Reasoning with Plans

Semantic Relationships among Interdependent and Contingent Landuse Plans

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Abstract

By their very nature, plans are situated in the context of other plans, which were made, are being made and modified and intersect in spatial, temporal and functional scopes. More informed decisions can be arrived at by reasoning with plans when deciding what to do. By harnessing the situated nature of the plans with respect to other plans rather than by relying on a single plan, we acknowledge that authority to act is distributed. To recognise which actions or which designs or strategies are alternatives, partial substitutes, contingent or otherwise interdependent on other actions is a crucial component of our reasoning about what to do and when. The semantic relationships of actions within a plan illuminate the relationships of actions among multiple plans of multiple actors about similar or related issues. This paper builds upon the fundamental advances over the last decade in the ontology of spatio-temporal settings and makes a case for building planning information systems that support reasoning with multiple plans as a way of improving the efficacy of plans.

Keywords : Plans, Substitutability, Interdependence, Urban Ontology

1 Introduction

Plans are made to be *used* in future decision situations in which investments and changes in regulations are interdependent and are faced with uncertain outcomes. A plan does not exist in isolation but should relate to other plans of the same actor and plans of other actors. To effectively use plans in these decision situations, explicit recognition of relationships with plans of others is needed. This paper tries to identify ways in which these relationships can be expressed semantically and used to reason with plans when deciding what to do.

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Using stylised cases from Champaign and McHenry counties in Illinois, this paper expands the typology of intentional actions in the context of urban development as set forth in Hopkins et al. (2005). It argues that discovering substitutability and interdependence of actions among various plans that were made and are being made is important in decision situations. Keeping track of decisions, as Kaza and Hopkins (2006b) claim, allows us to use and update plans more effectively than just making them for their own sake. Rejecting the idea of hierarchy of plans by geographic scope, this paper develops a model of considering plans of many actors by identifying relationships of partial substitutability, complementarity, functional interdependence and temporal sequence of actions. This has implications for the way that landuse plans are used and thereby also influences how plans are made.

We frame our starting points differently from many planning scholars. Plans are not regulations. Plans are not about collective choice procedures. Plans are not predictions about the future. Plans are not utopian visions about the form of cities. They are information about intentions of various actors. Plans may be formal or informal, secret among a group or public, serve one group's interests or another's, contradict each other, be used by the actors who made them or by others, and be of intersecting scopes across time, space, jurisdiction, and function. We build upon the claims that plans are records of intentions and should guide decision-making and action-taking. If plans are indeed records of intentions, then decision makers[1] should consider their own and others' intentions about actions that are contingent and interdependent.

The relationships of actions and intentions and their effects in planning is well recognised (e.g. Bratman, 1987). In particular, a planning process seeks to acknowledge and address the interdependencies among future actions—of one's own (Morgenstern, 1987; Huber and Durfee, 1995; Knaap et al., 1998) and of others (Bruce and Newman, 1978; Healey, 1997). However, the field of planning has recently focussed on the method of planning itself while ignoring the information that the planning efforts generate,information that is captured to some extent in plans. Rather than investigating whether and in what ways plans work in urban settings, much of the scholarship about planning and urban development avoids the specific phenomena of plans. We aim to focus the discussion on plans.

Plans of a particular actor[2] should at the very least, seek to address the interdependencies of multiple actions of the particular actor. In Bratman's terms, planning by an individual, attempts to address the 'temporally extended' agent's choices of actions. But, as Bratman recognises, we are also 'socially extended' agents. In simpler terms, we also have to recognise the interdependencies of our actions with actions of others. Needless to say, other actors have 'publicly available' plans as well. When authority is distributed, and players are numerous, interdependencies of actions of multiple actors are never fully resolved at the time of making of a plan of one actor. Thus, we ought to recognise the multiple plans as useful information to our own decision-making and explicitly consider others' plans.

[1]A decision maker could be any number of multiple entities but treated as a singular entity explicitly for this particular purpose.

[2]This paper uses terminology that is described in Hopkins et al. (2005). In particular, actor, asset, activity, action are higher order descriptors of urban development of which several follow. Also see `www.rehearsal.uiuc.edu/projects/pml` for more information.

Hopkins (2001) argues that plans work in five different ways 1)agenda, 2) policy 3)design 4)strategy and 5)vision to deal with interdependence and uncertainty of actions. Different types of relationships between intentions and actions that have not yet been realised, are exemplified by first four of these. Agenda is a mere listing of actions. Policy is a rule, which can be applied repeatedly. However, designs and strategies are more interesting because the relationships they typify are important to all future directed actions. Designs are fully worked out relationships between intents. Strategies, on the other hand, explicitly deal with uncertainty by specifying actions (or a set of related actions) under various likely but uncertain conditions (see figure 3). Thus, an agenda merely is a degenerate design and a policy is a degenerate Strategy. In this paper, we thus focus our attention on designs and strategies

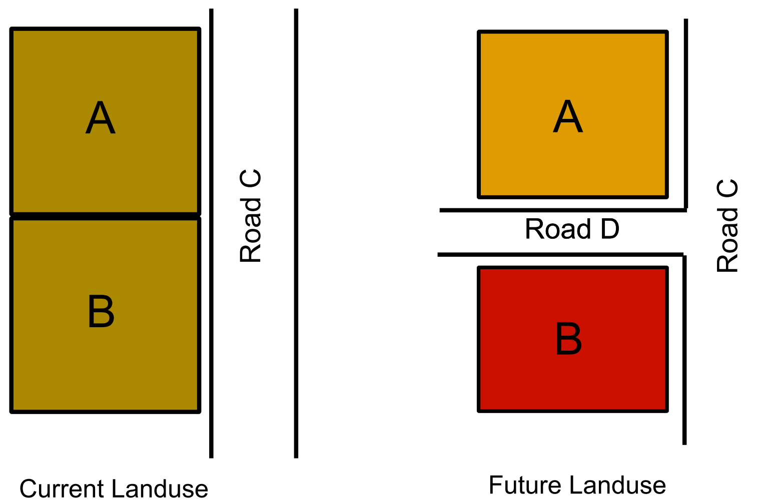
Actions, and therefore decisions that precede them and intentions that support them, are related to other actions in spatial, temporal, functional, and mereological (part/whole) ways; all of these are design relationships. Further, they are related to actors, in regards to ownership of the action. They are related to assets and activities in the changes they bring to them. On the other hand, two actions are interrelated as strategies if they are responses to likely but uncertain events. For example, building of a road and approval of a zoning change in the parcel adjacent to it only when the road is reasonably certain to be built are interdependent actions. They are related in their uncertainty about whether the road will ever happen or not. A plan-maker ought to recognise these interdependencies and make them explicit in the plan to the plan-user.

In this paper we sketch, how the relationships of actions within a plan help us discover the relationships of actions across plans by relying on examples and heuristics. We do not establish a comprehensive set of relationships between actions within designs and strategies or even a general framework. The first is futile and the second is discussed elsewhere in Keita et al. (2004); Worboys (2005); Hopkins et al. (2005). We argue that it is important for us to seek these relationships across plans in order to make them more useful in decision making. We support these arguments from stylised cases, without presuming that they reflect the entire gamut of relationships that need to be identified and sought. We then make arguments that these kinds of reasoning should be incorporated into planning practise to improve the efficacy of plans. We propose that building Information Systems to support this activity should rely upon the substantive knowledge of how urban development works and procedural knowledge about how plans are used.

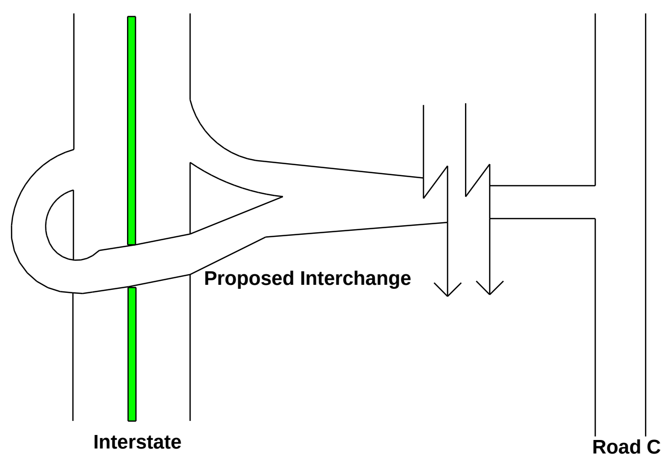
2 Relationships between actions: Interdependence & Substitutability

In this paper we are concerned with the semantic relationships of interdependence and substitutability of actions. Planning acknowledges, actions are situated with respect to other actions in space, time and functional context. The relationships between actions of one actor are worked out in their designs and strategies. However, cognitive limitations and inherent uncertainty of dependence of one's own action on others' actions preclude us from considering all such relationships.

Figure 1 explores an example of two plans about the same region, but at different scales and by different actors with different jurisdictions and interests. The local plan (figure 1(a)), proposes as a design, that a new road D be built connecting to road C and the future land use of the adjacent lots of A and B be commercial and high density residential when the road gets built. Actions are situated in space. However, the spatial relationships



(a) Local Plan



(b) DoT Plan

Figure 1: Interdependence across plans

such as distance, or adjacency are primarily due to the assets they change[3]. That is,

[3]Actions are not only about investments (changes to assets). They are also about changes to regulations. Rezoning a parcel is a change to regulation. It permits, prohibits or otherwise regulates certain rights of the owner. See Kaza (2004). We gloss over these subtleties to emphasise some key points.

when actions are about changes to assets which have spatial relationships. Building a new road D and rezoning the parcel A in the figure 1(a) are spatially adjacent, because and only because the road and the parcel are spatially adjacent. The building of D also invariably alters the area of A. However, actions may also work to change the relationships between assets that exist. In figure 1(a), at the current state, the two parcels A and B are related through adjacency relationship. The action of acquiring the RoW by the City, fundamentally alters, and in this case destroys the adjacency relationship between the parcels[4].

Actions are situated in time. More generally, they are temporally situated with respect to other events. While some actions have an explicit time stamp associated with them, for the most part the time attribute of the action is determined by its contingency relationship with other 'events' or actions[5]. In figure 1 the rezoning of the parcel B is contingent on building road D which is in turn dependent on the existence of the interchange. If a plan specifies explicitly that the rezoning may take place only after the RoW is acquired, then the plan perspicaciously does not give a specific date at which the road gets operational. We can thus infer that rezoning is likely only after the interchange is built and after (or as in most cases, simultaneously) RoW is acquired.

Actions are situated in context. There are functional relationships between actions. The functional relationships of contingency, priority, substitutability and parthood relationships are the focus of this paper. These substantive relationships are not logically inferable from the simple attributes of the actions, but have to be made explicit through expert knowledge and are very specific to the location, legal regime and function. A decision to build an airport, spawns a number of other decisions from acquisitions of land, creation of managing entities, to location of runways in relation to neighbouring subdivisions. Thus, these actions are associated with the decision to build the airport. However, taking them individually without accounting for the relationships, does not completely specify the building of the airport.

We explore different relationships that are between actions in many different plans about a particular location or a function, or by a particular actor made at different times. We focus primarily on recognition of interdependence and substitutability of actions and use the discovery of these relationships to find other relationships that are potentially useful. We discuss the different types of interdependence and different levels of substitutability among actions in the following sections.

3 Interdependence

Interdependence of actions is at the core of planning what Hoch (2005) among others, calls 'the co-ordination problem'. The choice of an action depends on choices about other

[4]We do not discuss the question of 'identity' of assets over time in this paper, while still acknowledging its profound importance for reasoning with plans.

[5]Actions are intentional events

(both one's own and others') actions, not unlike formulation of strategies in games, even when these other choices are uncertain. Plans try to address interdependence of actions, *ahead of time*, by specifying designs and strategies.

Building a road at a particular location, for example, is dependent on acquiring the right of way (RoW). The intentions of the sanitary district to extend the sewage interceptors are important in considering where to build the road. The local utilities' plans of extending other infrastructure depend on the city's decision to build the road and when. The acquisition of the RoW is further dependent on the decision of the rights holder, potentially another actor, about when and how to cede or sell the rights of easement to the city.

To discover interdependence among related actions, we could use the known interdependence among actions, for example actions expressed as designs and strategies within a plan. If a plan recognises building of a ring road, as being interdependent with the building of an interchange by a different set of actors, then we can recognise that acquiring rights of way for the ring road is interdependent with the interchange. To this end we can use the relationships of actions within plans to discover interdependence among plans.

Implicit in the characterisation of figure 1(a), is that acquisition of RoW for the new road, would change the characteristics of the parcels (area). The plan explicitly recognises the interdependence of the zoning change with the building of the new road. On the other hand, the state Department of Transportation's (DoT) plan (figure 1(b)) calls for building a new interchange, which will connect to Road C. The building of the interchange is by no means certain; the approval requires co-ordination of the Federal, state, local agencies and various other actors. Its final location may also be uncertain even after all the parties agree to fund the construction in principle. If the purpose of D is to enhance the connectivity of C with the interstate, then the location of D, to a significant extent, depends on the location at which the interchange gets built. Further, D may also share a temporal relationship with the interchange. If there is no credible commitment by the Federal actor to fund the interchange, the acquisition of the RoW for D by the local government is unlikely. A speculating private developer could be reluctant to invest in parcel A for the want of access. In other words, the local government may choose to acquire the RoW, *after* the negotiations among different actors about the interchange generate a high level of commitment. The decisions of the private developer, who may or may not be represented in the negotiations about the interchange, are thus, interdependent with the decisions of any number of actors. This example also illustrates that existence of interdependence on others' actions does not mean that one's own decisions are completely determined externally.

In a situation, where the rezoning of a parcel from agricultural to commercial use is to be decided, the planning commission, and by extension the local authorities who ultimately make the decision, should have access to both the plans of the local government as well as the plans of the DoT. The developer who requests such a rezoning understands that her decision to invest in that parcel should be informed by both the available plans and changing situations. The decision to invest in a speculative development should then include consideration of the probability that the interchange will be developed at a particular location and at a particular time. If a plan recognises the interdependence of rezoning parcels A and B with the building of the road D, then it can be infered that the rezoning is interdependent with the interchange. If another plan specifies the dependence of the interchange on the completion of a mandated study on the traffic effects of the interchange, then by transitivity, the rezoning decision is also dependent on the study. An interest group that has an interest in protecting agricultural land may thus find scuttling the study a viable action to take toward achieving its goals. In addition, each actor may consider other sources of information, including information only some actors are privy to, in making judgements and decisions.

Actions are also interdependent when they cannot be pursued without other actions being in place. This is the functional priority of one action over another. A temporally prior action need not be functionally prior. The owner of parcel A may propose to develop the parcel into a commercial strip before the interchange gets built. The interchange does not require the commercial development to be in place. However, the development of the parcel is functionally dependent on the provision of access, which is already provided by road C. In such cases, the city in thinking about its connectivity to a proposed interchange might require ceding of the RoW as a pre condition for approval for development. Actions are interdependent when the logic behind pursuing the one action requires the other.

Mitigating actions are also interdependent actions; the perceived ill-effects of a particular action are remedied by other actions. The action set, the combination of actions, has to be pursued to preserve the *status quo ante*. This kind of interdependence is often seen in the accompanying environmental reports of transportation proposals or noise buffers between incompatible landuses.

In the following sub sections we consider these interdependence relationships chiefly complementarity, priority, and contingency along with how urban ontologies that account for them are useful in reasoning with plans on what to do and when. We then use these concepts of interdependence along with consideration of alternative actions to discover further interdependence relationships between actions within and among plans.

3.1 Complementarity

Two actions are complementary with respect to an effect if they enhance the effect together more than either action when pursued alone. For example, in figure 2, if the intent is to divert traffic onto IL 23 passing through Marengo, then the interchange proposal between IL 23 and I 90 (shown as I in the figure 2) and the ring roads A and B are complementary. However, the combination of building roads A and C together, with I are not complementary. On the other hand, A & C are complementary actions, when expanding the interchange between US 20 and I 90 outside the county.

The decision to build either interchange, does not necessarily consider the configuration of the ring road. The location of the ring road on the other hand is also not entirely dependent on which interchange gets built and when. If it is likely that both the interchanges are built in near succession, then pursuing the construction of all three segments of the ring road makes sense. However, if one interchange is an alternative to the other with respect

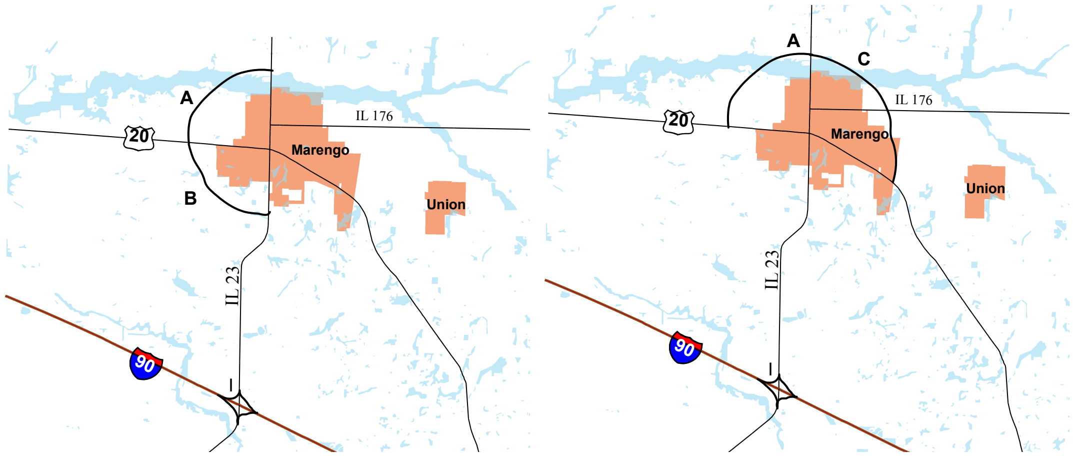


Figure 2: Complementary actions — Interchange and Peripheral Road

to budgetary constraints, then choice of the segments to suit the desired traffic patterns is useful.

A short explanation of the context is in order. The city of Marengo is in the south-west quadrant of the McHenry County, IL and is served only by one interstate I 90. This explains the enthusiasm for the County to get the interchange *I* built. The Kishwaukee River runs north of Marengo and is considered a significant natural resource. Hence the plan by the conservation district seeks to preserve the river area, by acquiring rights to the parcels and thereby preclude incompatible development and uses. One of the large portions of contiguous high quality farmland in the county is located south of the interchange, hence the non-profit group whose interest is soil conservation appeals for preserving this swath of land from development and lobbies for its protection. The question of which interchange to be built is complicated by the fact that I 90 is a toll way. The construction of a full interchange, therefore, also requires construction of toll booths with sufficient distance between two points of toll collection.

The ring road is depicted in the local plan of the City of Marengo. The plan of the neighbouring Kane county, includes the expansion of the interchange *J* between US 20 and I 90 (not shown in the figure), and upgrading of the toll booths associated with that interchange. For the city of Marengo to decide which segments of the ring road need to be built, it has to understand the commitment of various actors to building which interchange and thus be able to represent these expectation in its 'knowledge base'[6]. The following is a schematic representation of major relationships of actions in different plans[7].

```
Marengo Plan Agenda 1:  Build (A)
Strategy 1:  If Interchange I gets built then build (B)
else build (C)
```

[6]This does not belittle the benefits of human knowledge that is not easily encoded in a logical system. The knowledge base is presumed to conceptually include both human expertise as well as computer databases. The argument here is merely for a computer supported system to help human reasoning.

[7]This example though partly based on the existing plans of various agencies, is modified to suit illustrative purposes hence should be treated as stylised and fictional.

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Desgin 1 :  Connect (A ∧ (B ∨ C))( Connect A with either B or C)
⋮

Mchenry Conservation District Plan
Design 1:  Acquire contiguous parcels along the Kishwaukee river
Design 2:  Acquire land before Marengo commits to building A or C
⋮

McHenry County Plan
Agenda 1:  Support DoT plan to build Interchange I
⋮

McHenry Soil Conservator's plan
Goal 1:  Preserve the high quality farm land, south west of I 90
⋮

Kane County Plan
Agenda 1:  Support DoT plan to expand interchange J
⋮

IL DoT Plan
Alternatives (Expand (J), Build (I))
Strategy 1:  If (funding is X ∧ favourable recommendation of study )then build
I, else if the funding is Y then expand J
⋮
```

As noted in the schematic representation, Marengo's plan explicitly recognises the alternatives put forth in the DoT's plan and situates Marengo's actions in strategies to enhance the intended effect of traffic diversion. However, the conservation district only recognises the plan of the city to build the ring road. If the plans of the neighbouring Kane and McHenry counties are available along with a reasoning system, a simple query would determine that the conservation district's decisions are dependent on the city's plan, which is further dependent on the State DoT's plan and the counties' plans. Similar reasoning can be followed by the soil conservation group in McHenry county in their decision to support the interchange J in Kane County. By reasoning that the conservation group would support the building the interchange J to the detriment of building the interchange I, the McHenry County might enact regulations and provide incentives to preserve the farmland.

As has been demonstrated here, it is useful to have an ontology that not only represents one's own plan, but also represents others' plans in the same general ontological framework. Once such representations are fashioned, we can introduce a fairly minimalist reasoning system to help consider decisions about which actions to take and when. Even when we do not explicitly represent the plans in an ontological framework, reading others' plan with the purpose of seeking actions complementary actions to our own actions and goals makes our own actions more effective. Without sharing these plans and without using them in formulating our own actions, we ignore useful information that is available and reduce the efficacy of our own plans.

3.2 Priority

An action is prior to another either temporally or functionally. If action A occurs before or after B, then they share a temporal relationship. Allen and Ferguson (1997) discuss the representations of temporal events and relationships and reasoning with them. In this section, we are primarily concerned with the functional priority relationships of actions. An action A is functionally prior, if it is necessary before the occurrence of B. In other words, if we decide to do B, we have implicitly decided to do A.

These functional relationships should be generated from the local and legal context. If we decide to build an airport, we then have also committed to acquire the land and zone it appropriately. Similarly, building of a road requires RoW be in place and extending the trunk sewers necessitates, utility easements be in place. These functional relationships between actions are well understood by planning experts and should be easily translatable into ready references for access not unlike APA (2006) or Watson et al. (2003). On the other hand, standard land use planning texts like Kaiser et al. (1995) could also be used to crystallise existing professional knowledge to identify the functional relationships.

In the earlier example (figure 1) of the decision situations of various actors in McHenry County, the interchange I can be built only after a Federally mandated study is complete and produces a favourable recommendation. The study thus is a functional prior to the building of the interchange I. On the other hand, building the interchange I is not prior to building roads A, B, or C, because it is not a necessary action. The construction of either ring road is not necessarily dependent on the conclusion of the study even when complementarity relationship holds.

If the soil conservation group recognises the priority of the study and its recommendations as necessary for the building of the interchange I and if it believes that building I is inimical to its goals, then it could reason that lobbying for strong representation of its concerns during the study process would produce an unfavourable recommendation, and thereby not bringing about I. This course of action when it is made explicit in their negotiations with the McHenry County, which favours the interchange, could enact regulations that conserve the farmland to assuage the concerns of the conservation group.

3.3 Composition

Actions can be compositions of other actions. A `Create TIF District` action can be viewed as a single action or as a collection of `Certify Tax Base` → `Notify Public` →

`Adopt Redevelopment Plan` → `Sell Bonds`. These are the part-whole(mereological) relationships among actions. The granularity of actions (Worboys and Hornsby, 2004) is important in reasoning with plans.

One way to look at the composition relationship is to view it as a design relationship among multiple actions. In other words, the functionally sequential actions such as `Certify Tax base` etc. are present in a design of creating the TIF district. Once the design is specified we can encapsulate the lower order actions and specify the relationships between higher order actions. If however, there is an interdependence relationships between lower order actions and some other actions, encapsulation looses information. But such encapsulation preserves tractability of reasoning without resorting to decomposition to atomic actions and relationships.

Mereological relationships are studied in the abstract representations of geography in Casati and Varzi (1996). We argue that similar reasoning could be applied to actions and events in understanding the relationships between them. Parthood relationships are typically considered partial orderings; reflexive (A is a part of itself), antisymmetric (If A is a part of B and vice versa then A is B) and transitive (If A is part of B and B is that of C then A is part of C). We argue that recognising actions in the urban development context share parthood relationships, among other design relationships such as spatial, temporal, and functional, will help us in uncovering relationships among actions. For example, if action A is part of B and B is temporally prior to C; if D is part of C we can conclude that A is temporally prior to D.

As will be discussed in the later sections, multiple representations of the same action are useful for different purposes. If an action is a composition of others, we could reason that any interdependence relationship the higher order action has with other actions may be directly inherited by the lower order actions. If creating a TIF district is contingent on the availability of jurisdictional authority to create such a district, then in the context of the creation of the TIF, all the actions that compose it are contingent on this legislation by the state. However, as we will also see in the later sections, substitutability relationships are not directly inheritable.

4 Alternatives

Alternatives are mutually exclusive actions. The exclusivity arises either because of capability constraints of actors or locational constraints of situating the action in a spatio-temporal setting. Keeping track of alternatives as they are modified, discarded, considered and used in a decision making process is useful. In the subsequent sub-sections we discuss the ideas of complete and partial substitutability.

4.1 Complete Substitutes

The most complicated and useful exercise of planning is to recognise uncertainty of outcomes of actions and plan strategically with respect to goals and criteria. Thus in a

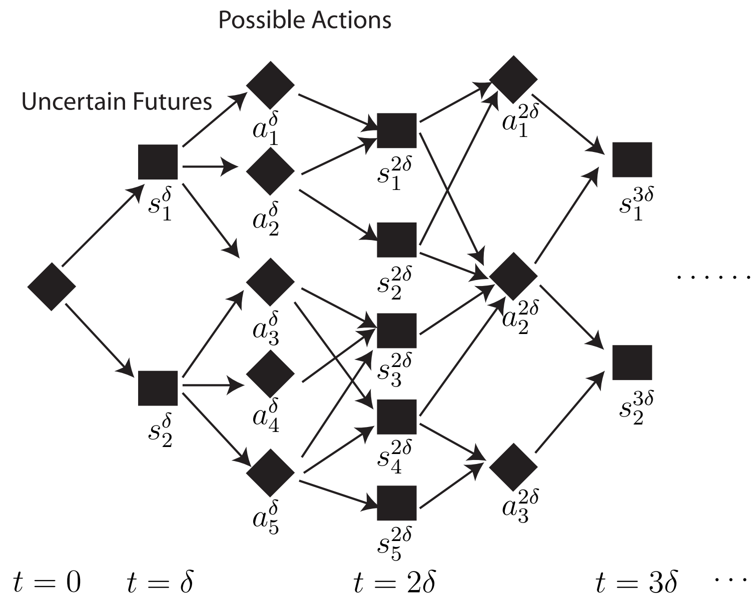


Figure 3: Inferring alternatives from strategies

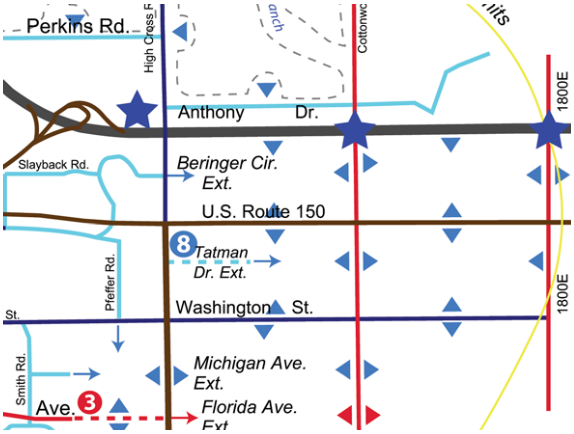
particular plan, strategies specify to sufficient depth, possible outcomes as well as possible actions in response to those outcomes (figure 3). The strategy could thus be represented as a directed graph delineated by events[8]. In such cases, alternative actions are actions that share same neighbours from edges coming into them with respect to the particular uncertain state. Actions a_1^δ, a_2^δ and a_3^δ are alternatives with respect to each other in response to state s_1^δ. Actions $a_1^{2\delta}$ and $a_2^{2\delta}$ are alternatives to each other but not with $a_3^{2\delta}$. It is fairly obvious that transitivity property does not hold for inferring alternatives: $a_3^{2\delta}$ is alternative to $a_2^{2\delta}$ but not to $a_1^{2\delta}$.

Alternatives can be of different types because:

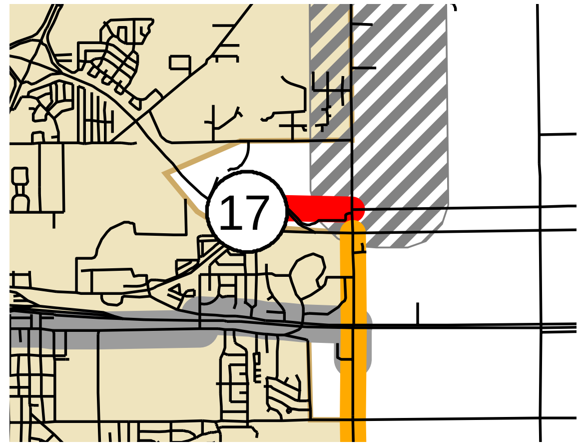
- Multiple entities cannot occur simultaneously.
- 'Same' entity cannot happen in multiple instances.
- Multiple things may not occur in the same place.
- Same purpose can be achieved by different actions.

The possible locations of the interchange in figure 4(a) are alternatives represented as stars. One interchange at one location can be built, but not all three because they are intended to serve the same purpose and they would create traffic conflicts if built close together. But in considering where to build the new interchange, it should be noted that there are three alternatives, which were considered at the time of the plan to dominate all

[8]The representation in figure 3 uses time as opposed to events. Passage of time is one kind of event. The occurrence of any state could be an event. See Worboys (2005).



(a) Urbana Plan



(b) CUAATS LRTP

Figure 4: Alternatives & Interdependence across plans

other choices of locations, even though no one of these three alternatives dominated the other two, at the conception of the plan. In the future, as additional decision situations occur, this set of available alternatives may change, be reduced or expanded.

It is not useful to think of these three alternatives as separate actions, to build or not to build each one, because they share an intention. The actions are alternatives *with respect to* each other. One can either build the interchange at one location or can build it at another or at neither place. That is, if I decide to build an interchange at one location, I automatically also decided that the interchange is not going to be built at the other location. A particular alternative thus has to include relationships with other alternatives. As alluded to earlier, designs are compositions of actions, thus designs could be alternatives to each other. Thus in the case of Marengo example, the DoT plan would represent expansion of interchange J and building interchange I as alternatives.

If a plan specifies an alternative action in recognition of other's intentions, then the planning process has recognised the other's plan and represents its intentions about actions in its knowledge base. For example, a transportation plan might specify building extra lanes on an interstate highway whereas a plan by the local business organisation, in a directly contradictory approach, might specify that the rail network should be strengthened instead of building the lanes. Implicitly these are alternative uses for the same budget capacity toward the same intent for accessibility. When one plan recognises that the other includes an alternative action set, then a locational query could recognise the semantic relationship of alternatives in the two plans. Also two actions can be recognised as alternatives if they produce the 'same' effect.

If two plans specify two different strategies as a response to a particular uncertain outcome, say state $s_2^{2\delta}$ in figure 3, then the two strategies are alternatives starting from the particular uncertain state. Even when one strategy does not exactly consider the same uncertain outcomes as the other strategy, having information about both strategies is useful information in considering which outcomes are more likely than others, which actions minimise the worst outcomes, or which action protect future options.

In most cases, however, plans are circumspect about alternatives. To recognise that two actions are alternatives, expert knowledge about the situation is usually required. Such knowledge might involve, for example, recognition of budgetary constraints, which may preclude pursuing one kind of action while simultaneously pursuing another. There may not be sufficient budget or borrowing capacity to build a new fire station and a new highway interchange; the two actions become alternatives with respect to budget even though they are not alternatives with respect to intended purpose. The knowledge about 'priors', which is necessary and cannot be pursued simultaneously, might be used to recognise the actions as alternatives. It may not be possible to build a new subdivision, for example, until the sewer services are extended. We can attempt to recognise the alternatives from the issues of location in a geographic context, location in a temporal context, and responsibilities actors and capabilities of actors, including their jurisdictions and budgets. Once such recognition is made, we can use the substitutability relationship to find other relationships with other actions.

Figure 4(b) is an excerpt of the plan by the Champaign Urbana Urbanised Area Transportation Study (CUUATS), which advocates building the ring road around the Champaign Urbana region. However, the location of the ring road, north-east of Urbana is contingent on the location of the interchange and thus leaves the decision about the location to a later date when the decision about the interchange is being made. The Urbana comprehensive plan makes it explicit that the decision about the interchange is not yet made and all the three alternatives are in contention. If CUUATS' plan explicitly recognised the interdependence, then we can infer the probable location of the ring road, as and when the interchange gets built.

4.2 Partial Substitutes

Partial substitutes differ from alternatives in that the actions are substitutable with respect to some purposes, not all. Alternatives are complete substitutes. A policy of subsidy for pollution abatement programs or a tax on pollution volume, are partial substitutes because they share the same intent of pollution reduction but produce different effects with respect to distributive justice considerations. An action A_1 is substitutable with an action

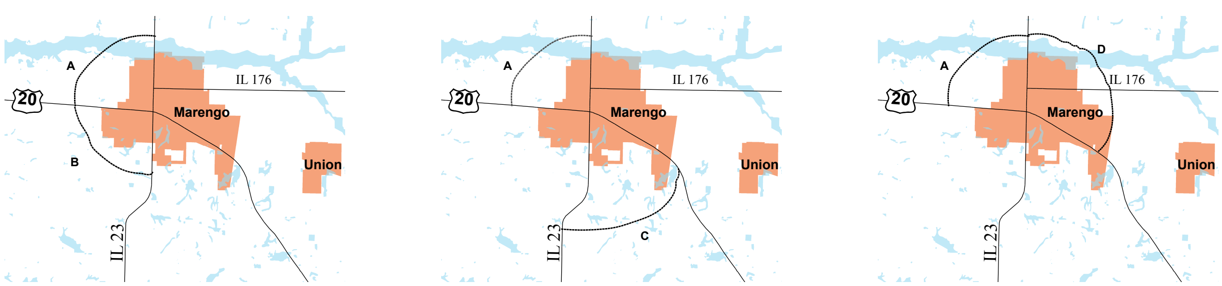


Figure 5: Partial Substitutability of Actions

A_2 if they result in the 'same' state Ω. To get at substitutability we may have to rely on intuition, and on previous cases in which substitutability was recognised and established — Case Based Reasoning (see e.g. Haigh and Veloso, 1995; Shi and Yeh, 1999). To illustrate an example of partial substitutability where projects of similar nature compete for approval, consider proposals A, B, C and D in different plans as also depicted in figure 5. The intent of A is to create a bypass for the traffic on IL 23. C and D create a bypass for US 20 both east and west of Marengo to IL 23, but not a bypass for IL 23. Thus they are only partially substitutable. In a similar fashion B and C are partially substitutable with A. Even when, as in the more interesting cases, actual location of B is different from that of A, they are partially substitutable with each other. To recognise the substitutability of the two designs one has to abstract the network of roads into a network of links and nodes with traffic patterns and query if both proposals accomplish at least some of the same purposes.

```
Plan1 :Agenda 12:  Improve B
Plan2 :Design 1:  Build A.
Plan3 :Design 4:  Build D and C
Plan4 :Design 3:  Improve B and Build C
⋮
```

Query1 : `Find proposals that link IL 23 and US 20`
Response

```
Plan1:  Agenda 12
Plan2:  Design 1
Plan3 :Design 4
⋮
```

Query2 : `Find proposals that will reduce the traffic on IL 23 in Northern part of the City`
Response

```
Plan1:  Agenda 12
Plan4 :Design 3
Plan2 :Design 1
⋮
```

Query2 : `Find proposals that will increase the traffic on US 20`
Response

```
Plan3:  Design 4
Plan4 :Design 3
⋮
```

To get at the semantic relationship of partial substitutability among the bypass links, queries 2 and 3 triggers a traffic simulation model for each of the available transportation projects and check if the traffic on IL 23 would be reduced. However if query 1 were to be asked, the recognition of topological relationship of connectivity is sufficient to recognise the substitutability. Thus the question of substitutability becomes a question of substitutes with respect to a particular attribute. If mere connectivity is the issue, then all the proposals are partial substitutes. However, if the intent is to find substitutes of an action that result in a state, in this case volume of traffic, then we arrive at different results. Alternatively the query could also be about the development pattern, instead of a pure traffic volume, in which case land use simulation coupled with traffic model should be triggered. As can be readily seen, the results of the queries would be heavily dependent on the assumptions of the models. In such cases multiple model framework and model triangulation are useful.

4.3 Representing Alternatives

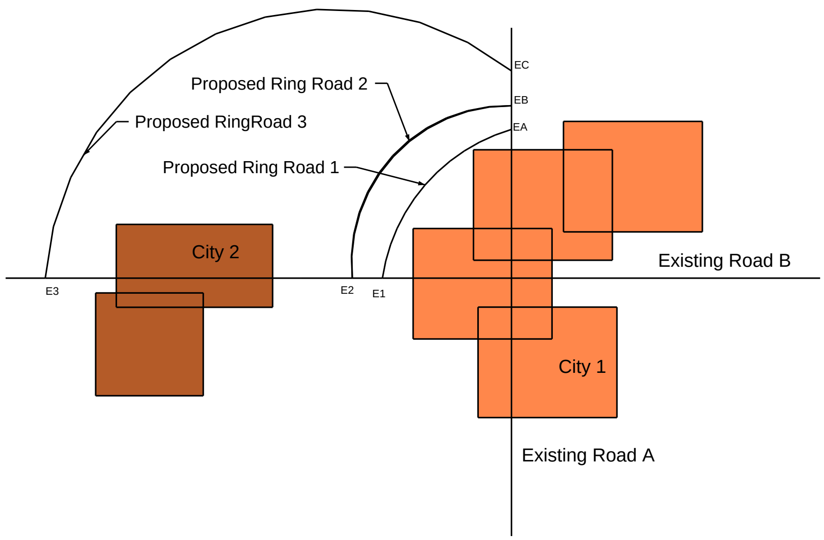


Figure 6: Alternative Ringroads

One way to represent alternatives in a knowledge base is to explicitly recognise which designs and strategies are alternative to each other. As shown in figure 6, the ring road 1 & 2 are alternatives because they differ only in locational attribute of the intention of City 1. However, the intentions that support the building of ring roads 1 and 3 are different and as such they are partially substitutable. If the City 2 also intends to divert its traffic away from the existing road B to A it should recognise the plans of the City 1 and that of other funding agencies and provide road 3 as an alternative to the ring roads 1 & 2.

However, some times the alternatives are uncountable. This situation is illustrated in figure 7 as in the case of the Urbana Comprehensive Plan about the location of the sub-collector streets. The main collector streets, or the RoW are specified in the city official maps. The preservation of connectivity relationships between these collectors is also important, but to represent them at a specific location perpetuates the idea of certainty about these sub collectors. Instead, the plan merely specifies that the locations should be decided later on and specifies rules about how the connectivity should be preserved. These are policies about connectivity which represent an infinite number of alternative locations for the sub collectors. The policies include specifying a minimum distance between any two roads and specifying that RoW's should be modified to suit the development proposals that occur.

Other methods of representing these policies include representing them with a probability field over space and using fuzzy sets and membership functions[9]. A field (Couclelis, 1992) is an entity whose values vary across the geography and can be considered an object (Cova and Goodchild, 2002) and thus representable along with others in a knowledge base. The probability field for each sub-collector has positive values between the two collector streets and is subject to modification by various policies regarding the minimum lot sizes in addition to minimum and maximum distances between sub-collectors. Thus any two proposals of location of sub collectors can be considered alternatives if their locations are within the extent of the field.

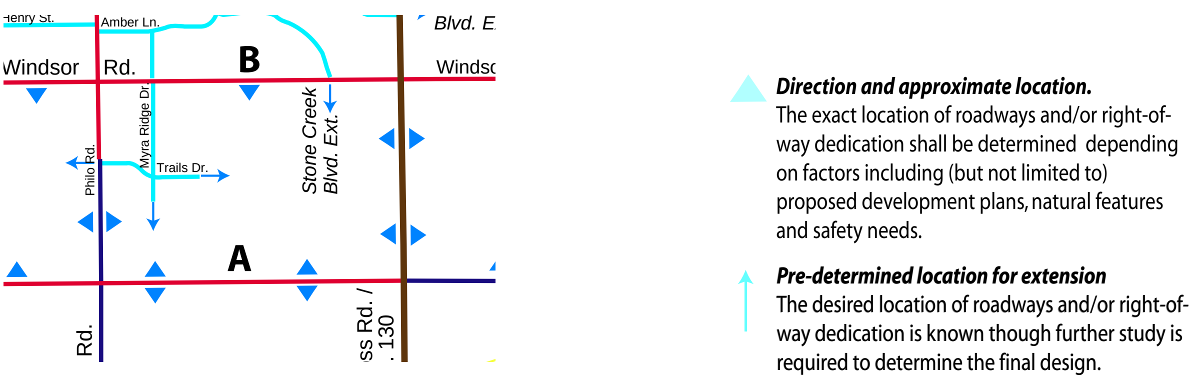


Figure 7: Infinite Alternatives

5 Non-uniqueness of representations

We make no claim that relationships of actions within one plan are adequately made explicit. In fact, we argue elsewhere that in some cases they are willfully not made explicit (Kaza and Hopkins, 2006a). This section illustrates an example of a plan for capital improvements in figure 8. This plan can be represented as an Agenda, a Design, or a Strategy. Say four new highway links are planned by a regional transportation agency as part of a long range transportation plan. Two of these links (O_1 and O_2) contribute to a ring road and three links (R_1,R_2 and R_3) increase radial capacity to and from the city center. The plan's intent is expressed as strengthening the core through increased access,

[9]In this case both serve the same function.

then enabling peripheral interaction if and when the suburban area grows to sufficient size. A simple approach is to model this plan as an Agenda with five Actions. In order to

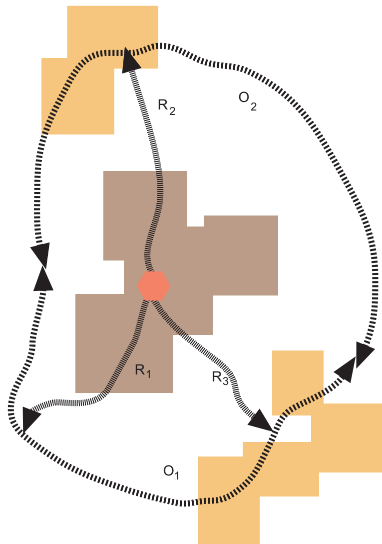


Figure 8: Infrastructure investments as Agenda, Design or Strategy

account for budgets and financing , the attributes of these Actions would include costs, revenue sources, and expected times of construction for each project. The Actions would be linked to a geography data set, which would be a network feature with each highway defined as a link. An agenda is a list of network connections

Build(O_1),
Build(O_2),
$\vdots$
Build(R_1&R_2&R_3)

This transportation improvements plan could also be modelled as a Design. In this case, the three radial links would be considered as a single design because they would be effective in strengthening the core if and only if all the links were built. Also the two ring road links would be considered a cohesive set because they would be effective in improving peripheral access if only both were built. The response or anticipation of developers would then consider the construction or anticipated completion of combinations of links rather than individual links. A design consisting of all the roads has design relationships among designs. A representation of such design would entail, that R_1, R_2 and R_3 be done in conjunction with the O_1 and O_2

ActionSet1(O_1, O_2), ActionSet2 (R_1, R_2, R_3)
NetworkConnect(O_1, O_2),
$\vdots$
NetworkConnect(R_1, R_2)
Connect(ActionSet1, ActionSet2)

Finally, this plan could be represented as a Strategy. In this case, the anticipated construction of the ring road links would depend on the prior construction of the radial links and the realization of the expected suburban growth because of the radial links. The timing of the construction of links and even the estimates of timing are dependent on the realisation of some state. A representation of strategy would include temporal precedence of the radials over the outer ring road.

`ActionSet1(`O_1, O_2`), ActionSet2 (`R_1, R_2`), Action(`R_3`)`
`NetworkConnect(`O_1, O_2`)`
⋮
`NetworkConnect(`R_1, R_2`)`
`Event`R_3` 'Succeeds' Event(ActionSet2)`
`Build(`O_1`) 'Succeeds' EventResidentialDevelopment(`X`) & Event(`R_1`) & Event(`R_2`)`

While many other relationships are apparent in the design and strategy, the key relationships are depicted here. 'Succeeds' is an event-event relationship which can be generalised from temporal relationships. The action of building the outer ring road is contingent upon certain level of residential growth in the periphery and is preceded by the building of radials. Any argument about a peripheral road must consider its relationship with the radials and the other peripheral. The designs and strategies that the peripheral is a part of can now be discovered in an information system that adequately represented these relationships. The radials can be considered independent actions in thinking about these investments as a strategy but not in the case of design.

The non-uniqueness of the representations of relationships within a plan poses both difficulties as well as opportunities for recognising the semantic relationships across plans. If two actions A and B are not recognised as contingent actions but merely as a list of actions, then we cannot infer the relationships of A to others' plans even when we recognise the relationships of B. This illustrates the key point that recognition of semantic relationships is a partial and incremental exercise and will remain so. As and when new relationships are discovered, we can begin to uncover richer interactions between actions.

6 Implications for the way we do planning

A prototype implementation of these kinds of computer-supported reasoning is under development using multiple PostGreSQL/PostGIS databases. These kinds of reasoning also build the case for updating one's plan as and when the situation changes. Irrespective of the availability of computer supported reasoning, if we start using the information that is available in plans, we can begin to understand the implications of others' actions on our own and act accordingly.

Since the claim is that plans are made by many actors, at different times and modified and made strategically public, the information that is used in reasoning with plans is in a distributed setting. The ownership and responsibility of keeping the plans up to date should thus also be distributed among the plan makers. Ideally an XML representation of planning relationships (using GML to represent geography) should suit the distributed nature of planning information in order to make this kind of reasoning pervasive and useful.

Formal plans are not the only kind of information that should be used in decision making. Our decisions rely on our understanding of how the world works and how we cope with it. Information about intentions is continually made available in newspaper reports, minutes of meetings and deliberations. Thus, reasoning about human action will not be an automated process but a computer supported enterprise, and information systems should be built keeping in mind such limitations.

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