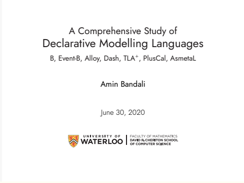
A Comprehensive Study of Declarative Modelling Languages



A Comprehensive Study of
Declarative Modelling Languages

B, Event-B, Alloy, Dash, TLA$^+$, PlusCal, AsmetaL

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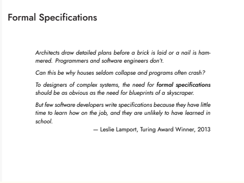
- hello, welcome!
- i'm Amin Bandali, and today i'm presenting my master's thesis, A Comprehensive Study of Declarative Modelling Languages
- thank you to each and every one of you for being here
- especially Prof. Atlee and Prof. Rayside for agreeing to be my second readers and reading my thesis in such a small amount of time



Formal Specifications

Architects draw detailed plans before a brick is laid or a nail is hammered. Programmers and software engineers don't.

Can this be why houses seldom collapse and programs often crash?

To designers of complex systems, the need for ***formal specifications*** *should be as obvious as the need for blueprints of a skyscraper.*

But few software developers write specifications because they have little time to learn how on the job, and they are unlikely to have learned in school.

— Leslie Lamport, Turing Award Winner, 2013

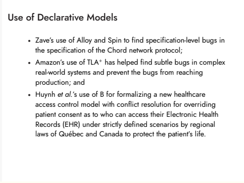
1. i'd like to start my presentation with a quote from Leslie Lamport about formal specifications, a shorter excerpt of which i used in my first chapter's epigraph
2. *read the quote...*
3. with this quote, Lamport makes the point for learning and using formal specifications as an important tool for software developers and especially software engineers

in this work we focus on the declarative behavioural modelling approach for formal specification

Declarative Behavioural Modelling

Declarative behavioural modelling is a powerful modelling paradigm that enables users to model system functionality abstractly and formally.

An *abstract model* is a concise and compact representation of the key characteristics of a system, and enables the stakeholders to reason about the correctness of the system in the early stages of development.



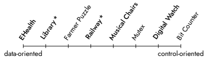
Use of Declarative Models

- Zave's use of Alloy and Spin to find specification-level bugs in the specification of the Chord network protocol;
- Amazon's use of TLA$^+$ has helped find subtle bugs in complex real-world systems and prevent the bugs from reaching production; and
- Huynh *et al.*'s use of B for formalizing a new healthcare access control model with conflict resolution for overriding patient consent as to who can access their Electronic Health Records (EHR) under strictly defined scenarios by regional laws of Québec and Canada to protect the patient's life.

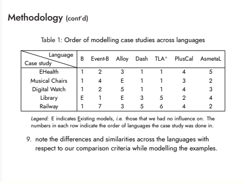
we are motivated to do this study by the many applications and demonstrated usefulness of declarative modelling languages and model checking to help design systems or analyze and verify properties about the design of existing systems

Methodology (cont’d)

8. expand our set of examples with 2 new larger systems, Library and Railway (marked with an asterisk), increasing our model count from 18 relatively small examples to 35 including the larger ones; our final case studies are those typeset in **bold**; and



the figure shows the data- vs. control-oriented characterization spectrum



Methodology (cont’d)

Table 1: Order of modelling case studies across languages

Case study \ Language	B	Event-B	Alloy	Dash	TLA$^+$	PlusCal	AsmetaL
EHealth	1	2	3	1	1	4	5
Musical Chairs	1	4	E	1	1	3	2
Digital Watch	1	2	5	1	1	4	3
Library	E	1	E	3	5	2	4
Railway	1	7	3	5	6	4	2

Legend: E indicates Existing models, *i.e.* those that we had no influence on. The numbers in each row indicate the order of languages the case study was done in.

9. note the differences and similarities across the languages with respect to our comparison criteria while modelling the examples.

the table shows the order of modelling each of the case studies across the languages

Control Modelling

concerned with control aspects and structure of transition systems

a transition system TS is a tuple (S, TR, I), where

- S is a set of snapshots,
- $TR \subseteq S \times S$ is a transition relation, and
- $I \subseteq S$: is a set of initial snapshots.

A model in a declarative modelling language defines a transition system that starts in an initial snapshot $s_0 \in I$ and progresses from a snapshot s to the next snapshot s' for $(s, s') \in TR$.

Control Modelling Criteria

- snapshot variables
- initialization
- **transition relation**
- **control state hierarchy**
- invariants
- inconsistency
- **frame problem**

- our criteria for control aspects of models are: ...
- in the interest of time we will focus on the **bold** ones in this presentation which we thought might be more interesting than the others
- if asked about inconsistency, elaborate:
  - deadlock
  - contradictory TR
  - contradictory TP
  - stuttering

Control Modelling — Transition Relation

- completely explicit: Alloy
- mostly explicit: TLA$^+$ and AsmetaL
- implicit: B, Event-B, Dash, and PlusCal

- in Alloy, TR is defined *completely explicitly* in model text, and its form can vary greatly depending on how the snapshot, variables, and transitions are defined. *e.g.* with a `State` signature as the snapshot representation and its fields as variables, TR can be decomposed into `pred`icates which can be viewed as transitions.
- in TLA$^+$, TR is by convention a predicate named `Next`, defined as the disjunction of all of the model's transition predicates (method best supported by TLC, TLA$^+$'s accompanying MC). AsmetaL has a more imperative style, and does not have a disjunction operator for combining transitions; and as such, we have have to use the `choose` rule instead. TR said to be defined *mostly explicitly* because in addition to the model text, both languages add implicit stuttering under certain conditions.
- the remaining languages have *implicit* TR, constructed automatically behind the scenes from the transitions. it's worth mentioning that PlusCal allows writing one's own TR if need to.

TR in B, Event-B, and PlusCal is implicitly formed as follows: at any step, any transition whose precondition is satisfied (*i.e.* is enabled) may be chosen to be taken. There is no requirement on the preconditions of the transition to be non-overlapping, and more than one trans may be enabled at a time, resulting in a branch in the snapshot space graph.

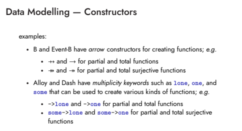
Control Modelling — Frame Problem

refers to the issue of how snapshot variables that are not explicitly constrained in a transition may or may not change from one snapshot to the next

is particularly an issue in declarative languages that rely on logical constraints on variables for describing the changed and unchanged variables in a transition

└─Data Modelling Criteria

- our criteria for data aspects of models are: ...
- we will focus on the **bold** ones in this presentation for similar reasons to Control Modelling earlier
- primitives in all languages consist of scalars and sets, with the exception of Alloy, which does not have scalars and “scalars” are represented using singleton sets



Data Modelling — Constructors

examples:

- B and Event-B have *arrow* constructors for creating functions; *e.g.*
  - $\nrightarrow$ and $\rightarrow$ for partial and total functions
  - $\twoheadrightarrow$ and $\twoheadrightarrow$ for partial and total surjective functions
- Alloy and Dash have *multiplicity keywords* such as `lone`, `one`, and `some` that can be used to create various kinds of functions; *e.g.*
  - `->lone` and `->one` for partial and total functions
  - `some->lone` and `some->one` for partial and total surjective functions

the -> operator in Alloy (and Dash) is actually the relation constructor, and the multiplicity keywords can constrain the constructed relation *e.g.* to be a function

A Comprehensive Study of Declarative Modelling Languages
└─Comparison Criteria
└─Data Modelling
└─Data Modelling — Typechecking

a common example of the second form of type error in Alloy/Dash is an expression being redundant due to being equal to the empty relation (*e.g.* due to mismatched type signatures)

Data Modelling — Typechecking

- TLA$^+$ and PlusCal have no type signatures, and typing constraints are stated and checked along with other invariants
- in Alloy and Dash typechecking consists of checking that no relation has been given different arities and that no expression can be shown to be redundant or contain a redundant sub-expression using solely the declarations
- B, Event-B, and AsmetaL have type signatures and typechecking that help statically catch errors like assigning a value from a set to a variable with a type signature declaring a different/incompatible set, and applying a function to arguments that do not match its type signature

└─Modularity Criteria

- our criteria for modularity aspects of models are: …
- all of the languages allow data decomposition; *i.e.* allow subformulas relevant to the data aspects of the model, such as axioms for a unit of data, to be declared separately
- but we will focus on decomposition into subtransition relations in this presentation

Modularity Criteria

Alloy, TLA$^+$, and AsmetaL have explicit representation of TR, while B has implicit representation of TR and achieves subtransition system decomposition by effectively prepending the components of the subtransition system(s) to those of the parent transition system to compose the resulting final transition system

Modularity — Subtransition Relations

- a subtransition system is a full description of a transition system
- subtransition systems are composed to create the single top-level transition relation implicitly or explicitly
- B, Alloy, TLA$^+$, and AsmetaL support decomposition into subtransition systems

for contributions, in addition to the set of comparison criteria and comparing the languages with respect to those criteria, we offer recommendations for the choice of modelling language, the research question we set out to answer