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Integration of Data Processing, Probabilistic Reasoning and Process Analysis to Resolve Fairness-Based Solutions for Mediated Political Disputes

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ABSTRACT

This paperpresents an intelligent layered framework, named FISA, which has the ability of resolving political disputes. The proposed framework, aims at crossing the gap between loose specifications of political situations and rigorous requirements of formal inference methods. That adaptation is performed using of data mining to discover both relevant topics and sequences associated with actors, which represent the underlying dispute by an arbitrary set of events that are arranged in temporal order. This allows performing probabilistic reasoning to determine the dispute resources and representing them as Communicating Sequential Processes, CSP.

The resulting CSP model is machine-generated and realistic; however, it could be nondeterministic. Therefore, several fairness techniques are relied upon to: 1) mitigate nondeterminism, 2) provide counter-example(s), 3) avoid probable deadlocks and 4) exploit temporal logic for examining reachability assertions. A case study of two neighboring countries C1 and C2 is investigated and represented by two conflicting processes.

Keywords: *Situation analysis, formal methods, Bayesian networks, sequence mining, communicating sequential processes, temporal logic, fairness.*

INTRODUCTION

There is a Common agreement that formal methods are sound, complete and capable to afford proofs [1, 2]. They have been used in various situation analysis applications that range from critical military situations [3] to complex traffic and road situation analysis [4]. However, to our knowledge such methods have not been employed to analyze typical political situations. This is due to the fact that political situations are complex, nondeterministic, interfered, uncertain, and subject to deadlocks. Therefore, political experts prefer to introduce their own vocabulary, language, rules and theorems, which by-pass the formal methods of reasoning that are based on logical modeling. To cross the gap between the rigour of formal methods and the looseness of the political situations, we have designed a Framework for Intelligent Situation Analysis, (FISA) to carefully mitigate such contradiction at several levels which are pointed out in the following:

Collected data level: First, a set of relevant topics {S} and the set of underlying sequential events {E} are represented by an arbitrary set of predefined patterns, where $S \wedge E \neq \phi$. Second, to provide knowledge discovery, two functions are used, one for topic mining and the other for sequent mining [5].

Event level: At event level, key words representing temporal remarkable incidents are handled as tokens in a parser that forms the output sequences as a syntactic structure of event order.

Reasoning level: A carefully designed Bayesian network "BN" is used to provide probabilistic reasoning. Since Concepts are a right way to proposed formalize a domain and BNs are the right means to obtain the cause from its effects, a probabilistic reasoning approach has been so that BNs could be work as a semantic organization of topics which can provide the conditional probability dependencies among such topics and the frequencies of data instances provide the necessary probability distributions.

Application level: At this level both fairness and reachability assertions are exploited to ensure the solution correctness.

This paper is organized as follows. Section 2 presents the related work to FISA. Section 3 illustrates the different modules of FISA framework, while Section 4 pointed out the mediation based political disputes. Section 5 presents a proof of concept and experimental work for illustrating FISA capabilities. Section 6 includes a comparison of FISA to other related work, while section 7 contains the conclusions.

2. RELATED WORK

The present decade witnessed interest in studying the problem of situation analysis for different applications [4]. We are here interested only in those works which provide situation analysis for political and/or military applications. Such works is summarized in the following:

An overview of the field of recommender systems [8] describes several recommendation methods that are usually classified into the following three main categories: 1) content-based, 2) collaborative, and 3) hybrid recommendation approaches. This work also discusses possible extensions that can improve recommendation capabilities. These extensions include, among others, an improvement of understanding of users and items, support for multi-criteria ratings.

Also, in [3] the authors conducts a theoretical investigation of a complex command and control operation (Army land-battle), based on cognitive task analyses and interviews with experts to make inferences on the battle activities, then summarizing several critical human factors issues associated with planning in a rapidly evolving environment. Their aim is to distribute collaborative planning of battle activities.

An interesting work in [1] considers the problem of reaching situation awareness from textual input and proposes an approach to probabilistically model uncertain event locations described by human reporters in the form of free text. The authors design techniques to store and index the uncertain locations, to support the efficient processing of queries.

The goal is to represent accurately uncertain location specified in reports to allow for efficient execution of analytical queries. In their project, they use two data sets, namely, the reports issued after 9/11 attacks and news that covered the Asia Tsunami disaster.

Another system is introduced in [9] to carry out complex systems that include political and military - emergent "unexpected" behavior. Such systems require approaches that are based on a comprehensive study of both the structure and the dynamics of these systems. Therefore, the author utilizes several analysis and planning techniques to provide a Program named COMPOEX capability of handling complex operations. Such techniques can enable systems analysts to compose conceptual and computational models for regional and nation situations. He integrates agent-based models, systems dynamics models, Bayesian networks, linear programming models, and other discrete-time models into Political-Military-Economic-Social-Infrastructure and Information (PMESII) simulation. Also, discusses the results of his experiments using PMESII, and reports his deductions.

According to decision making, [2, 10] explores an approach to model-driven engineering (MDE) of situation analysis decision support systems for marine safety and security operations. An Abstract State Machine (ASM) modeling is paired with CoreASM tool and has been used to analyze and validate ASM models. That approach, as such, facilitates analysis of the problem space and supports reasoning about design decisions and conformance criteria in order to ensure that they are properly established and well understood prior to building the underlying system.

Later, [10] has applied his Abstract State Machine "ASM" method and the CoreASM tool to design and analyze Situation Analysis Decision Support "SADS" systems. SADS system engineering relies upon systematic formal modeling approaches in order to manage complexity through modularization, refinement and validation of abstract models.

Recently, [11] proposed a framework named GECR in order to help non-expert persons to discover political risk stability across time based on sample political news. He employs a Bayesian network approach to model uncertain domains. His proposed framework is used as a decision support tool to predict the political risk level with a reasonable degree of accuracy.

It is obvious that existing systems and prototypes to-date are based on a heuristic design approach. Some of them partially lack formalisms while the others lack the use of formal methods entirely.

3. FISA ARCHITECTURE

This section details the proposed FISA Framework. It reads raw data news as its input and consequently infers critical situations, if any, as its output. Actually, such situations represent deep implication of what has been embedded in the input. It is then recommended that such input enters FISA via an extractor. That Extractor: reads raw data as input, exploits the idea of concept search to seek relevant paragraphs, and produces relevant paragraphs as output. FISA then consists mainly of four modules as depicted in Figure 1:

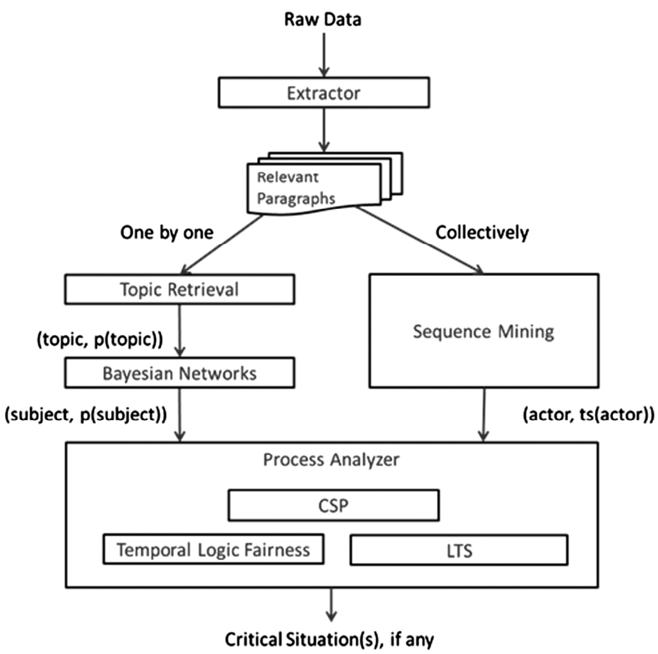


Figure 1: Framework for Intelligent Situation Analysis, FISA, p( ) denotes the probability and ts( ) denotes the temporal sequence

The main functionality of each module is as follows:

(1) Topic Retrieval:

a. Comes after the extractor, it takes relevant paragraphs from the extractor as input,

b. Looks for expressive words representing the topic.

c. Ranks the topic significance by evaluating a corresponding weight associated with that topic.

c. Output the pair (topic, P(topic)), where p() denotes the probability.

(2) Sequence Mining:

a. Reads the relevant paragraphs form the extractor as input.

b. For certain tokens [12] (before, after, next,…) uses temporal-based syntactic analyzer to construct sequences of events.

c. Relate every sequence to its actor.

d. Output the pair (actor, its event sequence).

(3) Bayesian Network:

BN is for probabilistic reasoning about resources of conflicts (subjects). The underlying Bayesian networks are constructed by domain experts taking into consideration the node ordering property so that each node interacts only with a bounded number of nodes. Thus, we add the symptoms obtained from the topic retrieval first, then the variables they influence and so on until we reach the leaves which are the real resources of conflict (subject). After construction, each BN works as follows:

a. It takes, as input, the symptom(s) expressed by the pair (topic, P(topic)).

b. It applies the joint probability distribution.

c. It gets the probability of resource of conflict P(res). If P(res) is less than a predefined threshold, ignore such resource, else call the Process Analyzer and pass the resource of conflict to it. If the dispute topics were changed, then either the expert is reviewed or another expert is consulted.

(4) Process Analysis:

Here, every process is expressible in Hoare notation and can described as: x:B à F(x)

This notation means that every process may be regarded as a function of F with a domain B, defining the set of events in which the process is initially prepared to engage, and for each x in B, F(x) defines the future behavior of the process if the first event was x [6].

For every actor (object) and resource of conflict (subject), use communicating sequence processes, CSP [6], Labeling Transition Systems, LTS and Temporal properties to analyze the input sequences of events, if critical situations (deadlock, others) are not found (reached), accept the solution, else use a counter-example to propose a proper solution.

(5) Linear temporal logic Fairness:

Fairness properties state that if something is enabled efficiently often, then it must eventually happen. Most likely, fairness assumptions are necessary to prove liveness. Here deferent event annotations are used to associate fairness constraints with particular events [13].

Five levels of fairness namely (Event-Level Weak Fairness, Process-Level Weak Fairness, Event-Level Strong Fairness, Process-Level Strong Fairness, Strong Global fairness) are employed [7] and they are defined as follows:

Event-Level Weak Fairness

Event-level weak fairness states that if an action becomes enabled forever after some steps, then it must be engaged infinitely often.

Thus, the event E satisfies event-level weak fairness if and only if, for every action "a", if "a" eventually becomes enabled forever in E, then a = aß for infinitely many i's. Thus, with [] and < > denote always and eventually, respectively one can write as in (1):

([] < > a is enabled) implies ([] < > a is engaged). (1)

An equivalent formulation is that every computation should contain infinitely many positions at which "a" is disabled or has just been taken. It means that an enabled action shall not be ignored infinitely.

Process-Level Weak Fairness

Process-level weak fairness states that if a process becomes enabled forever after some steps, then it must be engaged infinitely often.

The event E satisfies process-level weak fairness if and only if, for every process "p", if "p" eventually becomes enabled forever in E, then p is participated in aß for infinitely many i's, as in (2):

([] < > p is enabled) implies ([] < > p is engaged).(2)

Event-Level Strong Fairness

Strong local fairness states that if an action is infinitely often enabled, it must be infinitely often engaged. This means that an event E satisfies event-level strong fairness if and only if, for every action "a", if "a" is infinitely often enabled, then a = aß for infinitely many i's, as in (3):

([ ] < > a is enabled) implies ([] < > a is engaged). (3)

Strong fairness is stronger than weak fairness, since (< > [] a is enabled) implies ([] < > a is enabled).

Process-Level Strong Fairness

Strong local fairness states that if a process is infinitely often enabled, it must be infinitely often engaged.

An event E satisfies process-level strong fairness if and only if, for every process "P", if "P" is infinitely often enabled, then P participates in $a_ß$ for infinitely many i's, as in (4):

([] < > P is enabled) implies ([] < > P is engaged).(4)

Strong Global fairness

An event E satisfies global fairness if and only if, for every triple (s, a, s‘); in which s and s‘ are the present state and the next state, respectively. Such strong global fairness states that if a step (from a state s to a state s' by engaging in action a) can be taken infinitely often, then it must actually be taken infinitely often.

Strong global fairness [17] concerns both actions and states, instead of actions only. It can be shown by a simple argument that strong global fairness is stronger than strong fairness. Strong global fairness requires that an infinitely enabled action must be taken infinitely often in all contexts, whereas event-level strong fairness only requires the enabled action to be taken in one context.

4. MEDIATION BASED POLITICAL DISPUTES

Without loss of generality, that problem can be described for two countries that are opposing each other C_i; i = 1,2 and a single mediator as follows:

- There are several available resources that have stimulated the struggle between two countries C1 and C2.

  During the struggle either C1 or C2 can gain tactical resources temporally in order to enhance its situation before any mutual agreement.A resource in the dispute, either permanent or temporal, is exchangeable and is subject to a relevant sequence of events.
- Any country in the dispute is trying to take as maximum resources as it can; however, a conflict arises as its opponent is trying to push in the opposite direction. Actually, a county can perform a sequence of events in order to move from state to another or to return to its initial state. Always, C_i concern is its benefit regardless of the needs of its neighbor.
- The mediator has the ability to:
  - Search raw data to find out topics and event sequences.
  - Perform probabilistic reasoning to find out probable resources.
  - Search for dispute resolutions.
  - Present counter examples if a deadlock appeared.
  - Convince bath countries C1 and C2 by his exposed solution, if any.

It is worth mentioning that political disputes, by their nature are ill-defined, nondeterministic and their wrong treatment may lead to catastrophic results.

5. CASE STUDY

In this case study the dispute hasoccurred between two neighboring countries C1 and C2 in the existence ofa third actor, Md, who participates as a mediator.Such an actor adds another dimension to the model by introducing an additional set of resources.Each country is struggling to obtain not only the available resources (Land and Peace) but also to exchange hostages (Captive and Prisoners). A lot of details are published in several documents as unstructured textual news data.That raw data, as such is collected and taken as input FISA i.e. input to its extractor, Figure 1.

Extractor

The extractor, Figure 1, output is:
getland, holdland, getwater, holdwater, get wealth, holdwealth, getpeace, holdpeace, getsecurity, holdsecurity, getnaturalization, hold naturalization, start assassination, stop assassination, takecaptive, holdcaptive, givecaptive, get concessions, hold concessions, start strike, stop strike, takeprisoners, holdprisoners, giveprisoners, start explosions, stop explosions, obtainland, obtainpeace.

Such output represents the input to the following two modules:

1- The *topic retrieval* module: the relevant paragraphs passed to this module to obtain the pair that consists of both topics and their corresponding probabilities, Figure 2.Such pair is given in the following: < get land, .8 > , < get water, .2 > , < get wealth, .1 > , < get peace, .8 > , < get security, .2 > , < get naturalization, .1 > , < start assassination, .2 > , < take captive, .95 > , < get concessions, .2 > , < start strike, .3 > , < get prisoners, .9 > , < start explosions, .1 > .

2- The sequence mining module: each entire relevant paragraph passed to the sequence mining module,to get the included actors and their sequences of events, Figure 3.In this case the actors are C1, C2, and Md and the sequence of events associated with each actor is illustrated in the following:

C1:

"After" wait land and hold peace Then treat "Next" get land

C2:

"After" wait peace and hold land Then treat "Next" get peace

Md:

First Obtain land Second Obtain peace Then hold land "Next" hold peace

It is noticed here that treat has the meaning of negotiation ability.

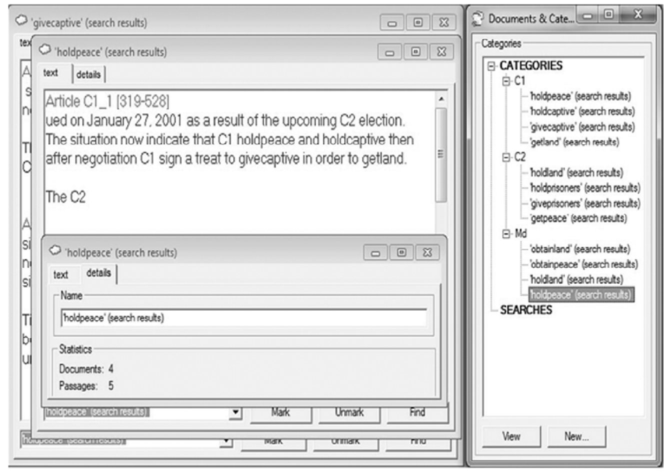


Figure 2: Topic retrieval output display and corresponding search results

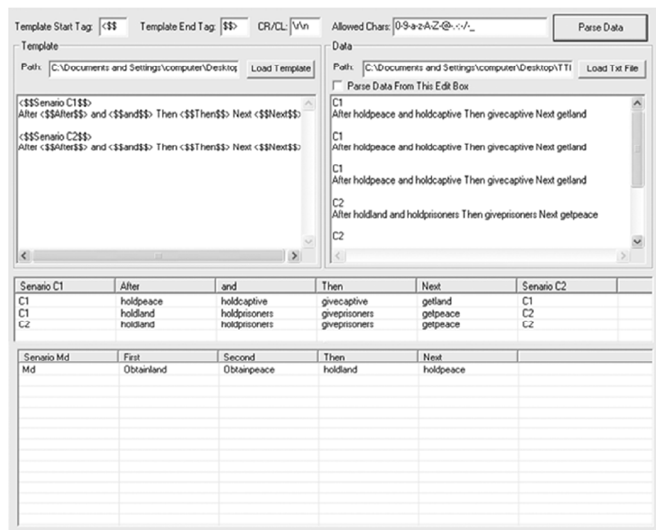


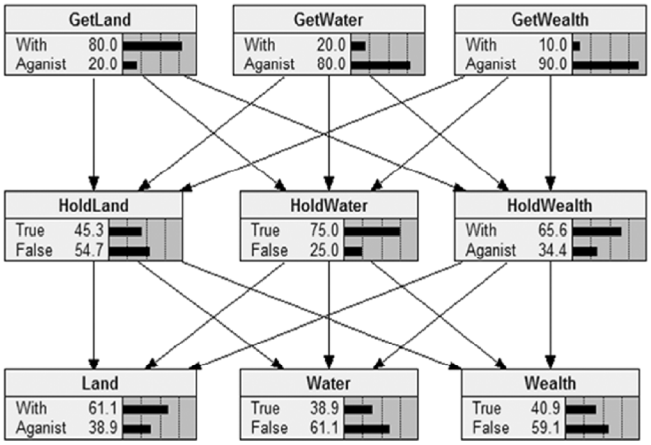
Figure 3: Sequence mining output display

Here it is obvious that the main influencing actors in the current situation are: C1(), C2(), Md() and the sequence of events controlled by it. That output will be passed to the PAT module.

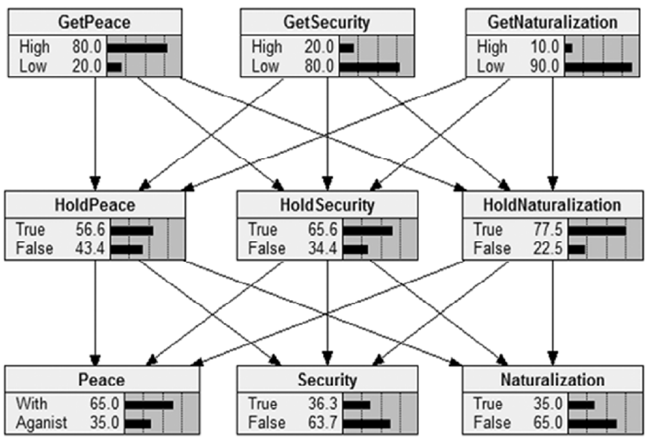
Bayesian Networks

The input to the Bayesian Network BN, Figure 4a, b, c, d, is obtained from the topic retrieval module, while each BN output representsa resource/hostage. SuchBNs are employed to allow us to perform probabilistic reasoning and to obtain the most probable conflicting (either strategic or tactical). Here, for example, C1 can start assassination, take captive and get concessions while C2 can tolerate strikes, take prisoners and control explosions.

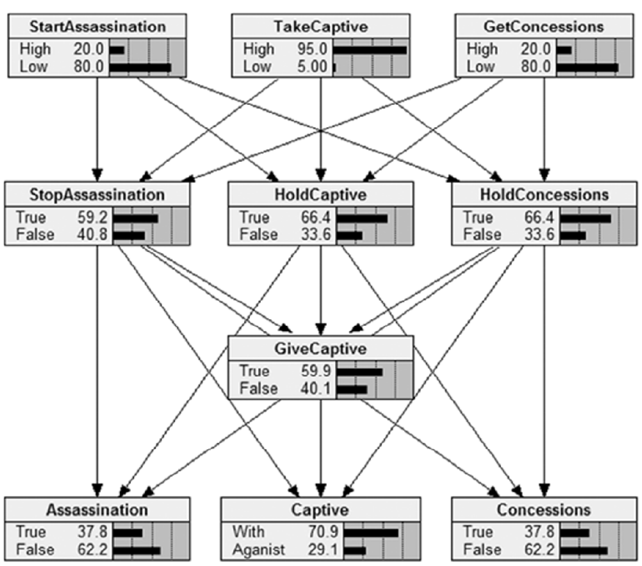
The outputs from this module together with the output from the sequence mining are used as input to the PAT module.



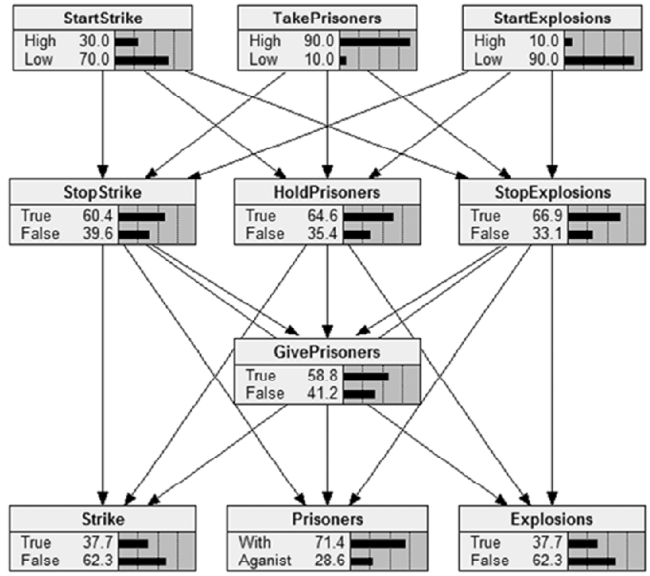
a: The Bayesian network for land



b: The Bayesian network for peace



c: The Bayesian network for captive



d: The Bayesian network for prisoners

Figure 4: The Bayesian network for land, peace, captive and prisoners

Process Analysis

In the process analysis module, it is important to notice that PAT gets its input from both Bayesian networks and sequence mining. These machine generated PAT inputs come from the processes and resources script are combined in the system using college(). The processes, resources, and system (denoted by college) are collectively representedas follows:

C1() = holdpeace -> holdcaptive -> givecaptive -> getland -> C1();
C2() = holdland -> holdprisoners -> giveprisoners -> getpeace -> C2();
Md() = obtainland -> obtainpeace -> holdland -> holdpeace -> Md();

land() = getland -> holdland -> land();
peace() = getpeace -> holdpeace -> peace();
prisoners() = takeprisoners ->holdprisoners -> giveprisoners -> prisoners();
captive() = takecaptive ->holdcaptive -> givecaptive -> captive();
college() = C1() || C2()|| Md() || land() || peace();
In that script || denotes parallelism.

C1_C2_MdDispute Resolution

1- Dead Lock Situation

Upon running the above script, a deadlock takes place, since the process analyzer starts by event ‘obtain land’ followed successfully by ‘obtain peace’, Figure 5.

However, the next expected event "hold land' could not address any automaton state. Consequently, the liveness is lost becausecollege cannot return to its initial state (state 1) i.e. a deadlock has occurred.

Figure 5: Part from random graph simulation (counter example)

To solve the deadlock, interleaving is introduced to yield the following representation:

College() = C1() || C2()|| Md() ||| land() ||| peace(); where ||| denotes the interleaving.

Accordingly, the deadlock is resolved and such situation is illustrated by Figure 6 that represents, for convenience, the basic part of the random graph simulation.

Such transition Diagram indicates that college() can return to the initial state (state 1) throughout more than one path (liveness) satisfaction.

2- Target Reachability Analysis

To check the reachability of each resource, we make use of the following assertions:

#assert college() |= []<> getland;
#assert college() |= []<> getpeace;
#assert college() |= []<> givecaptive;
#assert college() |= []<> giveprisoners;

Strategic Resources (Land and Peace)

After running the first two assertions, we found out that their reachability is not valid. This is indicated by Figure 7 for getting land and Figure 8for getting peace.The invalidation in Figure 7 is due to the holdpeace-getpeace loop, while the invalidation in Figure 8 is due to the holdland-getland loop.

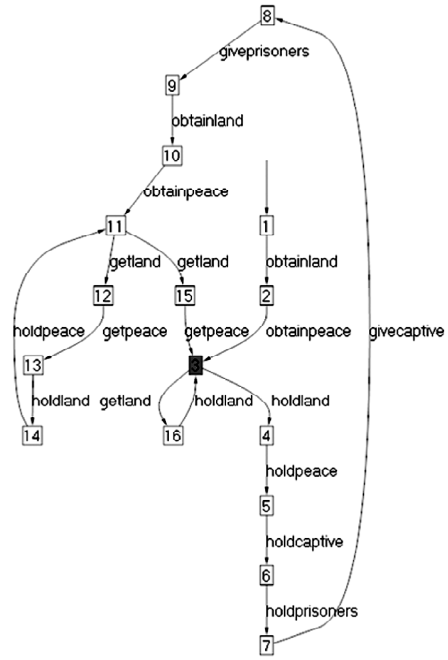


Figure 6: Part of random graph simulation of C1_C2_Md The complete graph consists of 256 nodes and 1056 edges.

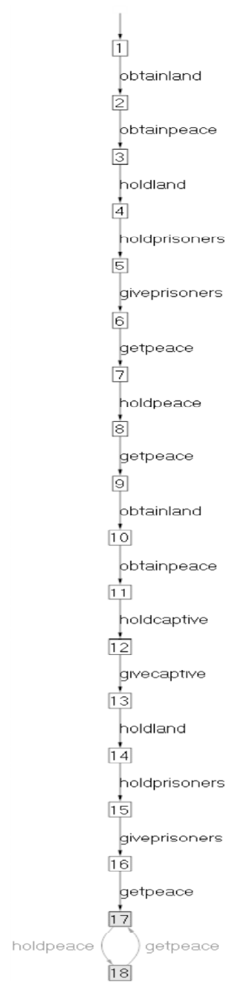


Figure 7: Counter example of getland

Figure 8: Counter example of getpeace

The counter example that has been proposed by applying event-level weak fairness for “assert college() |= [] < > getland” can be:

```
Counterexample: ***init -> obtainland -> obtainpeace -> holdland -> holdprisoners -> giveprisoners -> getpeace -> holdpeace -> getpeace -> obtainland -> obtainpeace -> holdcaptive -> givecaptive -> holdland -> holdprisoners -> giveprisoners -> getpeace -> (holdpeace -> getpeace -> )*
```

Also, the counter example that has been proposed by applying event-level weak fairness for “assert college() |= [] < > getpeace” can be:

```
Counterexample: ***init -> obtainland -> obtainpeace -> holdland -> getland -> holdprisoners -> giveprisoners -> holdpeace -> obtainland -> obtainpeace -> holdcaptive -> givecaptive -> getland -> (holdland -> getland -> )*
```

When event level week fairness is introduced, the temporal logic module, Figure 1, does not stop at the above loop and continues searching for trace(s) that eventually may reach the target, i.e. C1() can getland. Figure 9 includes more than one trace which can reach that target.Consequently, it found out 2traces, at least:

First trace: S1 -> S2 -> S12 -> S13 -> S216 -> S213 -> S19

In which holdpeace is replaced by getland, i.e. in this case C1() after getting peace should look for allowing C2() to getland instead of insisting to hold peace.

Second trace: S1 -> S2 -> S12 -> S13 -> S216 -> S16 -> S19

Thus C1 and C2 are advised to exchange land and peace.

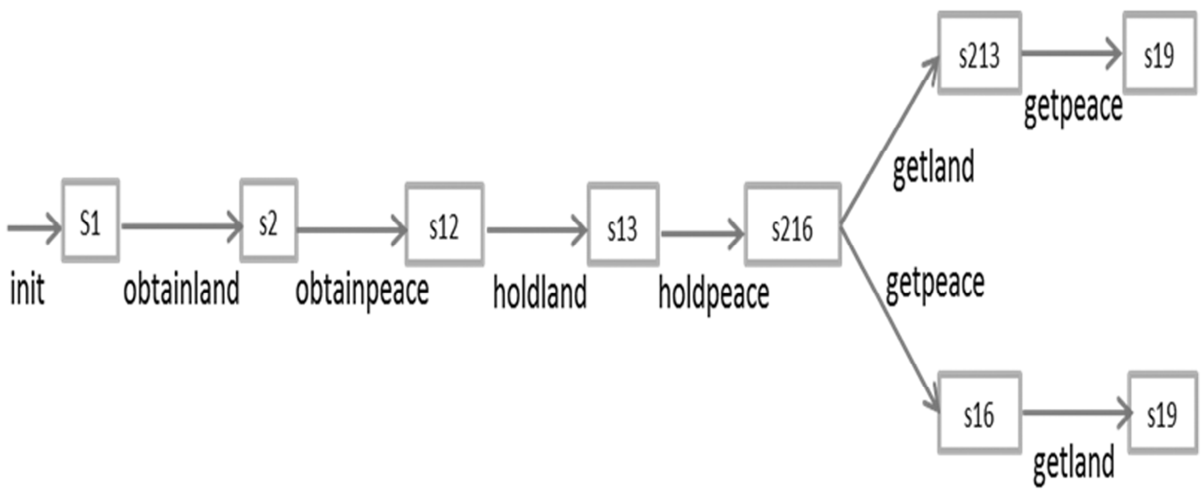


Figure 9: Possible traces extracted from random graph simulation

Tactical Resources (Captive and Prisoners)

Actually, weak fairness is concerned with actions/ events only, therefore, such event level weak fairness can reach neither givecaptive nor giveprisoners because of the loop “holdland -> getland -> holdpeace -> getpeace” (see the corresponding traces) shown in Figure 10 for givecaptive and shown in Figure11 for giveprisoners. In the second figure the generated states could not achieve givecaptive or giveprisoners, however, in the first figure giveprisoners could be reached, but such leads to state (12) with transition getpeace which never reaches giveprisoners.

Therefore, Strong Global Fairness is examined for the last two assertions, which are:

College() ¨• [ ] < > givecaptive;

College() ¨• [ ] < > giveprisoners.

This approach is taken because strong global fairness is concerned with (actions and states (context) - not actions only) all contexts. Such strong global fairness yields giveprisoners in the context of

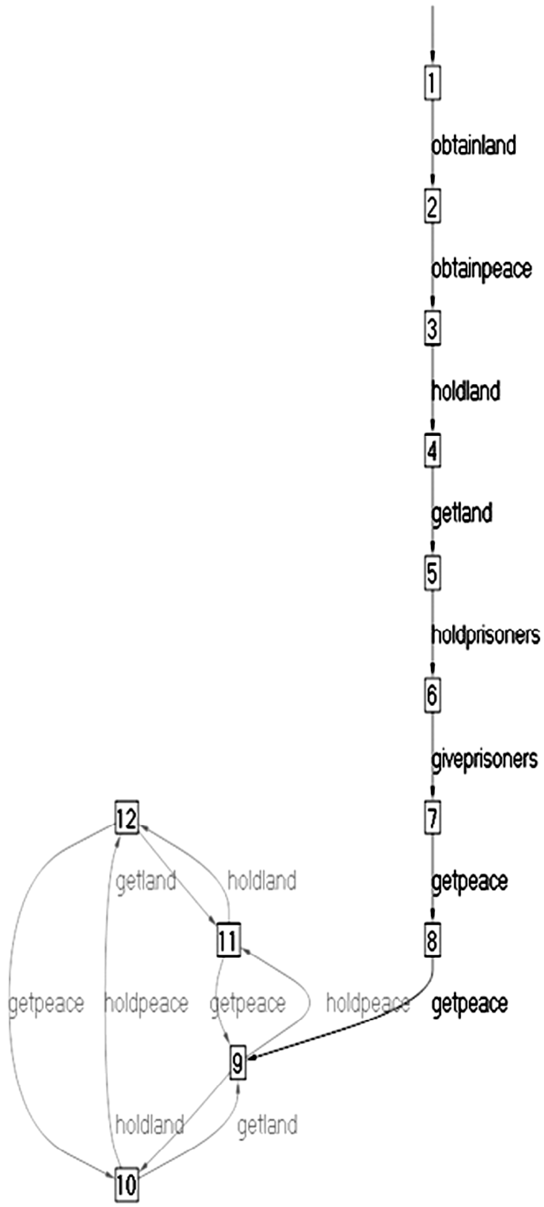


Figure 10: Counter example of givecaptive

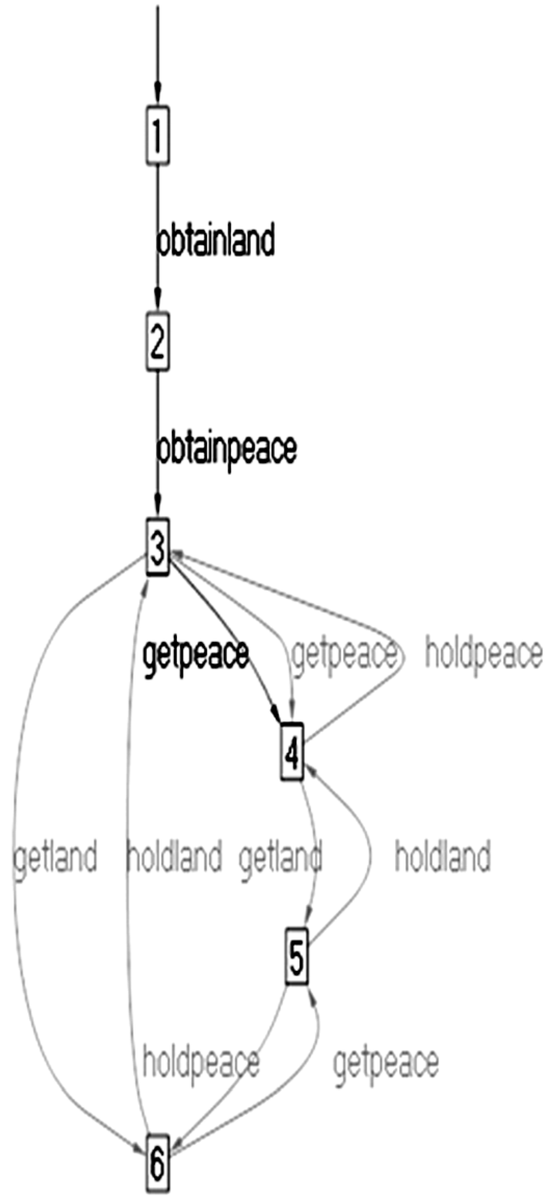


Figure 11: Counter example of giveprisoners

givecaptive, Figure 12 and givecaptive in the context of giveprisoners, Figure 13.

Consequently, by applying strong global fairness, that employs the current state and event (not only the event) as a context [17], on the underlying CSP model, the transition machines of Figures 12, 13 could be obtained. In Figure 12, state 5 and holdcaptive yields a particular context from which are reach state 6 and givecaptive context. That context as such enables us to reach state 7 and holdprisoners context that yields state 8 and giveprisoners context. From that context we might reach state 10 and getpeace context from which the final state (state 1) is reached. In the same sense Figure 13 can be directly interpreted.

Thus in conclusion, the dispute is resolved at two levels:

1- giveprisoners in the context of givecaptive and givecaptive in the context of giveprisoners.

2- land/peace interleaving i.e. C1 & C2 might exchange land and peace.

6. COMPARISON

This section includes a comparison of FISA with the works of other two groups [9, 1] that are concerned with decision making in the domains of situation

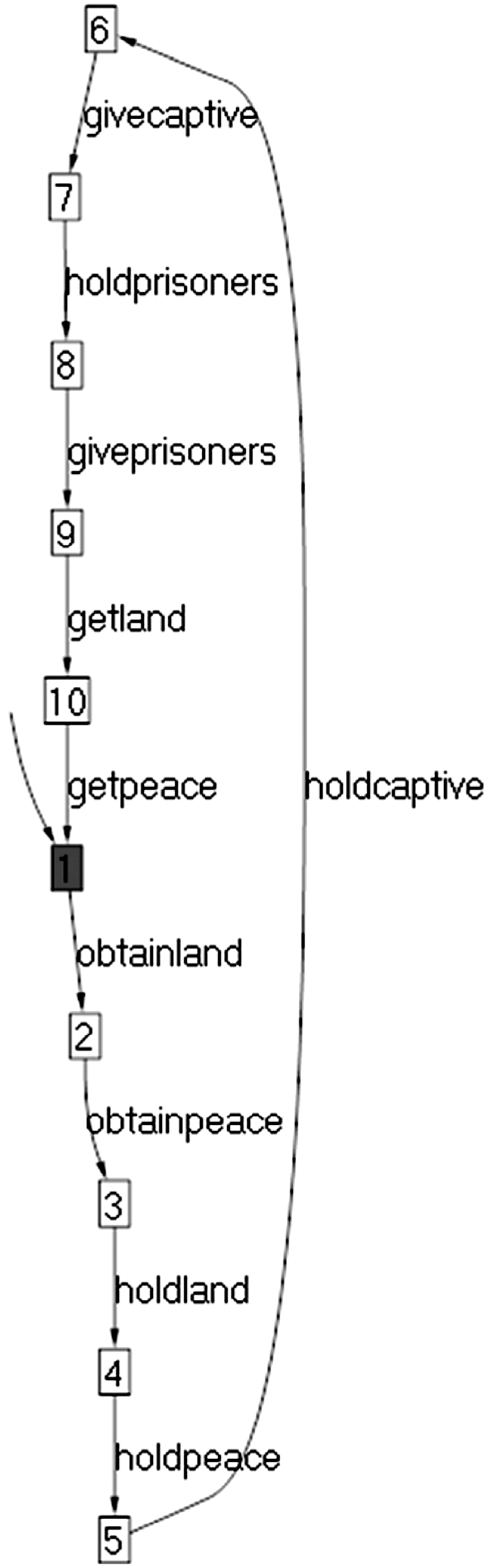


Figure 12: One trace for givecaptive from step by step simulation after applying Strong Global Fairness

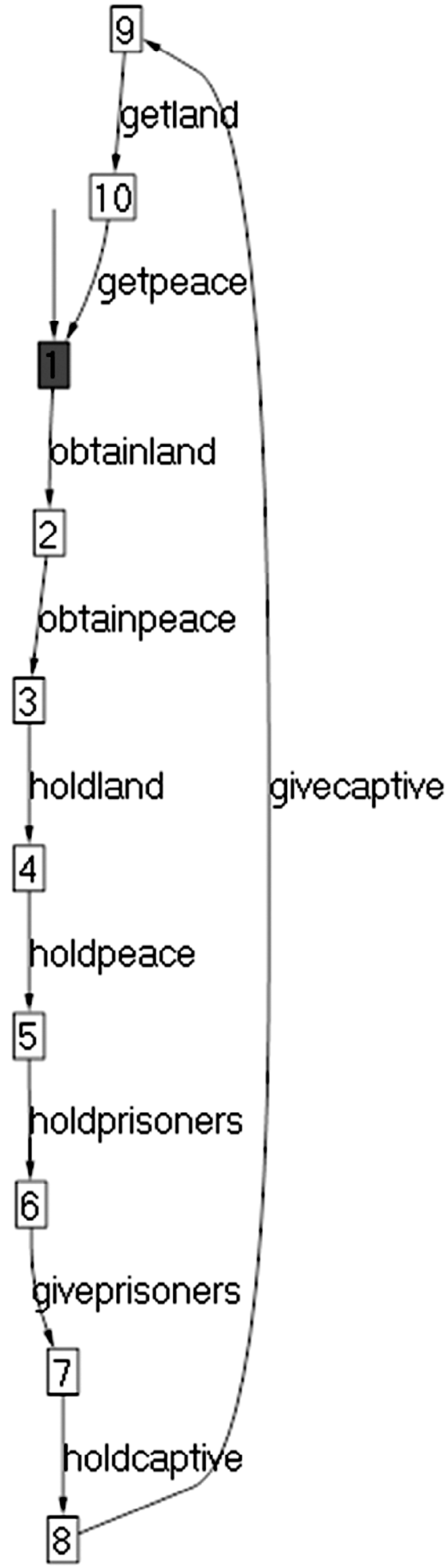


Figure 13: One trace for giveprisoners from step by step simulation after applying Strong Global Fairness

awareness and situation analysis. Testing a prototype of FISA [18] allows us to compare it qualitatively, Table 1, with similar related works. Despite, the fact that the comparison, given in Table 1 is limited (because the published materials are confined) it is obvious that FISA can be relied upon with the following advantages:

(i) Machine generation of the problem (dispute) model.

(ii) Finding out the model deadlock, if any. In this case a counter example is proposed.

(iii) Exploiting fairness constraints at various levels, to handle problem nondeterminism and performance reachability analysis for the underlying assertions to check whether, or not, a particular goal is reachable.

Table 1: Comparisonof FISA and other related works

Item		*SAW and SA* *[1]*	*SA* *[9]*	*SAW and SA* *FISA*
1	Sources	Uncertain spatial location information about real-world events (PDF files) from two different sources (Police department reports and newspaper articles).	Structure reports from non-physical systems (e.g. political, social networks, economics, and information flows). Intertwined with physical systems (e.g. infrastructures, and military systems).	Raw data news (text files and PDF files).
2	Tools/Methods to obtain Concepts	Mapping free text into Spatial Expressions (such as *near*, *behind*, and *infrontof*), Identify of the query requirements of SA applications using Quad-Tree Indexing framework, and efficient algorithms for query processing.	Agent-based models, systems dynamics models, Bayesian networks, Linear program models, and discrete-time models.	Extractor to obtain relevant paragraphs, topic mining to get topics and their probabilities, sequence mining to obtaining events sequences, Bayesian networks to decide the resources and events and Process analysis to check the possibility to find a solution(s).
3	Deadlock Discovery	No	No	Yes
4	SolutionPaths	No	No	Yes
5	Tasks	Proposes an approach to probabilistically model and represent event locations described by human reporters.	Improving the accuracy and reliability of the information available to the decision makers. Describes analysis and presents planning tools.	Solve political dispute problems.

7. CONCLUSION

This paper has presented a framework for intelligent situation analysis, FISA, which could be used to resolve political dispute. The framework, as such, succeeded to crass the gap between the looseness of political situations and the rigour of formal logical methods. The proposed approach is based on making use of a layered architecture that consists of four modules. These modules are relied upon to provide topic retrieval, sequence mining, probabilistic reasoning and process analysis.

The last module is the case of FISA. In that module, the code that represents the underlying system is machine generated and the corresponding processes are expressed in CSP. It has the ability of discovering deadlocks, if any, and proposing counter examples if-needed. As the political disputes, by their nature, are nondeterministic, FISA exploits LTL fairness constraints, at various levels, to reach its goal (dispute resolution).

A realistic study is given in details in order to prove the concept and to emphasize FISA capabilities. Such case study describes a mediation based political dispute that includes two struggling countries and a single mediator. The available resources have caused the struggle. Some of those resources are permanent (strategic) while the others are temporal (tactical). Despite the dispute complications FISA could devise a resolution by making use of strong global fairness where the solution is fairly seeked in all possible contexts (not only in one context).

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