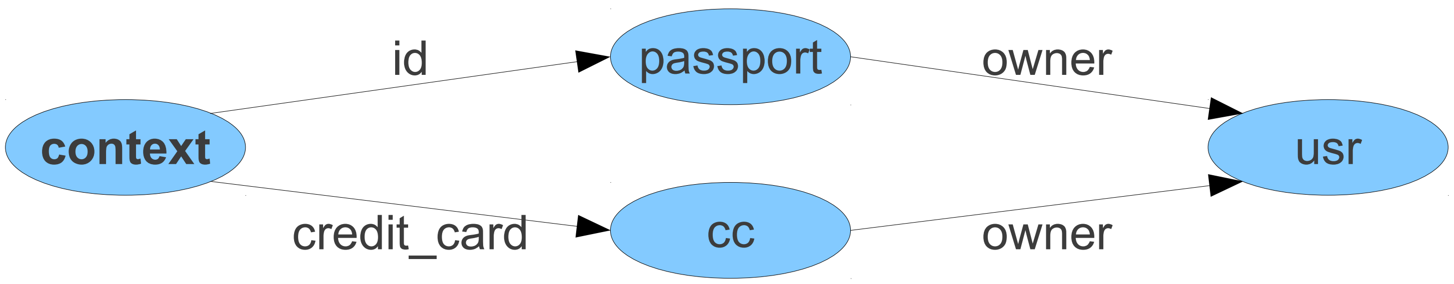
  - $\mathcal{ALC}$, $\mathcal{SHIQ}$: No way: tree/forest-model property



KAoS's approach

- Role-value maps + role composition [CCGRID'05]

  $\exists id \sqcap \exists credit\_card \sqcap \exists user \sqcap id \circ owner = credit\_card \circ owner$

KAoS's approach

- Role-value maps + role composition [CCGRID'05]

  $\exists id \sqcap \exists credit\_card \sqcap \exists user \sqcap id \circ owner = credit\_card \circ owner$
- Problem: reasoning becomes undecidable
  - Concept subsumption in $\mathcal{AL}$ with role-value maps and role composition is undecidable (!)
  - cf. survey in the Handbook of Description Logics, Ch. 5
- Possible consequences:
  - Access control does not terminate
  - Unauthorized access
  - Denial of service (improperly denied access)
  - Some policies are "illegal" (which ones?)
- KAoS's solution: not specified?!?

Datalog policy languages

- A minor difficulty: Only stratified negation is allowed
  - Multiple models undesirable (access control policies are supposed to be unambiguous)
  - Stratified neg. not enough to express all PTIME policies *but*
  - An ordering on the domain is enough (like Prolog's @>) to express *all policies in PTIME*

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  - An ordering on the domain is enough (like Prolog's @>) to express *all policies in PTIME*
- Further restrictions on policy languages
  - Policies should be monotonic w.r.t. the digital credentials disclosed (which are part of the context)
  - Rationale: no reliable way to check whether a user does *not* have a credential
  - Open question: can restricted Datalog-based policy languages express *all* credential-monotonic policies?

Summary on expressiveness

- Datalog-based languages are much less problematic from the expressiveness point of view
  - well-suited to popular reference applications
  - no expressiveness gaps

Reasoning tasks

Reasoning tasks

- Deduction
  - e.g.: is *Auth* entailed by *Policy* + *Context* ?
- Highly mature, both in DLs and rule languages
  - Tableaux, optimizations & heuristics
  - Abstract machines, intelligent grounding, ...

Reasoning tasks

- Deduction

however, more is needed

- Nonmonotonic reasoning
- Abduction
- Policy comparison (query containment)

Reasoning tasks: purposes (I)

- Deduction: access control
  - is authorization *A* entailed by policy *P* ?
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  - is authorization *A* entailed by policy *P*?
- Nonmonotonic reasoning: default decisions
  - open/closed policies
  - inheritance *with exceptions* along subject/object/role hierarchies
  - conflict resolution (e.g. denials/most specific take precedence)
  - Note: all these mechanisms have been independently introduced by researchers on security, not AI guys

Reasoning tasks: purposes (II)

- Abduction: credential selection (trust negotiation)
  - Given authorization *A*, a *Policy*, and a portfolio *P*
  - Find a set of credentials $C \subseteq P$ such that

$$\mathit{Policy} \cup C \models A$$

  - Warning: somebody does not know that this is a *classically sound inference…* [Kagal et al. POLICY 08]

$$\models \mathit{Policy} \wedge C \rightarrow A$$

Reasoning tasks: purposes (III)

- Policy comparison
  - does P1 grant at most the same authorizations as P2
  - in *all contexts* ?

useful for

- P3P-like compliance
  - is *X*'s policy compatible with Bob's privacy preferences?
- Validation
  - does the last update restrict/enlarge the policy?

Reasoning mechanisms: maturity

Reasoning mechanisms: maturity

- Nonmonotonic reasoning
  - Highly engineered and optimized implementations for rule languages / LP / ASP (negation as failure)
    - and policy models such as FAF (stratified LP+methodology)
  - Only theoretical results for description logics
    - High complexity: up to $\text{NexpTime}^{\text{NP}}$ and 3ExpTime
    - More practical approaches are still work in progress:
    - DL-lite, $\mathcal{EL}$ [B., Faella, Sauro IJCAI'09, ISWC'10, IJCAI'11]
    - No implementations

Reasoning mechanisms: maturity

- Abduction
  - Well-established approaches for logic programming
    - Starting with [Eshghi ICLP'88]
    - Several systems exist: ACLP, A-system, CIFF, SCIFF, ABDUAL, ProLogICA, and ASP-based implementations
  - Relatively recent approaches for DLs
    - [Di Noia et al.IJCAI'03] based on concept length / maximality w.r.t. subsumption / number of conjuncts
    - Tableaux algorithm in [Colucci et al. DL'04]
    - More general approaches from [Elsenbroich et al. OWLED'06]
    - No direct support from main DL engines yet

Reasoning mechanisms: maturity

- Policy comparison
  - Naturally supported by DLs
    - Subsumption checking
  - More complex for LP, due to general recursion
    - Equivalent to *Datalog query containment*
      - In general undecidable
      - Highly complex in many cases
    - Low-complexity solution in [POLICY'08]: Restricted recursion
      - Still covering inheritance hierarchies, certificate chains
      - Acceptable complexity via:
      - preprocessing + classical algorithm for conjunctive queries
      - Prototypical implementation, positive experimental results

Reasoning mechanisms: maturity

- Policy comparison for LP
  - Experimental evaluation on artificial "worst" cases

Body len \ N rules	10	20	30	40	50	100	150	200	250
10	.05	.08	.17	.27	.39	1.44	3.22	5.57	8.64
20	.12	.33	.60	1.01	1.54	6.14	13.70	23.84	37.33
30	.25	.76	1.61	2.88	4.45	16.99	39.00	68.80	108.17
40	.43	1.59	3.47	6.10	9.32	37.46	84.36	150.98	234.45
50	.76	2.88	6.49	11.50	17.63	70.63	161.92	279.65	442.37

Worst case performance
(in seconds)

Summary and conclusions

Summary and conclusions

- Today
  - Datalog-based policy languages can generally rely on more mature
    - foundations,
    - methodologies,
    - implementations
- This may change in the future,
  - as progress is being made on DL extensions and reasoning
    - nonmonotonic extensions
    - abduction
    - explanations (that we have not touched today)

Summary and conclusions

- Further opportunities for interesting work
  - Incomplete contexts (due to ontologies)
    - Old relevant work on querying disjunctive databases [B. & Eiter TCS 1996]
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    - Enhanced expressiveness
      - Full integration of policies and domain ontologies
    - Inherit problems
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      - Full integration of policies and domain ontologies
    - Inherit problems
      - Undecidable policy comparison
      - Maturity (explanations, abduction, advanced implementations)
  - More results on comparison of rule-based policies
    - Extending the class of comparable policies
    - With practical algorithms

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  - Usage control: say what to do with your information after you disclose it
    - Dynamic aspects, delegation, obligations
      - Multimodal, dynamic logics
    - Enforcement problems (voluntary?)
    - Expressiveness criteria / techniques ?

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    - Enforcement problems (voluntary?)
    - Expressiveness criteria / techniques ?
  - The BIG, BAD open problem: usability
    - Esp. ability of writing correct policies
    - Strong negative experimental results (CMU)
    - Explanation facilities, what-if scenarios, auto documentation (see also ProtuneX)

To be continued...

QUESTIONS/DISCUSSION?

A less formal view of expressiveness

- Easy for DLs, hard for rules:
  - Asserting the existence of anonymous individuals

    $$\exists \mathit{mother}.\mathit{Human}\ (\mathrm{John})$$

  - Rule skolemization makes reasoning undecidable, in general
    - but see *finitary* and *FDNC* logic programs (ASP)
- Easy for rules, hard for DLs:
  - Conditions involving 3 or more individuals
  - Cyclic patterns

because

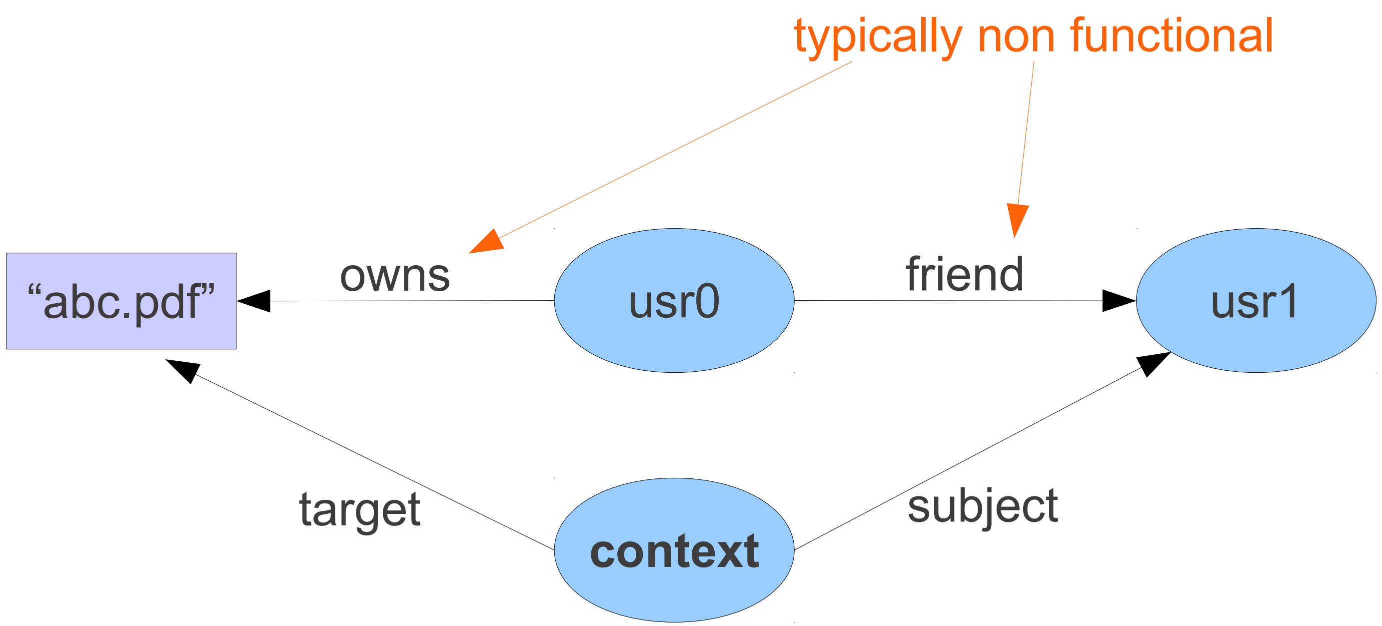
  - DLs are frequently fragments of 2-variable logic
  - and frequently enjoy tree- or forest-model properties

Looking for a solution

- “Features” and concrete domains [Lutz, KR'02]
  - Concrete domains: consist of distinguished nonstructured elements (numbers, etc.)
  - Feature paths: compositions of functional roles, ending with a “concrete role” (whose range is a concrete dom.)
  - $\forall fp_1, fp_2 .=$ similar to role-value map (fp_i are feat.paths)
- Current limitation
  - Decidability results cover inverse and/or nonfunctional roles R only if $fp_1 = R \circ g_1$ and $fp_2 = g_2$, with g_1 and g_2 concrete features

Still unresolved

- Grant access to “abc.pdf” to owner's friends



inverse role

$$target = subject \circ friend^{-} \circ owns$$

Outline

- Expressiveness
- Reasoning
- **Usability**
- Conclusions & further needs

Usability facets

- Formulating policies
- Understanding policies
  - static
- Understanding transaction outcomes
  - dynamic, context dependent
- No assumption on user's background

Usability facets: maturity

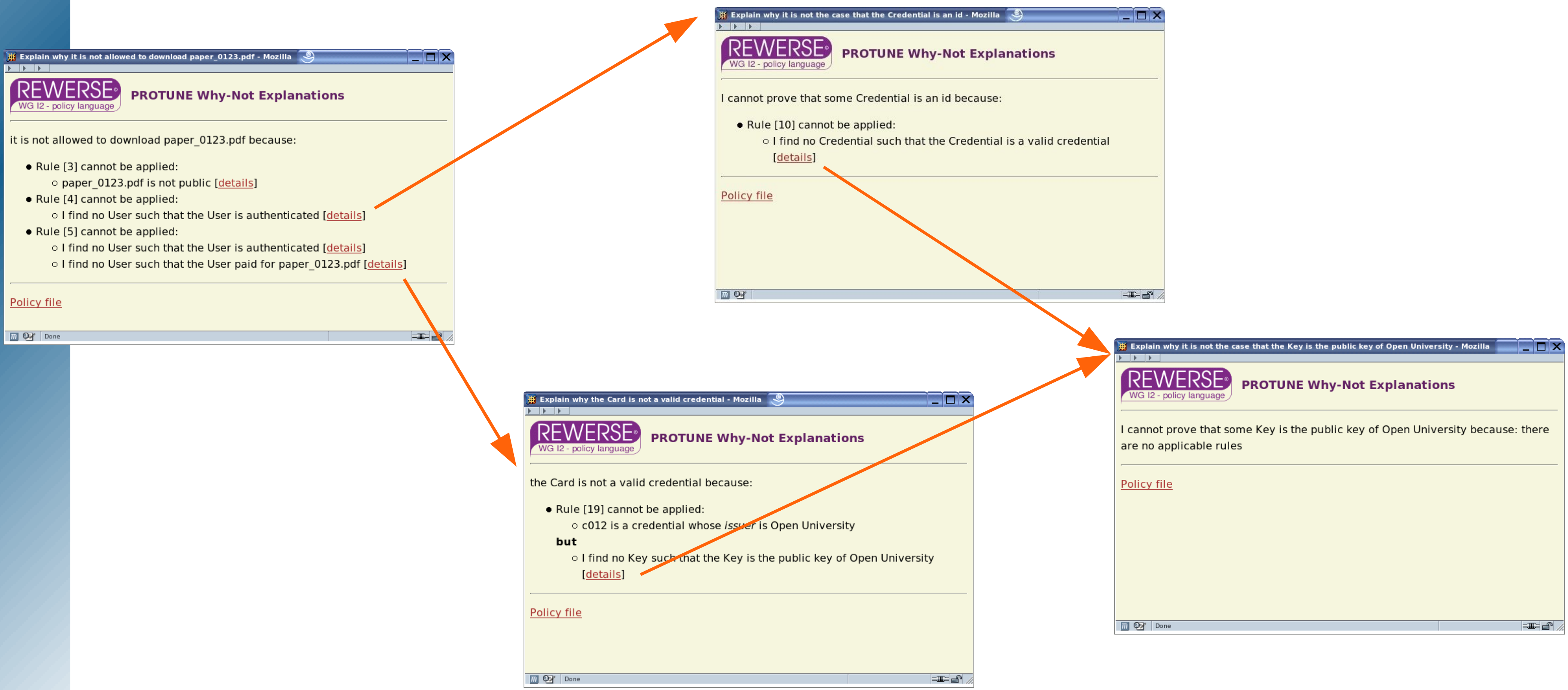
- Formulating policies
  - GUI for simple languages (Cranor and Sadeh @ CMU)
    - and machine learning
  - Controlled Natural Language (mainly Attempto)
  - Same level of (im)maturity for both DL and rules
- Understanding policies
- Understanding transaction outcomes
  - Explanation facilities
  - Discussed in the next slides

Explanation facilities

- History
  - Introduced since pioneering work on expert systems
  - Today: second generation explanation facilities
  - DL approaches started in [McGuinness,Borgida IJCAI'95]
  - However the benchmark is not a generic approach...
- **Protune-X**: second generation explanations
  - [ECAI'06] B., Olmedilla, Peer + Sauro
  - Tailored to trust negotiation to obtain
  - Generic heuristics
  - Deployment ease

Second generation features and Protune-X

- User-oriented navigation (proof tree not enough)
  - Departure from engine behavior / tracing



Second generation features and Protune-X

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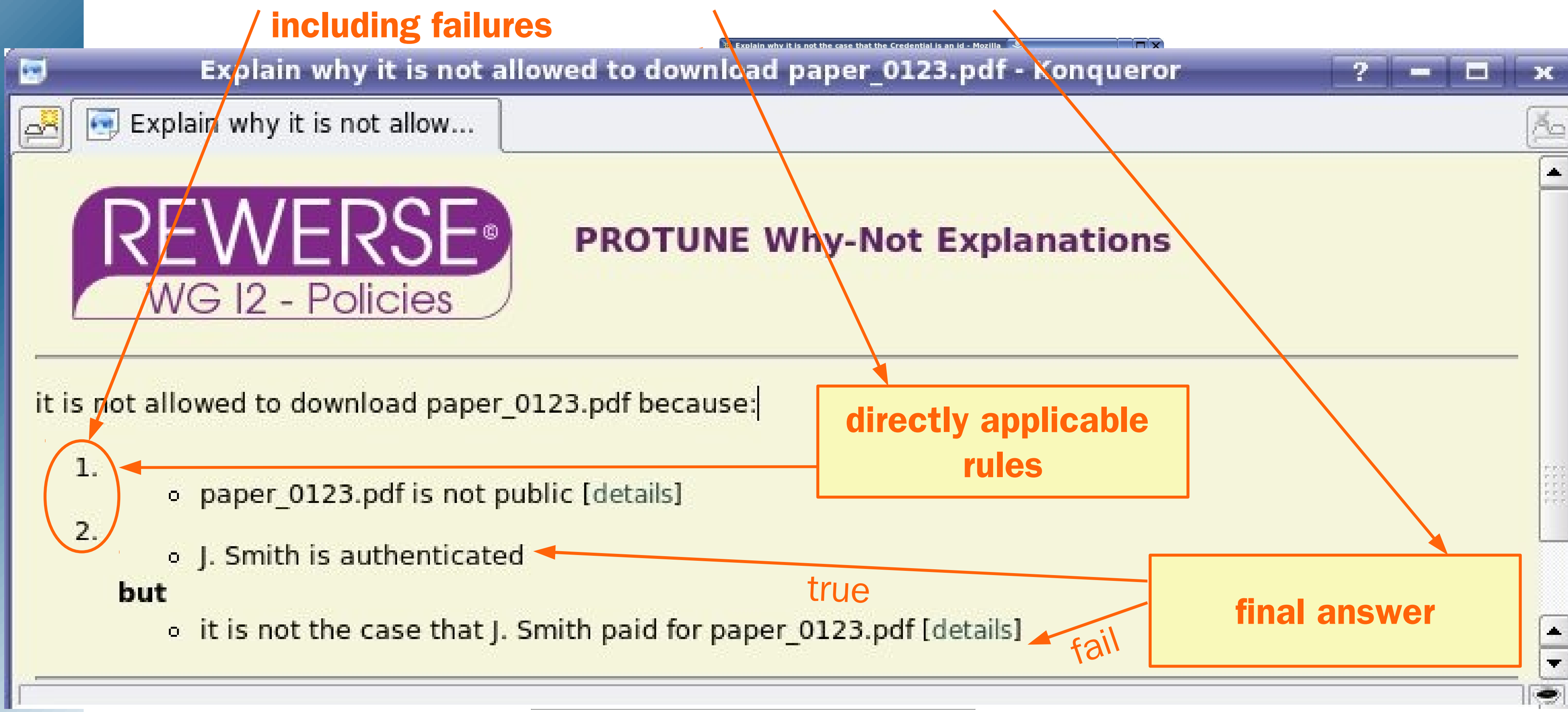
  - All proof attempts, local + global information



Second generation features and Protune-X

- Focus on user's interests (I): removing irrelevant information

2.
- J. Smith is authenticated

but the following conditions cannot be simultaneously satisfied:
- J. Smith subscribed some Subscription [Subscription = basic computer pubs] [Subscription = basic law pubs]
- paper_0123.pdf is available for the Subscription [Subscription = complete computer pubs] [Subscription = gold subscription]

Second generation features and Protune-X

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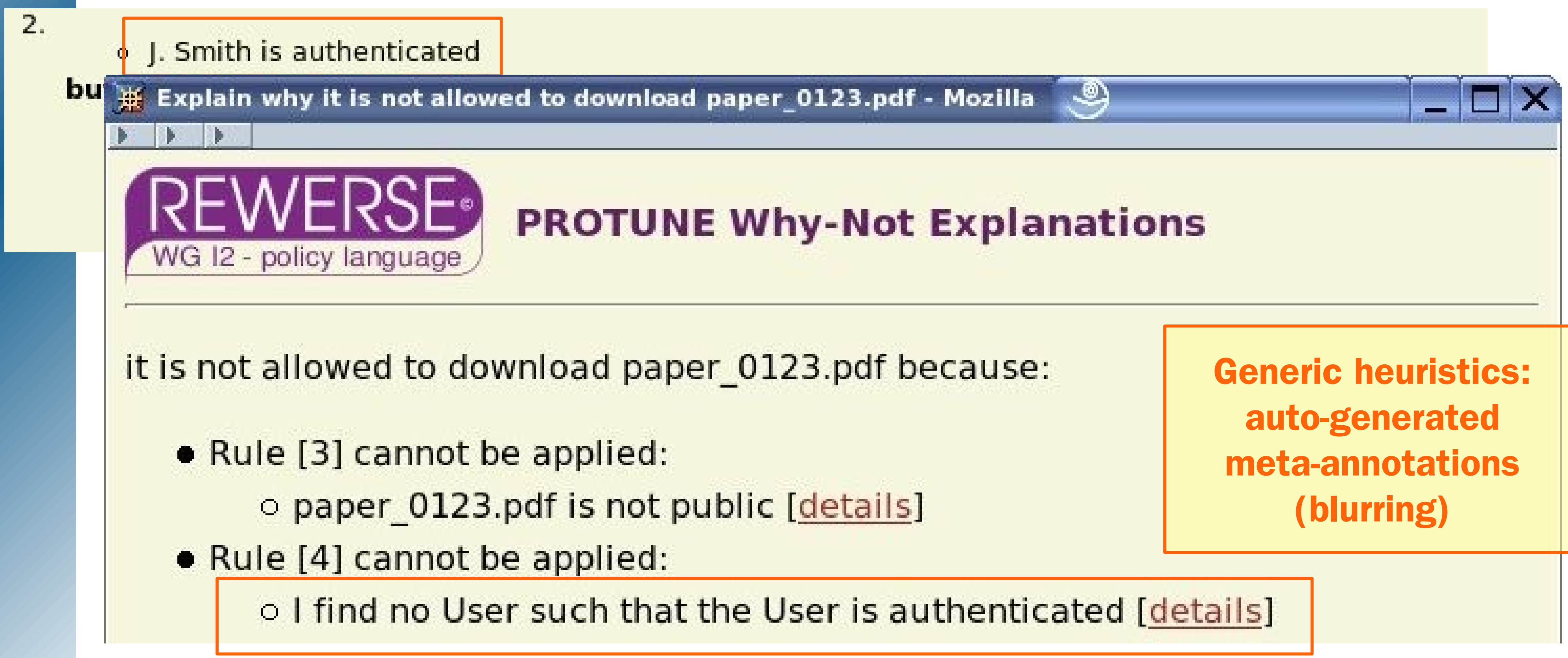
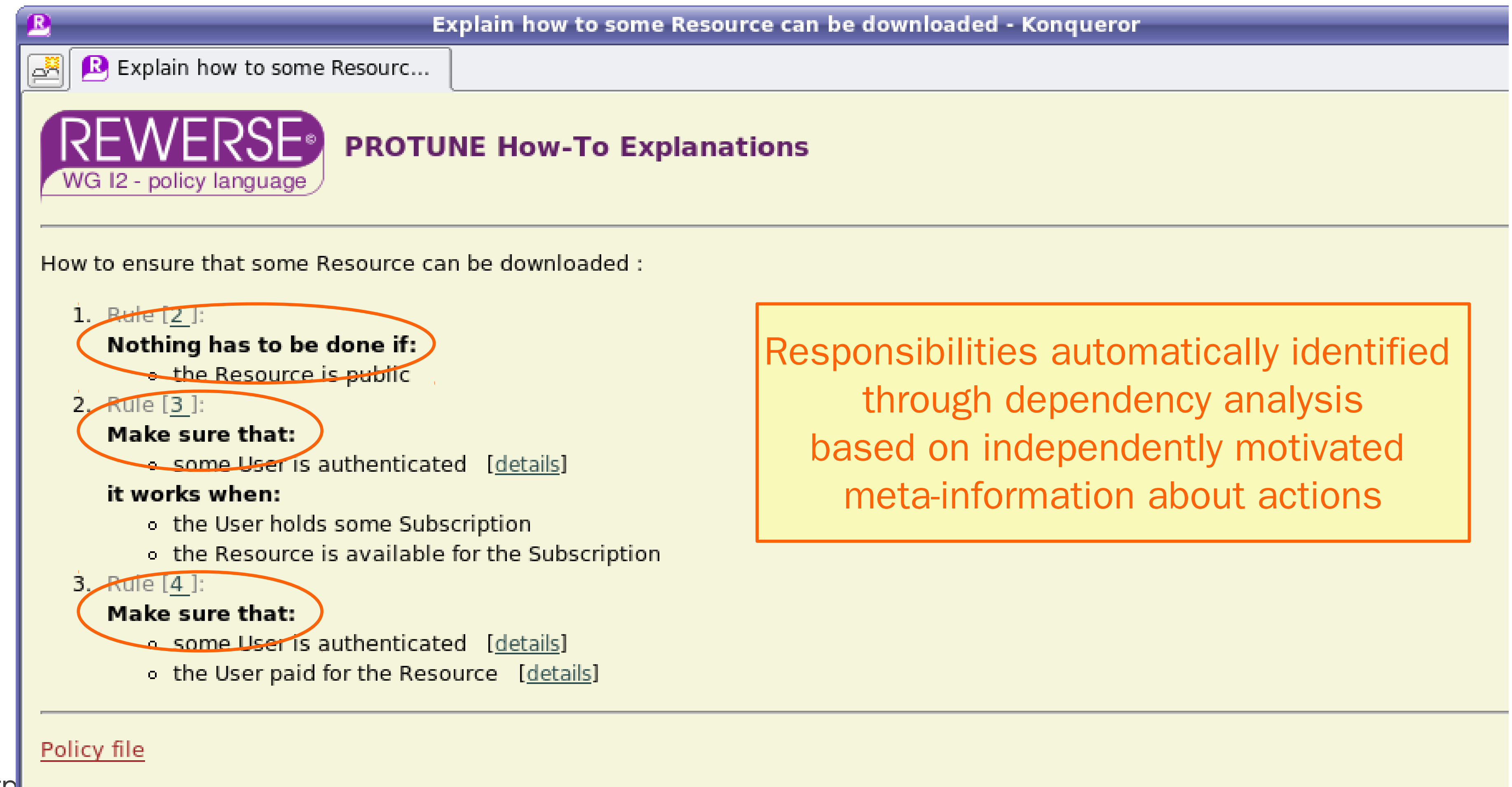


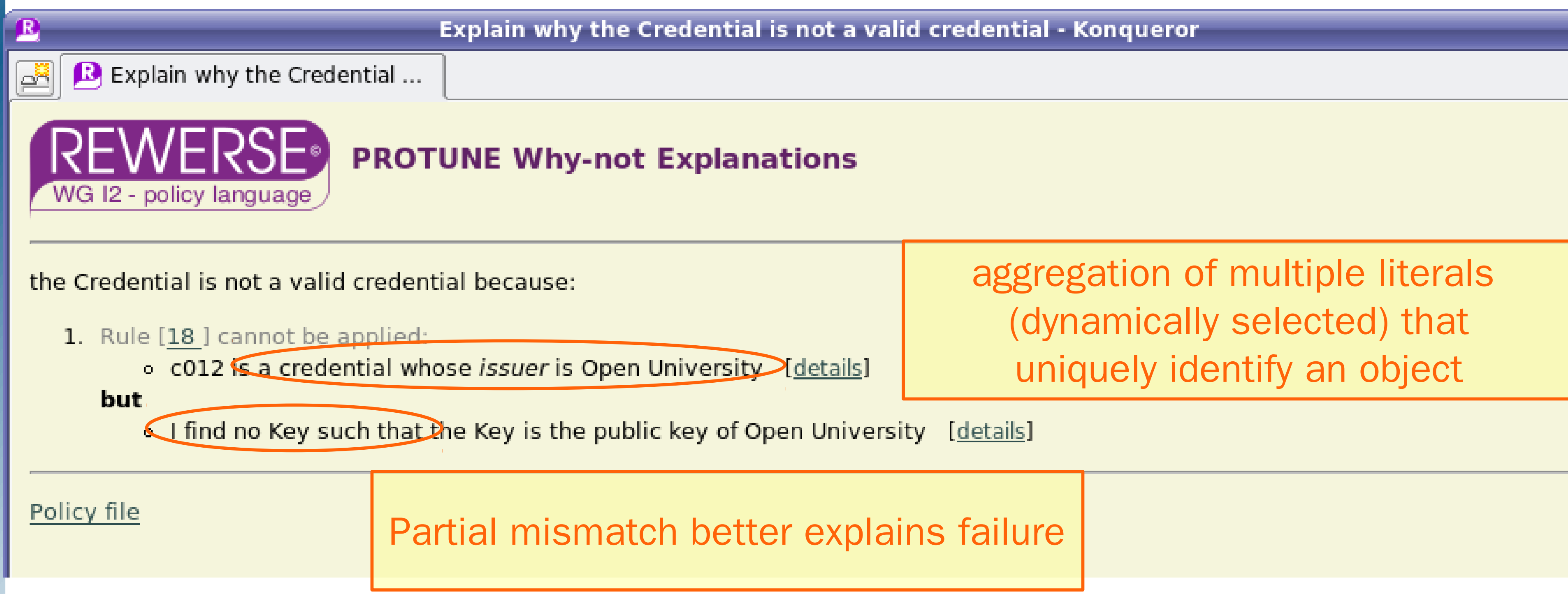
Second generation features and Protune-X

- Focus on user's interests (II): responsibilities
  - ad-hoc for trust negotiation, extendible to other app.s



Second generation features and Protune-X

- Key attributes, or denoting structured objects
  - Pre-specified in classical approaches
  - Dynamic in Protune-X



Summary of Protune-X's queries

- Static:
  - **How-to**
- Dynamic, context dependent
  - **Why / why not**
  - **What-if**
    - Simulated scenarios