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A Situation-Theoretic Model for Trial Reasoning
– a Preliminary Report –

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A Situation-Theoretic Model for Trial Reasoning - a preliminary report*

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Abstract

In this paper, we describe some features of a model that formalizes the inference of HELIC-II, an expert system being developed at ICOT to derive and debate alternative outcomes of criminal trials. Legal argumentation in this domain involves reasoning with cases, identifying legal rules, and debate between adversarial agents. It thus poses a special challenge for **distributed artificial intelligence** (DAI). Our formulation is based on **situation semantics**, an extension of logic that takes into account the notion of situations to determine the meaning of propositions. Such a situation-theoretic (ST) model works with two sources of information: statutes and cases that are known publicly, and the strategies that are used to debate conflicting arguments. In presenting this account, we attempt to show how to: (i) abstract various types of legal information, such as cases and statutes, within the framework of situation theory, (ii) draw alternative conclusions for new trials from such information, and (iii) facilitate the debate between legal agents.

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1 Introduction

Recently, there has been a growing amount of work that attempts to apply artificial intelligence to law [9, 2, 11, 3]. Most of these prototypes draw arguments by cases or rules or both. But only a few prototypes formalize their design principles and theories. In this paper, we report an initial effort to build a working model for reasoning in criminal law, that is, the way in which trial lawyers draw arguments from past cases and statutes and debate each other's claims. The proposed model formalizes the inference of HELIC-II, a parallel legal reasoning system being developed at ICOT [4].

Legal reasoning requires the interpretation of legal phrases and statutory predicates, from different viewpoints and in various situations. Lawyers argue by drawing analogies to past similar cases and by posing hypotheses. Although deductive reasoning plays an important role in law, legal rules tend to be incomplete, ambiguous, sometimes inconsistent, and hard to identify. Further, criminal law is adversarial; legal problems often have no one right answer. Usually there are at least two opposing viewpoints: plaintiff and defendant, or prosecutor and defense counsel. The arguments on both sides may be entirely reasonable, yet only one side wins. Because of the uncertainty and bias, there is room for debate. A large part of a lawyer's training involves learning to make arguments for and against the application of some statutory predicate, and for and against the similarity of a previous case to the current one.

These challenges make the domain of criminal law an interesting one from the viewpoint of distributed artificial intelligence (DAI) research [7]. Studying how legal knowledge is structured and processed may lead to useful insights. It would also guide the building of more robust expert systems that assist legal decision-making by focusing the user on relevant alternatives and by helping the user to reason and argue in court more effectively.

When we construct a formal model to represent and reason about knowledge of a practical domain, it is convenient to have available abstract analogues of real-world entities of that domain. This enables us to set up an abstract, necessarily simplistic, but precisely-defined model of the essentials of the application that we have in mind. It also helps us to carry out the study of this model within the framework of mathematics, using (and developing, when required) mathematical techniques. Examples of such theories are fluid mechanics, signal processing, and most branches of theoretical physics or biology. By and large, we conceive that the present study of legal reasoning also falls into this category.

The backbone of the proposed model is *situation theory* [5], so, we call it a situation-theoretic (ST) model. We adopt situation theory instead of classical logic because its semantics better captures the 'situation-dependency' of the meaning of legal predicates [5] than possible-world semantics of logic. Also, to a lesser extent, we think it provides a neater notation when we come to describe relations between sets of sentences.

In this study, we distinguish two types of legal situation. A *real* situation is a part of reality, picked out by some legal experts, such as judges and lawyers, as a single entity and is documented in the statute or a judicial case. On the other hand, an *abstract* situation is an abstract, set-theoretic construct – a set of *infons*, built up out of a stock of well-defined terms. The ST model deals with the latter. The presumption is that abstract situations and the constraints between them would be adequate to describe the flow of information in real situations [8], and would therefore be resourceful for the design of legal reasoning systems.[1] Our emphasis is to apply the techniques of situation theory to study legal reasoning issues of opposing views and different situations.

This paper is organized as follows. Section 2 introduces basic terms and notation. This study requires both the application of existing techniques from situation theory and the development of new constructs that are tailor-made for the task in hand. Section 3 defines specific constructs for modeling legal argument and illustrates their use with simple examples. In the last section, we outline an approach towards legal debate based on this ST model.

2 General Terms

The first order (basic) terms of the ST model are *objects, parameters, relations, infons*, and *situations*, and the higher-order terms are *object types, situation types*, and *constraints* [5, 8].

2.1 First Order Terms

An object designates an individuated part of the real world: a constant or an individual in the sense of classical logic. A parameter refers to an arbitrary object of a given type. An n-place relation is a property of an n-tuple of argument roles, $r_1, ..., r_n$, or slots into which appropriate objects of a certain type can be *anchored* or placed.

Example 2.1
We can define 'eats' as the four-place relation of action type

$$< \text{eats}:Action \mid eater:ANIMAL,\ thing\text{-}eaten:EDIBLE\text{-}THING,\ location:LOC,\ time:TIM >$$

[1]Implementing formal concepts with the computer languages developed at ICOT, such as *Quixote* or MGTP, will be discussed in a separate note [12, 10].

where *eater, thing-eaten, location,* and *time* are roles and the associated types, $ANIMAL$ denotes the type of all animals, *EDIBLE-THING* denotes the type of all edible substances, LOC and TIM are types of spatial and temporal location. □

An *infon* σ is written as: $\ll Rel, a_1, ..., a_n, i \gg$ where Rel is a relation, each argument term a_k is a constant object or a parameter, and i is a polarity indicating 1 or 0 (true or false).[2] An infon that has no free parameters is called a *parameter-free* infon; otherwise, it is a *parametric* infon. If σ is an infon and f is an *anchor* for some or all of the parameters that occur free in σ, we denote by $\sigma[f]$ the infon that results by replacing each v in dom(f) that occurs free in σ by its value (object constant) $f(v)$. If I is a set of parametric infons and f is an anchor for some or all of the parameters that occur free in I, then $I[f] = \{\sigma[f] \mid \sigma \in I\}$. Furthermore, if the relation of an infon does not consist of logical connectives, that infon then is a *basic* infon; it is a compound infon otherwise.

Definition 2.1 (Compound Infon)
For any two infons σ and β, the following are compound infons.

(i) $\ll \wedge, \sigma, \beta, 1 \gg$ is $\sigma \wedge \beta$.

(ii) $\ll \vee, \sigma, \beta, 1 \gg$ is $\sigma \vee \beta$.

(iii) $\ll \neg, \sigma, \beta, 1 \gg$ is $\neg\sigma$.

(iv) $\ll \rightarrow, \sigma, \beta, 1 \gg$ is $\sigma \rightarrow \beta$.

(v) $\ll \exists, \dot{x}, \sigma, 1 \gg$ is $\exists\dot{x}\sigma$, where σ involves the parameter $\dot{x}$.

(vi) $\ll \forall, \dot{x}, \sigma, 1 \gg$ is $\forall\dot{x}\sigma$. □

If an (basic) infon contains an n-place relation and m argument terms such that m < n, we say that the infon is *unsaturated*; if m = n, it is *saturated*. Any object assigned to fill an argument role of the relation of that infon must be of the appropriate type or must be a parameter that can only *anchor* to objects of that type. Our model requires that an infon must fill a minimum set of argument roles of the relation of that infon. This is called the *minimality condition* for that relation. Which argument roles need to be filled depends on what the relation is. We call an infon that satisfies the minimality condition of its relation a *well-informed infon*.

[2]This notation is intended to emphasize that 'infons' are semantic concepts, not syntactic representation.

Example 2.2
The infon $\sigma_1 = \ll$eats, John, now, $1\gg$ expresses that John is now eating. It is an unsaturated infon while $\sigma_2 = \ll$eats, John, apple, home, now, $1\gg$ is a saturated one. Also, the infon $\sigma_3 = \ll$eats, banana, apple, home, now, $1\gg$ does not qualify as a well-formed infon, since 'banana', not being an animal, is not eligible to fill the *eater* role. □

In this way, the formation of infons distinguishes between *falsity* (polarity 1 or 0) and *nonsensity*, in that the filling of argument roles with inappropriate objects is completely ruled out. Obviously, an unsaturated infon can always be extended into a saturated one.

An ST model contains a collection of abstract situations that describe old and new legal cases (real situations) and a set of constraints that govern the implication relationships between situations. It has a world, w, that is a unique maximal situation of which every other situation is a part. There are several special relations: the *supports relation*, $\models$, which relates a situation with an infon; *involves*, which relates two situation types and may also attach a condition; and a number of temporal relations that relate two infons, such as *meets, before*, and *during* as defined in [1]. The notation $s \models \sigma$ denotes a *proposition* about σ whose truth values are situation-dependent and may be at issue, whereas $w \models \beta$ asserts that β is a *fact*.

An abstract situation is said to be *coherent* if it does not support both an infon and its negation. Two abstract situations s and s' are said to be *compatible* if their union is a coherent situation. The situations within an abstract legal case are presumed to be compatible with one another, but there is no such presumption across abstract cases. An infon is said to be *persistent* if s_1 is part of s such that any infon that holds in s_1 also holds in s.

Condition 2.1 (Supports Relation)
i. For any situation s, and any basic infon σ, $s \models \sigma$ if and only if (iff) $\sigma \in s$.

ii. For any s, and any infons σ and β,

- $s \models \sigma \wedge \beta$ iff $s \models \sigma$ and $s \models \beta$.
- $s \models \sigma \vee \beta$ iff $s \models \sigma$ or $s \models \beta$ (or both).
- $s \models \neg\sigma$ iff $s \models \overline{\sigma}$, where $\overline{\sigma}$ is the same as σ but with the opposite polarity.
- $s \models \sigma \rightarrow \beta$ iff $s \models \sigma$ implies $s \models \beta$.
- For any s that contains (as constituents) all members of u, $s \models (\exists \dot{x} \in u)\sigma$ iff there is an anchor, f, of $\dot{x}$ to an element of u, such that $s \models \sigma[f]$.

- For any s that contains all members of u, $s \models (\forall \dot{x} \in u)\sigma$ iff for all anchors, f, of $\dot{x}$ to an element of u, we have $s \models \sigma[f]$.

iii. For any s, and any set of infons I, $s \models I$ if $s \models \sigma$ for every infon σ in I. □

2.2 Higher-Order Terms

Classification corresponds to the cognitive process of discriminating uniformities or regularities in the world at various abstraction levels. It is supported in one form or another by many formal notations intended for data or knowledge modeling. The ST model considers two classes of uniformities: *object types* and *situation types*. An object type is determined over some initial situation.

Definition 2.2 (Object Types)
For any situation s, any parameter $\dot{x}$, and any set of infons I (in general involving $\dot{x}$), an *object type*, $T = [\dot{x} \mid s \models I]$, is the type of all those objects x to which $\dot{x}$ may be anchored in the situation s, for which the conditions imposed by I obtain. □

Example 2.3
The type of all people in Toyko now can be denoted by $[\dot{p} \mid w \models \ll \text{person}, \dot{p}, \text{Tokyo}, \dot{l}_{now}, 1 \gg]$. □

Example 2.4
Let s denotes Mary's environment (LOC_1 and TIM_1 are parameters of place and time respectively), the infon $[\dot{e} \mid s \models \ll \text{action}, \text{Mary}, \dot{e}, LOC_1, TIM_1, 1 \gg]$ denotes the type of all those situations Mary enacts (within s). □

We write $x : T$ to indicate that an object x is of type T and $T \sqsubseteq T'$ when every object of type T is of type T', that is, $\sqsubseteq$ is a partial order relation.

Proposition 1
Let *O-TYPE* be a set of object types and $\top$ and $\bot$ be the maximum and the minimum elements of *O-TYPE*, then the structure $\Upsilon = (\textit{O-TYPE}, \sqsubseteq, \top, \bot)$ is a lattice. □

The *semantic distance* between any two object types in Υ is defined as the shortest path (the least number of links and in downward or forward direction of search) from one element to another, excluding $\top$ and $\bot$. For example, the semantic distance of a type and its parent type is 1.

Definition 2.3 (Situation Types)
Given a parameter of SIT, $\dot{s}$, and a set, I, of infons, there is a corresponding *situation type*:

$$S = [\dot{s} \mid \dot{s} \models I], \text{ or } s : S$$

the type of situation in which the conditions in I obtain. □

Example 2.5
If $\dot{p}$ is a parameter that denotes a person and $\dot{l}$ denotes a location, then $[\dot{s} \mid \dot{s} \models \ll$driving, $\dot{p}$, car, $\dot{l}, 1 \gg]$ denotes the type of situation in which someone is driving a car at somewhere. □

Example 2.5 describes a case in which an object-type is a type of situation. A situation-type is not the same as an object-type. Situation-types classify situations according to their internal structures, but with object-types, the situation is typed from the outside.

Definition 2.4 (Restricted Parameter)
Let $\dot{r} = v \| C$, where C is a set of infons or conditions. Given a situation s, a function f is said to be an anchor for $\dot{r}$ in s if:
(i) f is an anchor for v and for every parameter that occurs free in C;
(ii) for each infon σ in C: $s \models \sigma[f]$;
(iii) $f(\dot{r}) = f(\dot{v})$. □

The idea is that the restricted parameter $v \| C$ will denote an object of the same type as v which satisfies the requirements imposed by C. This amounts to our putting a condition on anchors that is more stringent than the mere preservation of types.

Example 2.6
Consider $\dot{r_1} = IND_1 \| \ll$mother-of, $IND_1, IND_2, 1 \gg$ and a situation s in which Mary is the mother of Tom. We have $f(\dot{r_1}) =$ Mary and $s \models \ll$mother-of, Mary, Tom, $1 \gg$. □

The ST model recognizes two aspects to a constraint: a relation between types of situation, and a relation between particular situations (Barwise's notion of type/token distinction [6]). To reflect the characteristics of legal knowledge, this model has grounded the former in terms of the latter.

Definition 2.5 (Constraints)
Let S and S' be situation types such that $S = [\dot{s} \mid \dot{s} \models I]$ and $S = [\dot{s'} \mid \dot{s'} \models I']$.
i. A *type constraint*, $ch : [S \Longrightarrow S']/B$, is an implication relation over S and S' under a set of background conditions B; ch is called the *information channel* of this constraint.

ii. a *token constraint*, $(s_1 \models I) \overset{ch}{\longmapsto} (s_2 \models I')/B$, is a relation over two situations, $s_1 : S$ and $s_2 : S'$, and is connected by the channel ch to the type constraint $ch : [S \Longrightarrow S']/B$, such that $s_2 \models I'$. □

The channel *cr* points to a set of *background conditions*, B, which must be satisfied before its type constraint is said to connect correctly to a situation. In this way, the involvement of background conditions make the information content of a constraint highly context-dependent. Note that the implication relations differ from the logical relation, $\rightarrow$. The latter relates two infons while the former relates two situations (token constraints) or two types of situation (type constraints). The set of background conditions of a constraint is expected to be compatible with every situation of antecedent of that constraint, that is,

Condition 2.3 (Background condition)
For any constraint, $ch : [S \Longrightarrow S']/B$ and any s of type S, $w \models \ll$involves, S, S', B, $1\gg$ and $s \cup B$ is coherent.

Example 2.7
The sentence "Smoke means fire" can be interpreted by the following constraint, which asserts that the presence of smoke entails there is a fire at some place *at that very moment*. The assumption made (background condition) is that smoke and fire are temporally coincident concepts. That is,
$ch : [\dot{s_0} \mid \dot{s_0} \models \ll$smoke-present, $\dot{l_0}, \dot{t}, 1 \gg] \Longrightarrow [\dot{s_1} \mid \dot{s_1} \models \ll$fire-present, $\dot{l_1}, \dot{t}, 1 \gg]/ \ll$same_occurrence, smoke, fire, $1\gg$
□

3 Domain Terms

This section introduces a set of specific terms, *relevance level, infon matching, situation matching, legal constraints*, and *substitution rules*, that extend the general ST terms into the legal domain. The definitions of these specific terms and the conditions and rules that govern their interaction include many heuristics that pertain to legal information processing.

3.1 Relevance Level

Every infon in an old case is assigned with a level of relevance to be determined by the legal experts involved. The ST model uses the notion of restricted parameters to encode such information. For example, $\dot{\sigma} = \sigma \| \ll$ relevance-level, $\sigma, \dot{\lambda}, \dot{t_b}, \dot{t_e}, 1 \gg$, where $\dot{\lambda}$ denotes one of the following objects: exact, important, and trivial, in descending order of relevance. The parameters $\dot{t_b}$ and $\dot{t_e}$ are anchored to indicate the beginning time and the ending time, that is, the duration, to which this assertion is valid under a particular situation. This notation thus makes the level of relevance of an infon both temporal- and situation-dependent.

Example 3.1
The type of legal precedents $C = [\dot{c} \mid \dot{c} \models \ll$relevance-level, σ, exact, t_1, t_2, $1\gg]$ denotes all the cases that anchor the relevance of σ being exact. A token of this type would be $c_1 \models \ll$relevance-level, $\ll$driving, John, Toyota, $1\gg$, exact, t_1, t_2, $1\gg$, that is, 'John is driving a Toyota' is a crucial piece of evidence in c_1. □

3.2 Infon Matching

A critical process of legal reasoning is to match the situations of a new case with those similar precedents in order to generate legal concepts which may hold in the new case [4]. One then uses these concepts and original evidence to draw conclusions from statutory laws (legal rules). Since cases are composed of infons, we first define the matching relation between these basic units of information. An infon in a case is presumed to be parameter-free and not contain roles of situations or compound infons.

Condition 3.1 (Exact Matching of Infons)
For any $\sigma_1 = \ll Rel_1, a_1, ..., a_n, i_1 \gg$ and $\sigma_2 = \ll Rel_2, b_1, ..., b_m, i_2 \gg$, $\sigma_1 \simeq_{iem} \sigma_2$[3] iff (i) m = n; (ii) $i_1 = i_2$; (iii) Rel_1 and Rel_2 are of the same type; (iv) for every argument a_i of non-infon type, there exists b_k which is of the same role or type and has not been matched with another argument; (v) for every a_j of an infon type, there exists b_y that satisfies the same conditions of Condition 3.1. Otherwise, $\neg(\sigma_1 \simeq_{iem} \sigma_2)$.[4] □

The kind of infon matching described in Condition 3.1 is fairly straightforward. Sometimes lawyers would loosen such matching conditions so that less similar concepts could also be matched. To this, we introduce the notion of *partial matching* of infons that relaxes (i) Condition 3.1.i to allow m $\neq$ n such that the matching of a certain percentage, k_r, of roles is sufficient, and (ii) Conditions 3.1.iii and 3.1.iv to extend the limits imposed on the *semantic distances* between

[3] a *Rel* b intends to denote $w \models \ll Rel, a, b, 1 \gg$, or at least $s \models \ll Rel, a, b, 1 \gg$, where s is a large part of the world that encompasses both new and old cases.

[4] An equivalent form of $\neg(\sigma_1 \simeq_{iem} \sigma_2)$ is $s \models \neg \ll \simeq_{iem}, \sigma_1, \sigma_2, 1 \gg$, or by Condition 2.1, $s \models \ll \simeq_{iem}, \sigma_1, \sigma_2, 0 \gg$.

the relations and roles to some integers k > 1 and k' > 1. Let us denote Ψ as a matching function that takes into account these *relaxation* factors and returns 1 (success) or 0 (failure).

Condition 3.2 (Partial Matching of Infons)
For any $\sigma_1 = \ll Rel_1, a_1, ..., a_n, i_1 \gg$ and $\sigma_2 = \ll Rel_2, b_1, ..., b_m, i_2 \gg$, where m $\neq$ n and $i_1 = i_2$, given that a matching function Ψ and the relaxation factors k_r, k, and k', $\sigma_1 \simeq_{ipm} \sigma_2$ iff $\Psi(\sigma_1, \sigma_2, k_r, k, k') = 1$; otherwise, $\neg(\sigma_1 \simeq_{ipm} \sigma_2)$. □

Thus, $\simeq_{ipm}$ is a weaker form of $\simeq_{iem}$. In fact, $\simeq_{ipm}$ is a subset of $\simeq_{iem}$: if $\sigma_1 \simeq_{iem} \sigma_2$ holds then $\sigma_1 \simeq_{ipm} \sigma_2$ is also true. This study does not attempt to provide *a priori* formulation of the "relaxation of semantic distances" or the "closeness of match" of any given pair of infons. The criteria of formulation, we believe, are extra-logical and largely application-dependent. When every object type has only one parent, it is easy to see that the following proposition holds.

[Proposition 2]
For any infons σ_1, σ_2, and σ_3,
(i) If $\sigma_1 \simeq_{iem} \sigma_2$ and $\sigma_2 \simeq_{iem} \sigma_3$ then $\sigma_1 \simeq_{iem} \sigma_3$.
(ii) If $\sigma_1 \simeq_{iem} \sigma_2$ and $\sigma_2 \simeq_{ipm} \sigma_3$ then $\sigma_1 \simeq_{ipm} \sigma_3$. □

3.3 Situation Matching

Using the matching relations of infons as building blocks, a set of situation-matching relations are specified over $SIT_n \times SIT_o$, where SIT_n denotes the type of situations in new cases and SIT_o denotes the type of situations in old cases. The ST model considers three such relations each reflects a different degree of similarities, or strength, between matched situations. Suppose that s_n is a situation described in a new case and s_o is of an old case,

Condition 3.3
(i) (Exact Situation Matching)
$s_n \simeq_{sem} s_o$ iff for every σ of $s_o \models \sigma$, there exists ρ of $s_n \models \rho$ such that $\sigma \simeq_{iem} \rho$; otherwise, $\neg(s_n \simeq_{sem} s_o)$.

(ii) (Strong Partial Matching)
$s_n \simeq_{ssp} s_o$ iff for every σ of $s_o \models \sigma \| \ll$importance-level, system, σ, exact, 1 $\gg \vee \ll$importance-level, σ, importance, 1$\gg$, there exists ρ of $s_n \models \rho$ such that $\sigma \simeq_{ipm} \rho$; otherwise, $\neg(s_n \simeq_{ssp} s_o)$.
□

Note, Conditions 3.3.i and 3.3.ii allow for the possibility that an infon in a new case matches multiple infons of an old case, or vice versa. Given the ambiguity and complexity of legal phenomena, it is rare to find an exact match between cases. A common technique is to search for old cases whose sets of important propositions (measured by relevance levels) can be matched. We call this the strong partial matching of situations. Often, even such cases are hard to find, and it is necessary to loosen the matching criteria further. One way to do this is to ignore a portion of important propositions (infons) of old cases. In so doing, weaker conclusions would be drawn, but hopefully, could still serve as convincing arguments in court.

Condition 3.3.iii (π-Partial Matching)
Let P be a set of percentage values such that $\pi \in P$. For any two situations s_n and s_o, $s_n \simeq_{s\pi p} s_o$ iff (i) for every σ of $s_o \models \sigma \| \ll$relevance-level, σ, exact, $1\gg$, there exists ρ of $s_1 \models \rho$ such that $\sigma \simeq_{ipm} \rho$; and (ii) π of *importance* infons in s_o partially match infons of s_n; otherwise, $\neg(s_n \simeq_{s\pi p} s_o)$. □

We call this way of matching the *π-partial matching* of situations, where π belongs to a set of pre-defined percentage points. These points are supplied by domain experts and tried out empirically with test cases. The purpose of π is to provide a feel for similarity between situations, not to impose an absolute measurement. For instance, one cannot say for sure that a 75% matching of situations is definitely better than a 70% one, whereas a 90% match is more credible than a 60% one. To resolve incompatible conclusions, this model relies more on the debate between agents concerning the background conditions of derivation than on such heuristic measurement.

[Proposition 3]
For any s_n of a new case c_n and s_o of an old case c_n,
(i) If $s_n \simeq_{sem} s_o$ then $s_n \simeq_{ssp} s_o$ and $s_n \simeq_{s\pi p} s_o$.
(ii) If $s_n \simeq_{ssp} s_o$ then $s_n \simeq_{s\pi p} s_o$.
□

Proposition 3 gives us an ordering of similarity for the matching relations. When there is no danger of confusion, we shall write $\simeq_s$ to denote a matching relation between situations and $\simeq_i$ between infons.

3.4 Legal Constraints

Agents of both sides can extract different information from the same legal case to support their arguments. What information can an agent pick up and how credible is such information depends on individual perspective as well as on legal constraints. There are two types of legal constraints: *case rules* and *legal rules*. Case rules are argumentation used by rival sides in old cases to derive plausible legal concepts and propositions. These rules vary from case to case, and their interpretation depends on particular viewpoints and priorities. In contrast, legal rules are general provisions and definitions of crimes. They are supposed to be universally valid (in the country where they are written in statute) and neutral, that is, the applicability of these rules is independent from the view of either side (plaintiff or defendant) and every item of information (infon) stated is treated with the same level of relevance. In this ST setting, a case rule is treated as a special form of type constraint – a *reflexive* one that provides more information about the same case.

Rule 3.1 (Case Rule)
For any two situation types $S = [\dot{c} \mid \dot{c} \models I_\alpha]$ and $T = [\dot{c} \mid \dot{c} \models I_\omega]$ a case rule that relates S and T is written as $cr : [S \Longrightarrow T]/B$. □

I_α is the antecedent or premise of the case rule while I_ω is its consequent or conclusion, and cr is the information channel of that rule. Both I_α and I_ω consist of only parameter-free infons. The reliability and the scope of application of a case rule will be subject to a set of *background conditions*, B. The conditions include factual information of the case rule, such as its legal document number, the penal code quoted, and the legal perspective (plaintiff or defendant), as well as the legal theory and hypotheses on which this rule is based. Hypotheses are crucial in the debating process to establish the degree of certainty and the scope of applicability of that rule for a legal case. In general, the only occasion when it becomes necessary to take background conditions into account and investigate what they are, is when the conclusion drawn from the case rule leads to conflict with others or a change in circumstances that weakens the applicability of that rule.

The proposition that a case c supports a case rule, cr with a set of background condition B, is represented in the token form (see Definition 2.5.ii): $[(c \models I_\alpha) \overset{cr}{\longmapsto} (c \models I_\omega)]/B$, or for short, $[I_\alpha \overset{cr,c}{\longmapsto} I_\omega]/B$. When there is no danger of conclusion, we will write a constraint without stating its background conditions.

Example 3.2

We first introduce the following relations:

- < driving:*ACTION* | *driver:D-IND, car-driven:AUTO, destination:LOC* >
- < accident:*EVENT* | *causing-agent:C-IND, object:P-IND, s:INF, t:TIM* >
- < injury:*PHYSICAL-HARM* | *injurer:P-IND, t:TIM* >
- < care:*EVENT* | *compensation-agent:R-IND, object:P-IND, reason:INF* >
- < negligence:*INTENT* | *agent:IND, accident:A-INF* >

The relation 'driving' is an action type, 'accident' and 'care' are both event relations, 'injury' is a relation of physical harm, and 'negligence' is some sort of intention. Note, *D-IND, C-IND, R-IND, P-IND* are immediate subtypes of the type of individuals, *IND*. Denote χ as $\ll$driving, John, Toyota, 1$\gg$ for short, the following case rule makes use of several infons of these relations.

$$
\begin{aligned}
cr_1 :\ & [[\dot{c} \mid \dot{c} \models \chi \wedge \ll \text{accident, John, Mary}, \chi, 1 \gg \wedge \ll \text{injury, Mary, } 1 \gg \wedge \\
& \ll \rightarrow, \ll \text{accident, John, Mary}, \chi, 1 \gg, \ll \text{injury, Mary, } 1 \gg, 1 \gg \wedge \\
& \ll \text{negligence, John, } \ll \text{accident,John,Mary}, \chi, 1 \gg]] \\
& \Longrightarrow [\dot{c} \mid \dot{c} \models \ll \text{care, John, Mary, } 1 \gg] \\
& / \{ \ll \text{article, 218, } 1 \gg, \ll \text{view, prosecutor, } 1 \gg, \ldots \}
\end{aligned}
$$

or $cr_1 : [[\dot{c} \mid \dot{c} \models I_{1,j}] \Longrightarrow [\dot{c} \mid \dot{c} \models I_{2,j}]]/B_1$

The case rule, cr_1, can be read as "In any case in which a person (John) caused a traffic accident in which another person (Mary) was injuried, John has a responsibility of care to, or should compensate, Mary; even if the accident was due to John's negligence." The partial background conditions show that this rule quotes article 218 of the Penal Code and is insisted by the prosecutor. For simplicity, we write only the important or exact infons involved in this case rule. For example, the gender of the parties is not mentioned here, as it is of trivial relevance in such an accident. It is worth noting that many of the infons stated are unsaturated ones. □

Many case rules can apply to the same case, and often yield incompatible conclusions. But the background conditions make clear the hypotheses and perspective of these rules. In addition, the constraints specified in two case rules may be 'hooked' together by the notion of *serial composition*, which does not apply to the rules across cases.

Rule 3.2 (Serial composition)
For situation types, $S = [\dot{c} \mid \dot{c} \models I_s]$, $T = [\dot{c} \mid \dot{c} \models I_t]$, and $U = [\dot{c} \mid \dot{c} \models I_u]$, if $cr_1 : [S \Longrightarrow T]/B_1$ and $cr_2 : [T \Longrightarrow U]/B_2$ then $c : [S \Longrightarrow U]/B_1 \cup B_2$. □

We write $cr = cr_1; cr_2$ to indicate that c is the serial composition of c_1 followed by c_2. The set of background conditions of the composite rule is a union of the background conditions of the component rules. Following from Rule 3.2 and the relationship on type/token constraints stated in Definition 2.5, we have:

Proposition 4
If $cr = cr_1; cr_2$, then $[I_s \overset{cr,c}{\longmapsto} I_u]/B_1 \cup B_2$. □

Certainly, one would expect that Condition 2.3 carries forward to the composition of rules, that is, $c \cup \{B_1 \cup B_2\}$ must be coherent, or the composition is not permissible. As an example, a court case is usually set up with two conflicting legal perspectives: plaintiff or defendant, and the background conditions of any case rule can embrace only one of them. Such domain-specific knowledge is expressed as *domain postulates* in our model. For any set of background conditions B, $B \models \ll \leftrightarrow, \ll$view, plaintiff, $1\gg, \ll$view, defendant, $0\gg$, $1\gg$ or $B \models \ll \leftrightarrow, \ll$view, defendant, $1\gg, \ll$view, plaintiff, $0\gg$, $1\gg$, but not both. (Note that the prosecutor's view is assumed to be equivalent to the plaintiff's while the defense attorney's view is the same as the defendant's.) If a case rule represents the plaintiff's view, its background conditions would then preclude the view of the defendant, that is, $\ll$view, defendant, $0\gg$, or $\neg \ll$view, defendant, $1\gg$. Thus, a consequent of this rule cannot input to another one that supports the defendant's view. In other words, the coherency condition on serial composition precludes the composition of rules of opposite legal views. The legal theory and hypotheses of a case rule in an ST model are made up of various domain postulates in its set of background conditions.

Owing to its generic nature, a *legal rule* is represented as a type constraint between two parametric situation types, rather than parameter-free situation types. Denote I^p_α and I^p_ω as two sets of parametric infons such that all parameters that occur in the latter also appear in the former. A legal rule is written as:

Rule 3.3 (Legal Rule)
$lr : [[\dot{s} \mid \dot{s} \models I^p_\alpha] \Longrightarrow [\dot{s} \mid \dot{s} \models I^p_\omega]]/B^p_{lr}$. □

In contrast with the case rules, the set of background conditions of a legal rule carries only *factual information*, such as the penal code and the type of crime covered, and contains parametric infons. A case c that supports a token of this rule is expressed as: $[I^p_\alpha[f] \stackrel{lr,c}{\longmapsto} I^p_\omega[f]]$ / $B^p_{lr}[f]$, where f is an anchor for all of the parameters that occur free in I^p_α, I^p_ω, and B^p_{lr}. For simplicity, we sometimes ignore f in the expression, that is, $[I^p_\alpha \stackrel{lr,c}{\longmapsto} I^p_\omega]$ / B^p_{lr}.

Example 3.3

Consider the following relations.

- < intention | *agent:IND, goal:G-INF, action:A-INF, t:TIM* >
- < death | *agent:IND, t:TIM, l:LOC* >
- < homicide-crime | *agent:IND, action:A-INF, result:INF* >
- < illegality | *legal-situation:INF* >

where *G-INF* denotes the goals of all agents' intentions and *A-INF* denotes all action situations (restricted in an infon form). A definition about the crime of homicide taken from [4] is:

$$\begin{aligned} lr_1 : [[\dot{s} \mid \dot{s} \models & [\ll \text{intention}, \dot{p}_1, \ll \text{death}, \dot{p}_2, t_0, 1\gg, \dot{a}, 1\gg \wedge \\ & \ll\rightarrow, \ll \text{intention}, \dot{p}_1, \ll \text{death}, \dot{p}_2, t_0, 1\gg, \dot{a}, 1\gg, \ll \text{death}, \dot{p}_2, t_1, 1\gg, 1\gg \wedge \\ & \ll \text{illegality}, \ll \text{legal}, \dot{p}_1, \dot{a}, \ll \text{death}, \dot{p}_2, t_1, 1\gg, 1\gg, 1\gg] \\ & \Longrightarrow [\dot{s} \mid \dot{s} \models \ll \text{homicide-crime}, \dot{p}_1, \dot{a}, \ll \text{death}, \dot{p}_2, t_1, 1\gg, 1\gg]] \\ & /\{\ll \text{article}, 199, lr_1, 1\gg, \ll \text{type}, \text{homicide-rule}, lr_1, 1\gg, ...\} \end{aligned}$$

where $t_1 \succ t_0$ (t_1 is after t_0). The legal rule lr_1 states that "A person p_1 intends to kill another person p_2. p_1 has acted according to this intention, and that action causes the death of p_2 later. If there is no evidence to refute the *illegality* of p_1's action, p_1 has committed a crime of homicide." The notion of illegality is to capture odd cases that are outside the scope of lr_1. □

Example 3.4

As an exception to the legal rule lr_1, the illegality of the action of a person is refuted when that person acts in self-defense.

$$\begin{aligned} lr_2 : [[\dot{s}' \mid \dot{s}' \models & \ll \text{intention}, \dot{p}, \ll \text{death}, \dot{p}', t, 1\gg, \dot{a}', 1\gg \wedge \\ & \ll\rightarrow, \ll \text{intention}, \dot{p}, \ll \text{death}, \dot{p}', t, 1\gg, \dot{a}', 1\gg, \ll \text{death}, \dot{p}', t', 1\gg, 1\gg \wedge \\ & \ll \text{self-defense}, \dot{p}, \dot{a}', 1\gg] \\ & \Longrightarrow [\dot{s}' \mid \dot{s}' \models \ll \text{illegality}, \ll \text{legal}, \dot{p}, \dot{a}', \ll \text{death}, \dot{p}', t', 1\gg, 1\gg, 0\gg]] \\ & /B^p_{lr_2}. \end{aligned}$$

where $t' \succ t$. $B^p_{lr_2}$ includes facts such as ≪article, 38, 1≫ and ≪type, legality-rule, 1≫. Note that the use of the same parameter of a type in a constraint enforces it is anchored to the same object, For example, $\dot{p}$ denotes the same person in all the infons stated in lr_2. □

3.5 Substitution Rules

A critical process of reasoning in every legal case is to decide which of the legal constraints apply in that case. For example, the prosecutor is required to establish *criminal intent* and *causality* between the defendant's action and its consequence in order to apply legal rules. On the other hand, the defense lawyer tries to refute all such claims of the prosecutor. Since there is no fixed rule to define the intent and causality, the lawyers of both sides normally seek hints from old cases. This process is modeled as the interaction between the matching conditions and substitution rules.

When a situation of a new case supports the antecedent of a case rule, one can draw a conclusion about the new case similar to the consequent of that rule. Let a case rule be $cr : [[\dot{s} \mid \dot{s} \models I_1] \Longrightarrow [\dot{s} \mid \dot{s} \models I_2]]$ and with the background condition B.

Rule 3.4 (Case Substitution)
Given a new case c_n, an old case c_o, and $[I_1 \overset{cr,c_o}{\longmapsto} I_2]/B$, if $c_n \models I_1'$ such that $I_1' \simeq_s I_1$, then $[I_1' \overset{cr^s,c_n}{\longmapsto} \theta(I_2)]/\theta(B) \cup B'$, or $c_n \models \theta(I_2)/B_n$. □

where cr^s is called a *pseudo-channel*, relative to cr. It connects the new case, c_n, to the channel, cr, through the substitution function θ. This function replaces all terms (objects and relations) in I_2 and B that also occur in I_1 with their matched counterparts in I_1'. The new set of background conditions, B_n, consists of $\theta(B)$ together with the information about the matching condition of antecedent situations and the pseudo-channel, cr^s. Note that $c_n \models \theta(I_2)/B_n$ implies that $c_n \cup B_n \models \theta(I_2)$.

Proposition 5
Refer to Rule 3.4, $\{c_n \cup B_n\}$ is coherent.

Proof: The substitution only replacs terms and does not change the polarities of infons. Thus, we would expect $\theta(B)$ to remain coherent with the new case. The matching information B is unrelated to $\theta(B)$ and also does not create compatibility problems. □

In a court case, both sides (plaintiff and defendant) normally are ignorant about the assumptions and hypotheses of each other's claims. An essential technique used to reveal such 'hidden'

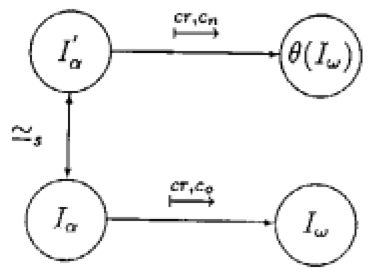

Figure 1: Case subsitution rule.

information is through cross-examination. Incorporating the background conditions into legal constraints (case and legal rules) allow us to capture this essential feature of legal reasoning for knowledge-based applications.

Example 3.5

Consider a case c_b involved Bill injured Jane in a motor cycle collision. The prosecutor of this case tried to claim that Bill should compensate Jane and invoked the case rule cr_1 (see Example 3.2). Denote $\sigma =$≪motoring, Bill, Honda, 1≫. The relevant part of this case can be described as:

$c_b \models \sigma \wedge$ ≪collision, Bill, Jane, σ, 1≫ $\wedge$ ≪injury, Jane, 1≫ $\wedge$
≪→, ≪collision, Bill, Jane, σ, 1≫, ≪injury, Jane, 1≫, 1≫ $\wedge$ ≪sprain, Jane, 1≫
$\wedge$ ≪intention, Bill,≪injury, Jane, 1≫,1≫.

or, $c_b \models I_{1,b}$. The new relations that appeared in addition to those defined in Example 3.2, are:

- < motoring:*ACTION* | *agent:D-IND, motor cycle:AUTO, destination:LOC* >
- < collision:*EVENT* | *causing-agent:C-IND, object:P-IND, s:INF, t:TIM* >
- < injury:*PHYSICAL-HARM* | *injurer:P-IND, t:TIM* >
- < sprain:*PHYSICAL-HARM* | *sprained-agent:P-IND, t:TIM* >
- < intention:*INTENT* | *agent:P-IND, goal:G-INF* >

Let us set the semantic distances between relation types, k, to be 1 and between role types k' to be 2. Then it follows from Condition 3.3 that c_b partially matches the antecedent situation of cr_1, that is, $I_{1,b} \simeq_{ssp} I_{1,j}$.[5] Note that the infons of 'sprain' and 'injury' relations in Bill's case match the same 'injury' infon in the case rule.
From the case rule cr_1 of Example 3.2 and Rule 3.4, we have $I_{1,b} \overset{cr_1^s, c_b}{\longmapsto} \theta(I_2)/B_b$, or $c_b \models \ll$care, Bill/John, Jane/Mary, $1\gg /B_b$, where $B_b = \theta(B_1) \cup \{\ll$match-condition, $\simeq_{ssp}$, $1\gg$, $\ll$channel, cr_1^s, $1\gg\}$. The notation x/y denotes that x substitutes for y. Since the relation 'care' of the old case has no matching counterpart in the new case, it is simply carried forward to the new conclusion. □

It is possible that both sides may draw inconsistent conclusions. For example, by applying another case rule cr_2, the defendant in Bill's case may argue that:

$$c_b \models \ll \text{care, Bill/John, Jane/Mary, } 0 \gg / B_b'$$

where $B_b \neq B_b'$. If it is so, c_b then seems to support a proposition and also its negation, that is, $c_b \models \ll$care, Bill, Jane, $1\gg$ and $c_b \models \ll$care, Bill, Jane, $0\gg$. This contradicts our presumption that every abstract case is coherent. The culprit of this incoherency, however, would become apparent once we take into account the background conditions of the case rules. The incoherency is not due to c_b but the union of c_b and the background conditions of cr_1 and cr_2, that is,

$$\{c_b \cup B_b \cup B_b'\} \models \ll \text{care, Bill, Jane, } 1 \gg \wedge \ll \text{care, Bill, Jane, } 0 \gg .$$

To debate over the conflict, a strategy of this ST model is to establish the preference ordering between the background conditions of such incompatible claims. The key elements of such a strategy include many situation-dependent factors, such as the strength of matched conditions, the hypotheses made, and the support of legal theory.

Proposition 6

Given any case c such that $c \models I_1/B_1$ and $c \models I_2/B_2$, if $I_1 \cup I_2$ is incoherent, then B_1 and B_2 are incompatible with each other.

Proof: $c \cup B_1 \models I_1$ and $c \cup B_2 \models I_2$ imply $\{c \cup B_1\} \cup \{c \cup B_2\} \models I_1 \cup I_2$. If $I_1 \cup I_2$ contains some σ and its negation, $\overline{\sigma}$, this means that $\{c \cup B_1\}$ is incompatible with $\{c \cup B_2\}$, and subsequently, B_1 and B_2 are incompatible. □

[5] The matching of the two situations would be exact if not for the difference between 'negligence' and 'intention' infons. The relation 'negligence' has an argument of accident role which is of *A-INF* type, whereas 'intention' has a goal role which is of *G-INF* type. Both *A-INF* and *G-INF* are subtypes of *INF* (the type of all infons). Moreover, this matching does not need to compare the relevancy levels of infons.

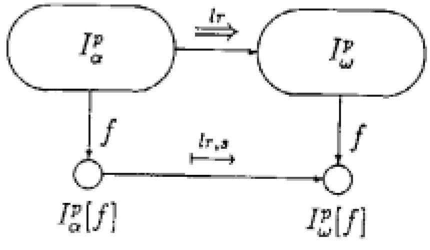

Figure 2: Legal subsitution rule.

To combine the conclusions drawn from different legal constraints, the background conditions of both conclusions is required to be compatible. That is,

Condition 3.4 (Conjunction of Conclusions)
Given that $c \models I_1/B_1$ and $c \models I_2/B_2$, we have $c \models I_1 \cup I_2/B_1 \cup B_2$ only if B_1 and B_2 are compatible.

A consequent is derived from a legal rule in the following way:

Rule 3.5 (Legal Substitution)
For any situation s, $s \models I^p_\omega[f]/B \cup B^p_l[f]$ if $s \models I^p_\alpha[f]/B$ and $[I^p_\alpha[f] \stackrel{lr,s}{\longmapsto} I^p_\omega[f]]/B^p_l[f]$. □

where f anchors both I^p_α and I^p_ω into sets of parameter-free infons in s. Note that such a consequent also carries with it the background conditions of the antecedent situation, in addition to the conditions of the original legal rule.

In this section, we have introduced an ST notation for case matching and legal implications. Armed with such apparatus, we can represent, diagramatically, the flow of information in a trial case.

Let us take a simple example. In Figure 3, I_1 and I_3 are subsituations of a new case, c_n, while I_1' and I_3' are of some old case(s). Two legal concepts or conclusions are drawn in this argument. The conclusion I_5 is derived from the serial composition of two case rules, cr_1 and cr_2, and one legal rule, lr_1. Further, part of the intermediate result, I_2, is used to generate another conclusion I_6. From the coherency criterion of Condition 3.4, it follows that I_5 and I_6 must share the same

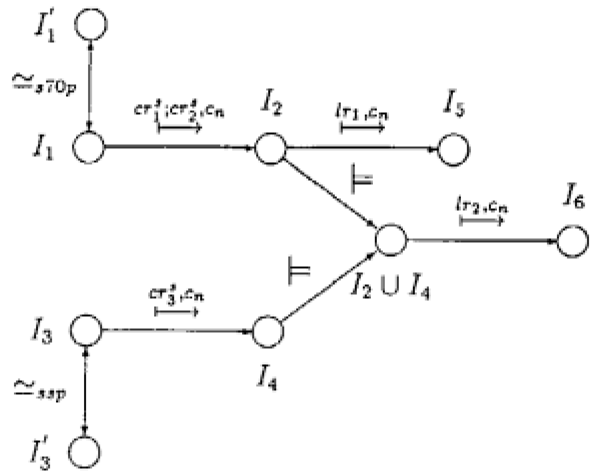

Figure 3: A visual graph of legal argumentation.

legal perspective: plaintiff's or defendant's. This figure also indicates that the matching relation of I_3 (strong partial matching) is stronger than that of I_1 (70%-partial matching). One can also probe into legal constraints and background conditions, linked by appropriate pseudo-channels, of these arguments in order to retrieve the underlying hypotheses and legal theories. Such a *visual graph* provides a compact and intuitive representation of the intricate interaction of legal constraints and matching relations.

4 Remarks on Debate Strategies

The debate of a criminal trial generally starts off with the plaintiff or the prosecutor putting forward certain legal argument about the criminality of the defendant. The defendant counters this claim either by disproving its credibility or by finding a stronger argument that supports his or her innocence. The prosecutor then counterattacks the defendant's argument or asserts another claim. Hence, the debate involves several iterations of one side asserting a claim and the other trying to disprove it. Legal trials frequently have no right answer, though only one side can win. The final decision rests in the hands of the judge(s) or jury, after both sides have been given sufficient opportunites to examine each other's justifications.

In the previous section, we describe how legal arguments can be derived from old cases and statutes, and the inference is in the mode of *forward reasoning*. In this section, we outline an approach to facilitate the debate between both sides over derived arguments. The debating process in this ST model involves *backward reasoning* about the background conditions of the rules as well as comparing the matching strength of cases. Such a debate does not aim to obtain an absolute answer, as this would not match up with the reality. Rather, it provides a forum to scrutinize the hidden assumptions and justifications of possible alternatives of a trial. In due process, 'shaky' conclusions would be identified and wiped out, and this helps the lawyer focus the effort to develop the promising arguments for the real trial. Our approach to legal debate considers three general strategies or a combination of them.

1. Direct Disproof of Arguments

In this strategy, an agent confronts the other's accusation directly. The agent probes into the background conditions of an argument and attempts to show the invalidity of the conditions with specific domain knowledge. Once the set of background conditions is disproved, the argument does not hold anymore. To acquire sufficient domain knowledge to disprove opposing claims directly, sometimes, may be difficult. Hence, the following two strategies suggest two indirect means.

2. Strength of Case Matching

This amounts to compare the degrees of similarity of the current case with quoted cases. For example, if the prosecutor agent derive σ from a case rule with a 60% partial match, and the defendant obtain the dual $\overline{\sigma}$ from another rule with a 90% match. All things being equal, then, the defendant's argument would be more convincing than the prosecutor's. However, as mentioned in the previous section, the comparison of matching strength, does not work well in the case of a close call, such as 80% match vs. 90% match.

3. Backgrounds of Rules

This strategy compares another type of strength, the legal theories or hypotheses of implication rules that derive conflicting conclusions. The theories and hypotheses are parts of the background conditions of these rules. Suppose that one agent derives σ under a legal theory Th_1 and the other obtain the negated conclusion under another theory Th_2. The latter agent can discredit the former's claim if he/she can show that Th_2 is legally 'stronger' theory than Th_1. This process often involves a set of domain postulates (discussed in Section 3.4. Again, the efficacy of such a strategy would require considerable work in knowledge acquisition, but, we believe, the magnitude should be less than that of the first strategy.

This paper is not intended to be mathematical; a longer version of this paper will provide a more formal and detailed treatment on the proposed model and debating strategies. From the perspective of law, this work helps to guide the design of more robust and intelligent systems that would improve the productivity of trial lawyers, systems such as HELIC-II being developed at ICOT. On the other hand, from the perspective of artificial intelligence, the formal model shows that the situation theory can be an invaluable tool to model the complexity of trial reasoning.

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