VMC: A Tool for Product Variability Analysis

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joint work with fellow FMT lab members:
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Paris, France
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Outline

(Software) Product Line Engineering

Paradigm

To develop a family of products (product line) using a common platform and mass customization

Aim

To lower production costs of the individual products by

- letting them share an overall reference model of the product family
- allowing them to differ w.r.t. particular characteristics to serve, e.g., different markets

Product variants can be derived from a product family, thus allowing for reuse and differentiation

Production process

Maximize commonalities of product whilst minimizing cost of variations

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Variability management/modeling

Feature modeling

Provide compact representations of all the products of a product family in terms of their *features* (pieces of functionality)

Variability modelling

How to explicitly define **optional**, **alternative**, **mandatory**, **required**, or **excluded** features of a product family as variation points

Managing variability with formal methods

Show that a certain product belongs to a product family or—instead—derive a product from a family by properly selecting features

Formally prove characteristics of products and families alike

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Aim of our research activity at large

Aim

- One formal framework to express both feature-based constraints over the products of a family and constraints over their behavior
- Tool support for product derivation and for the formal verification (by model checking) of properties over products and families alike

Outcome : iFM'10, ACOTA @ ASE'10, PLEASE @ ICSE'11, FMOODS'11, SEW-34 @ FM'11, SPLC'11, iFM'12, SPLC'12

- MTS: Modal Transition Systems (Larsen et al.)
- MHML: CTL-like action- and state-based branching-time temporal logic (a.k.a. vACTL)
- VMC: Variability Model Checker

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Running example: family of coffee machines

Feature-based constraints

- The only accepted coins are 1€, exclusively for European products, and 1$, exclusively for Canadian products (**alternative** features)
- All products must offer coffee (**mandatory** feature); only European products may offer cappuccino (**excludes** relation among features)
- A ringtone must be rung in products offering cappuccino (**requires** relation among features), while it may be rung in other products (**optional** feature)

Behavioral constraints

- After coin insertion, user must press a button to choose whether (s)he wants sugar, after which (s)he may select a beverage
- The optional ringtone is rung after delivering a beverage

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- After coin insertion, user must press a button to choose whether (s)he wants sugar, after which (s)he may select a beverage
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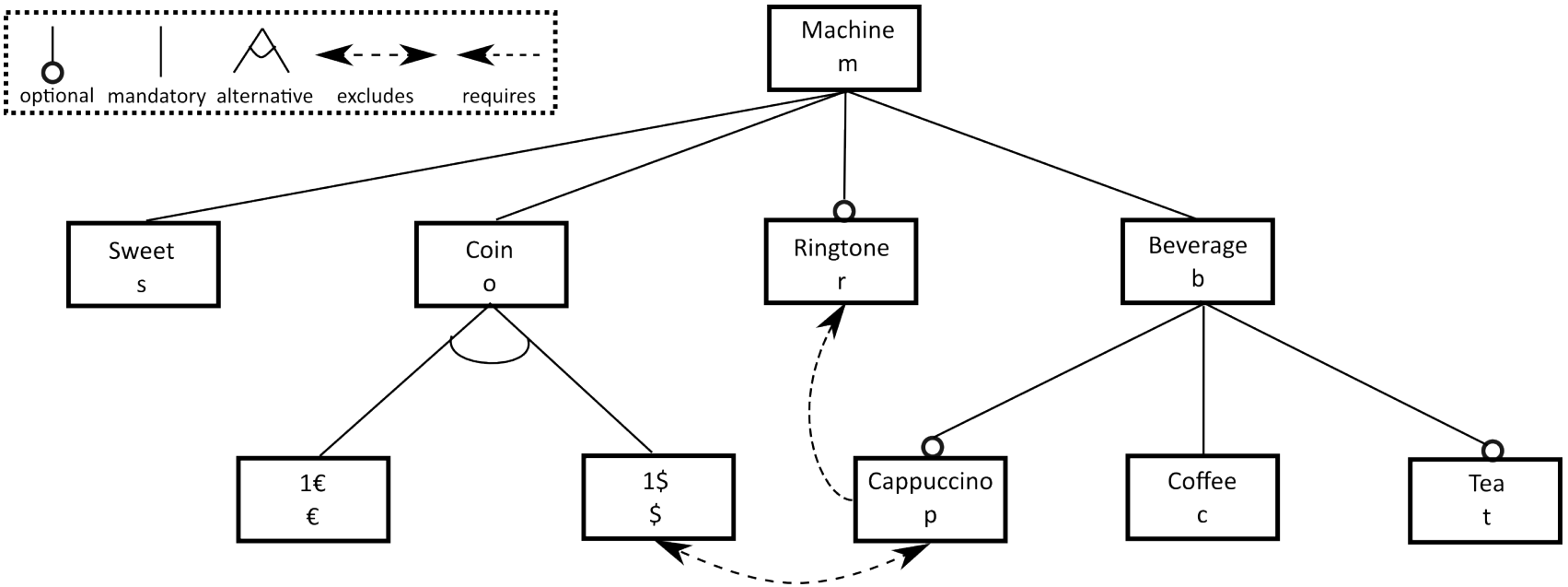
Coffee machine family: Feature model



10 different valid products (coffee machines defined by features)

$$\{\{m, s, o, b, c, €\}, \{m, s, o, b, c, €, r\}, \{m, s, o, b, c, €, t\},$$
$$\{m, s, o, b, c, \$\}, \{m, s, o, b, c, \$, r\}, \{m, s, o, b, c, \$, t\},$$
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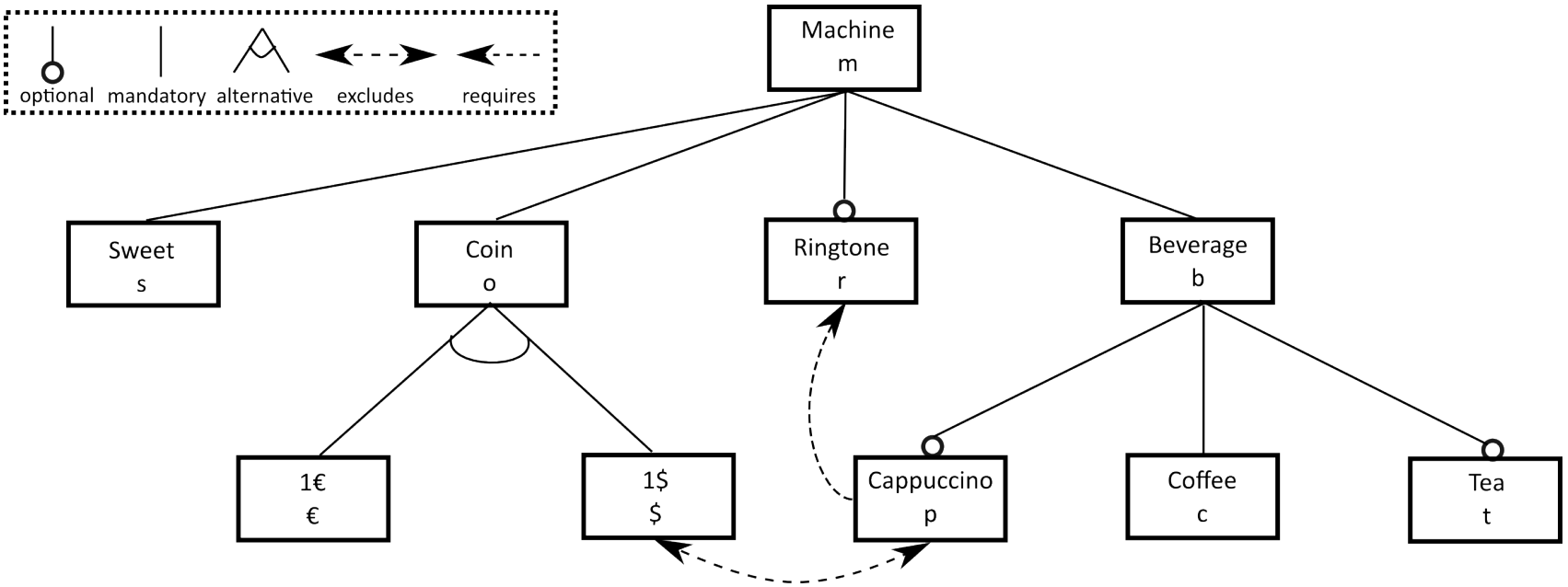

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Modal Transition Systems (MTSs)

Use for behavioral modeling of SPLs recognized by Uchitel et al.

An MTS is an LTS distinguishing **optional** (may) and **mandatory** (must) transitions to formalize a product family's

- *underlying behavior*, shared among all products, and
- *variation points*, differentiating between products

A product (LTS) is derived by including all (reachable) must transitions and a subset of the (reachable) may transitions

MTS however cannot model variability constraints regarding **alternative** features nor regarding the **requires** and **excludes** inter-feature relations

Our solution: add a set of variability constraints (hiding our logic) to the MTS to define which derivable products must be considered valid ones (we defined an algorithm to derive only—and possibly all—valid ones)

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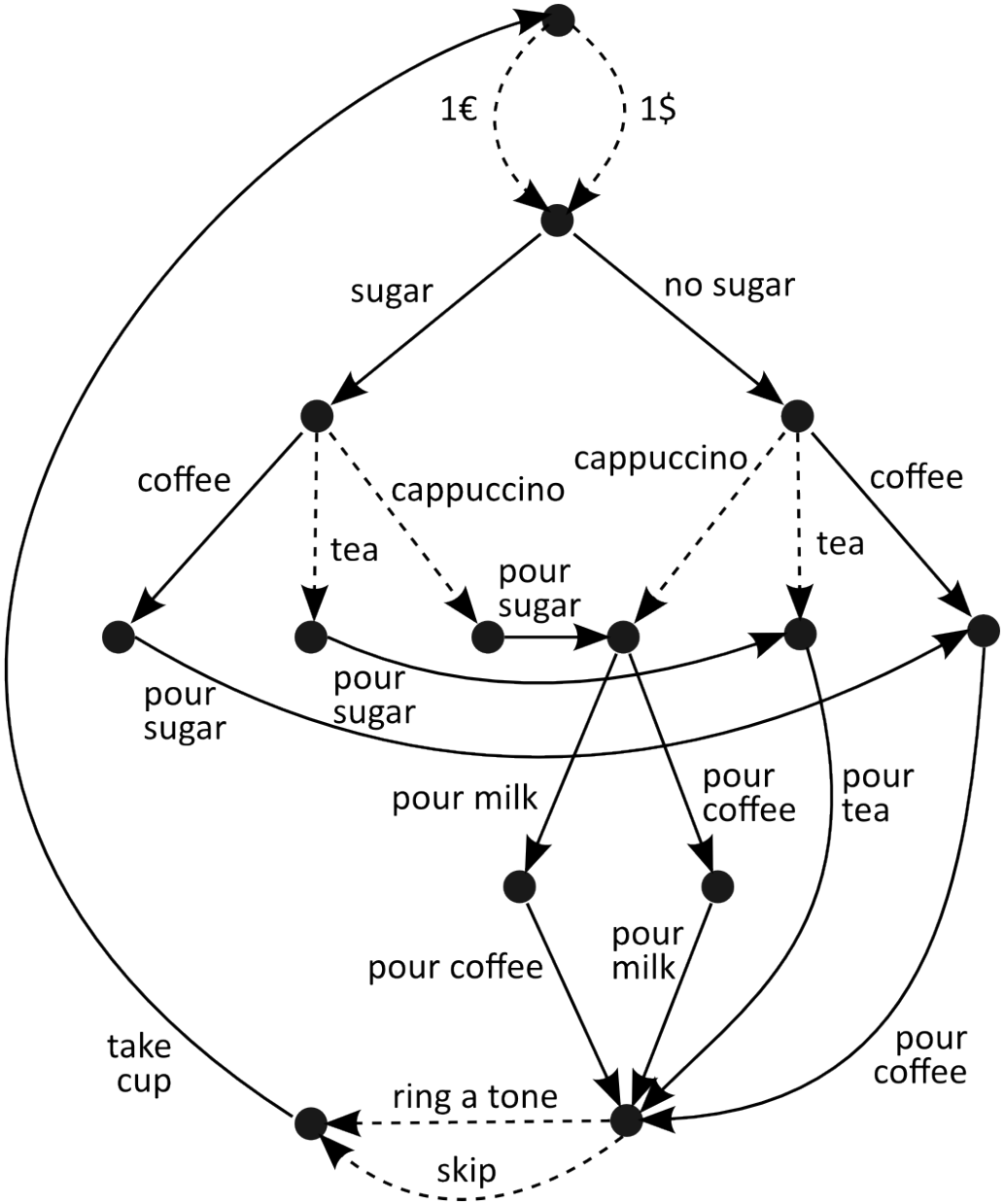
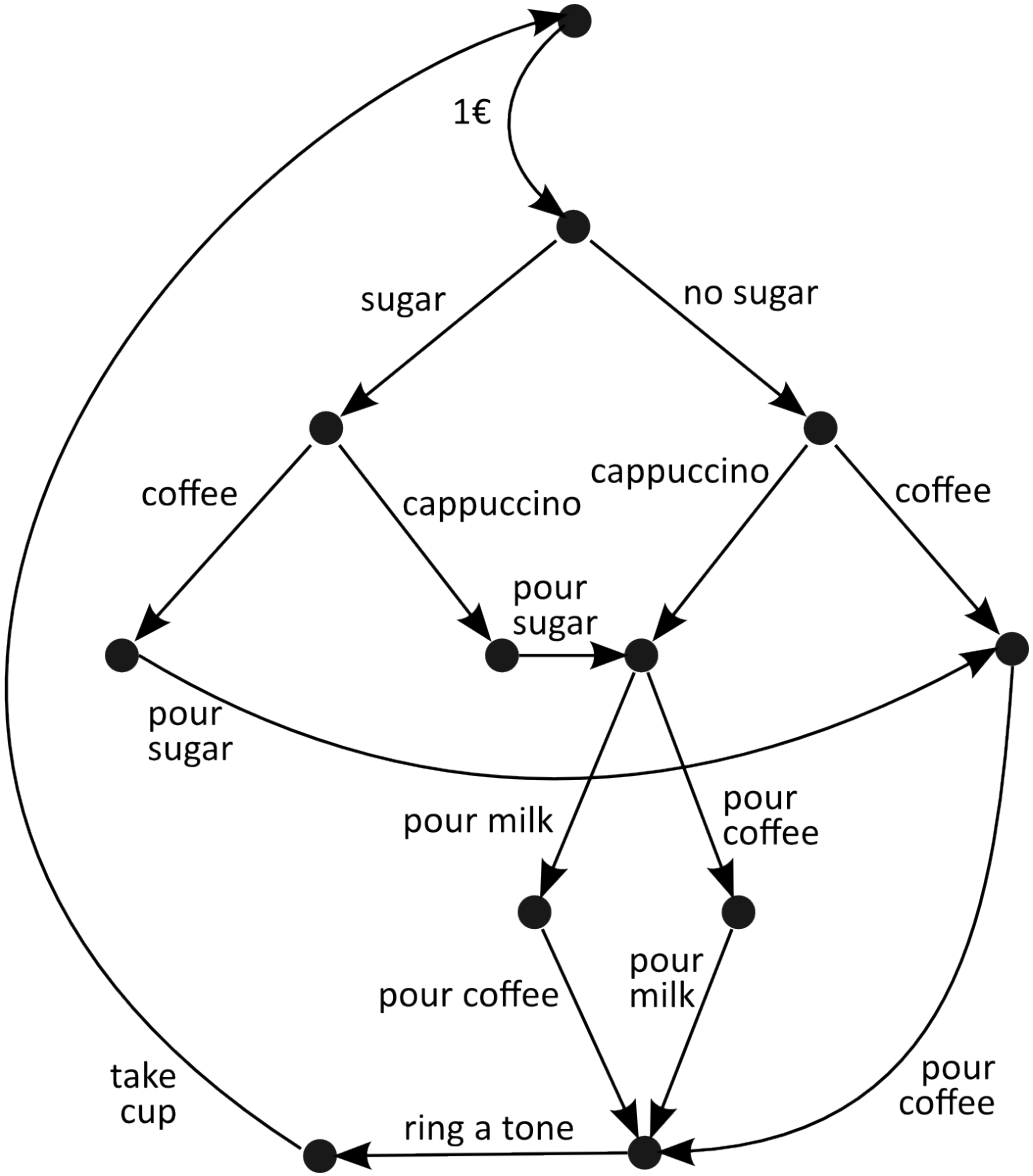
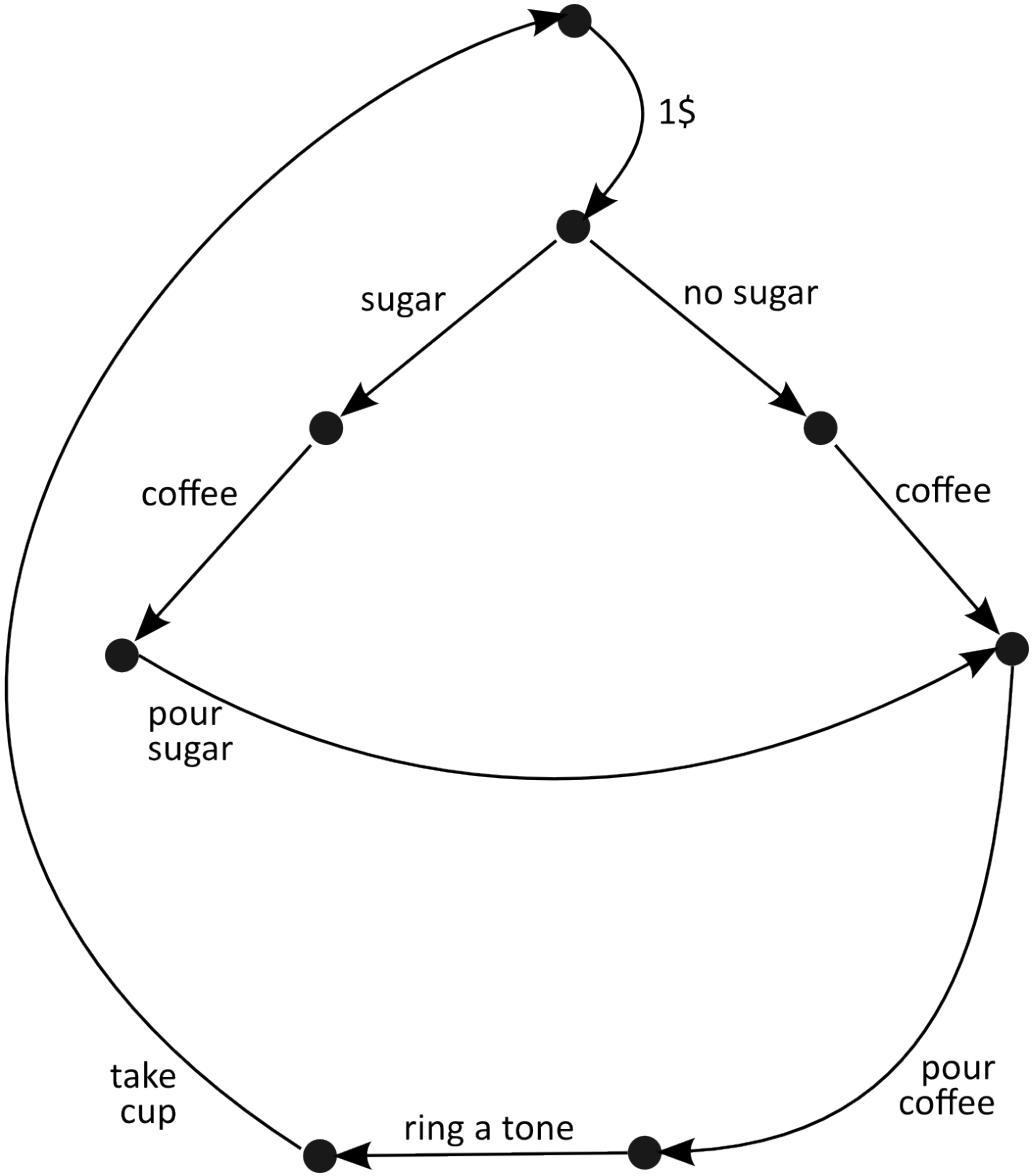


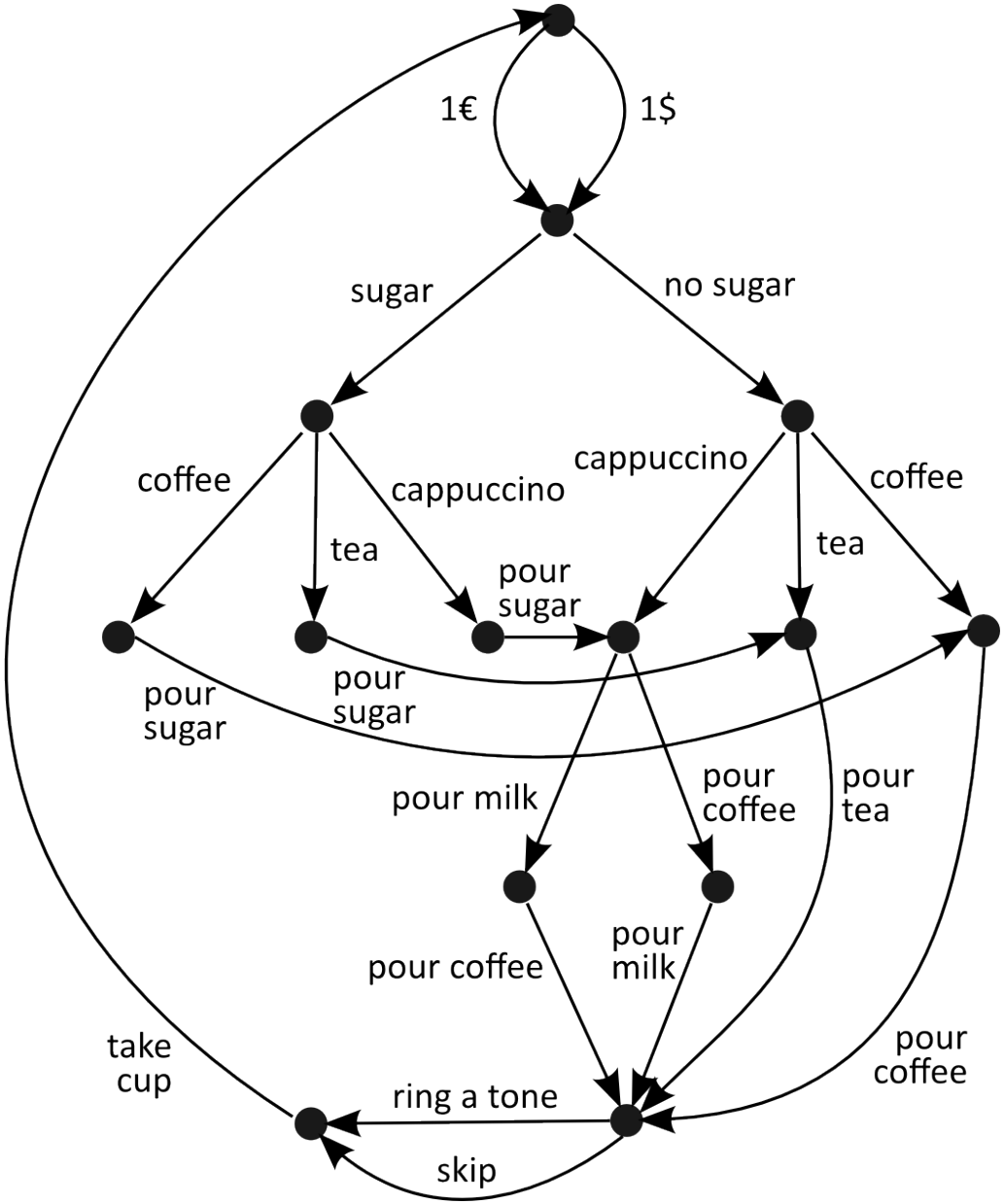
A valid European coffee machine ($\{m, s, o, b, c, €, p, r\}$)



A valid Canadian coffee machine ($\{m, s, o, b, c, \$, r\}$)



A correct but not a valid product LTS of MTS



VMC: Variability Model Checker

A tool for modeling and analysis of behavioral variability in SPLs

Given a textual encoding of an MTS and a set of variability constraints:

- interactively explore the MTS
- derive and explore (all) the family's valid products (LTSs)
- visualize the family/products graphically as MTS/LTSs
- verify branching-time temporal logic properties over family/products
- interactively explain why a product does (not) satisfy a property

Freely usable online: `http://fmtlab.isti.cnr.it/vmc/`

Verification engine and advanced explanation techniques are features of the highly optimized family of on-the-fly model checkers developed at our FMT lab over the last decades for verifying formulae in CTL-like action- and state-based branching-time temporal logics (e.g. FMC, UMC, CMC)

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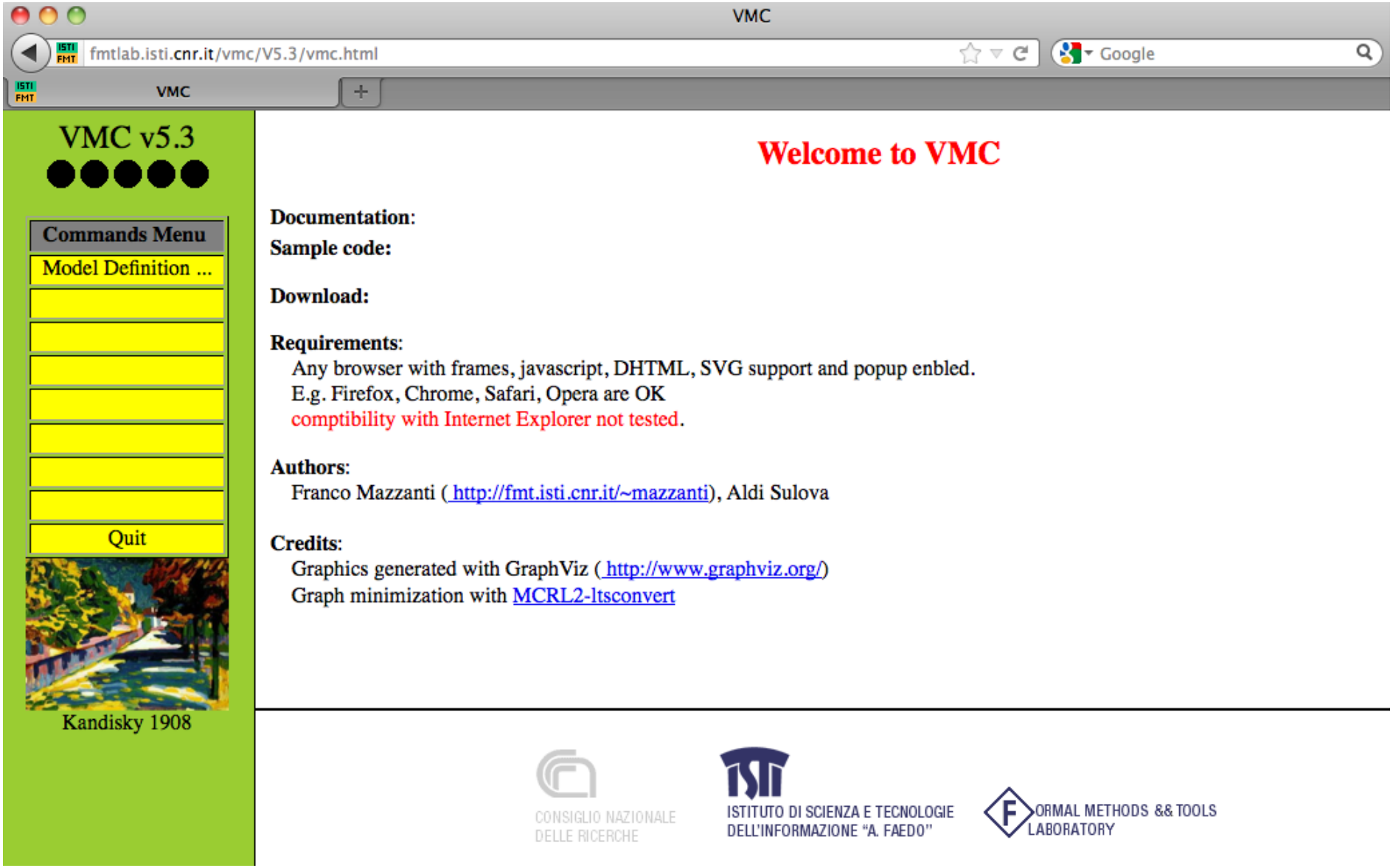
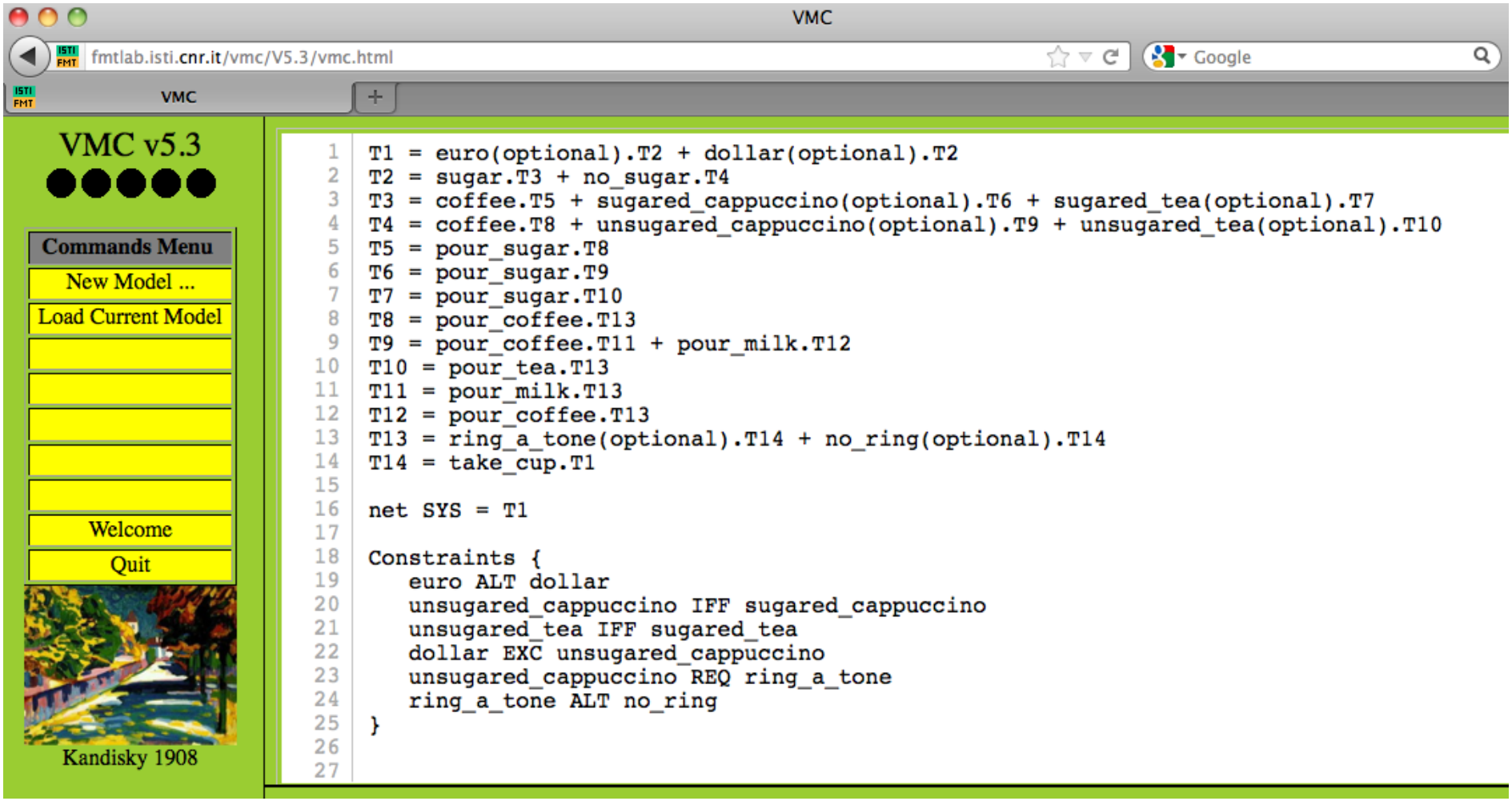
VMC's web interface

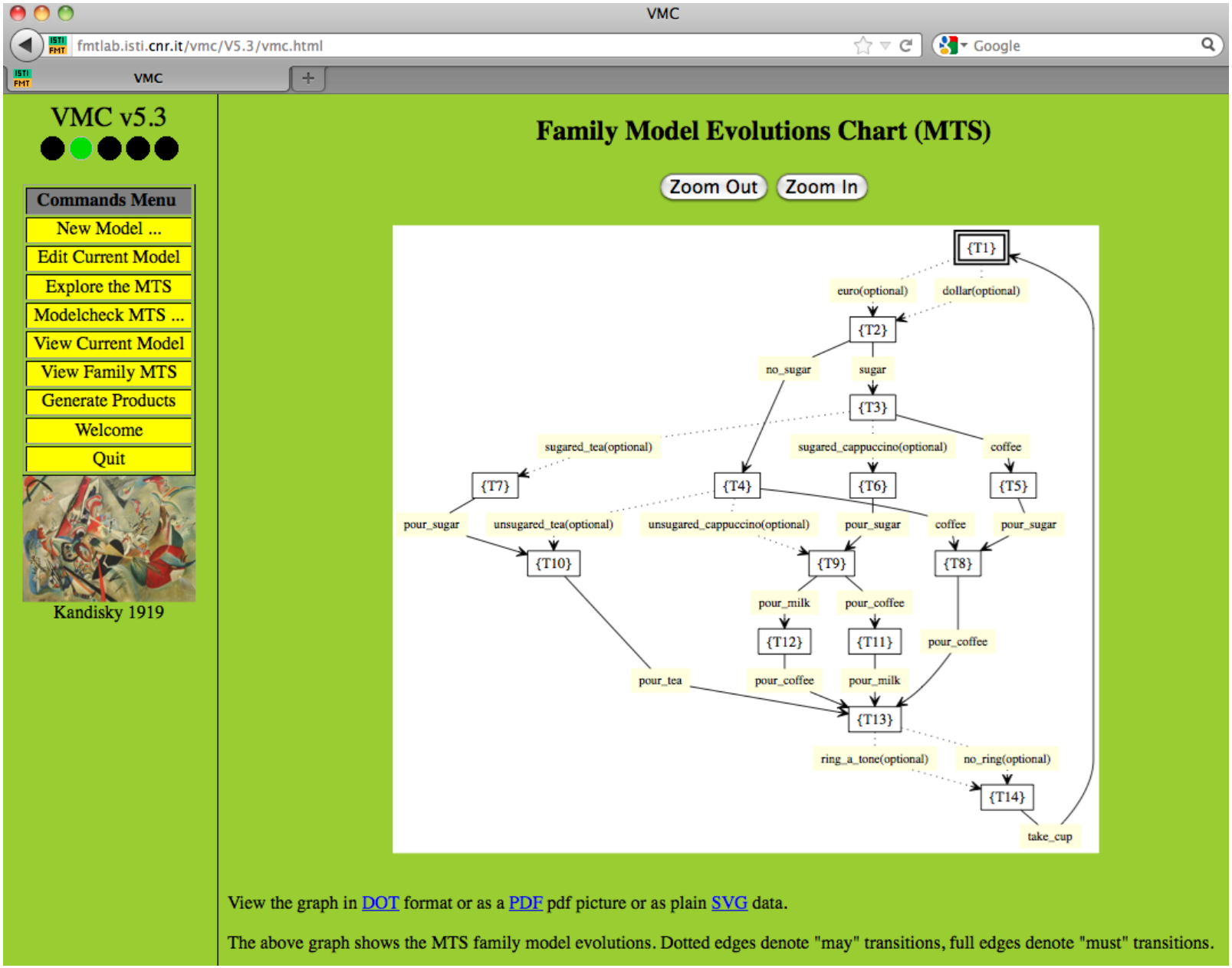


Family of coffee machines specified in VMC

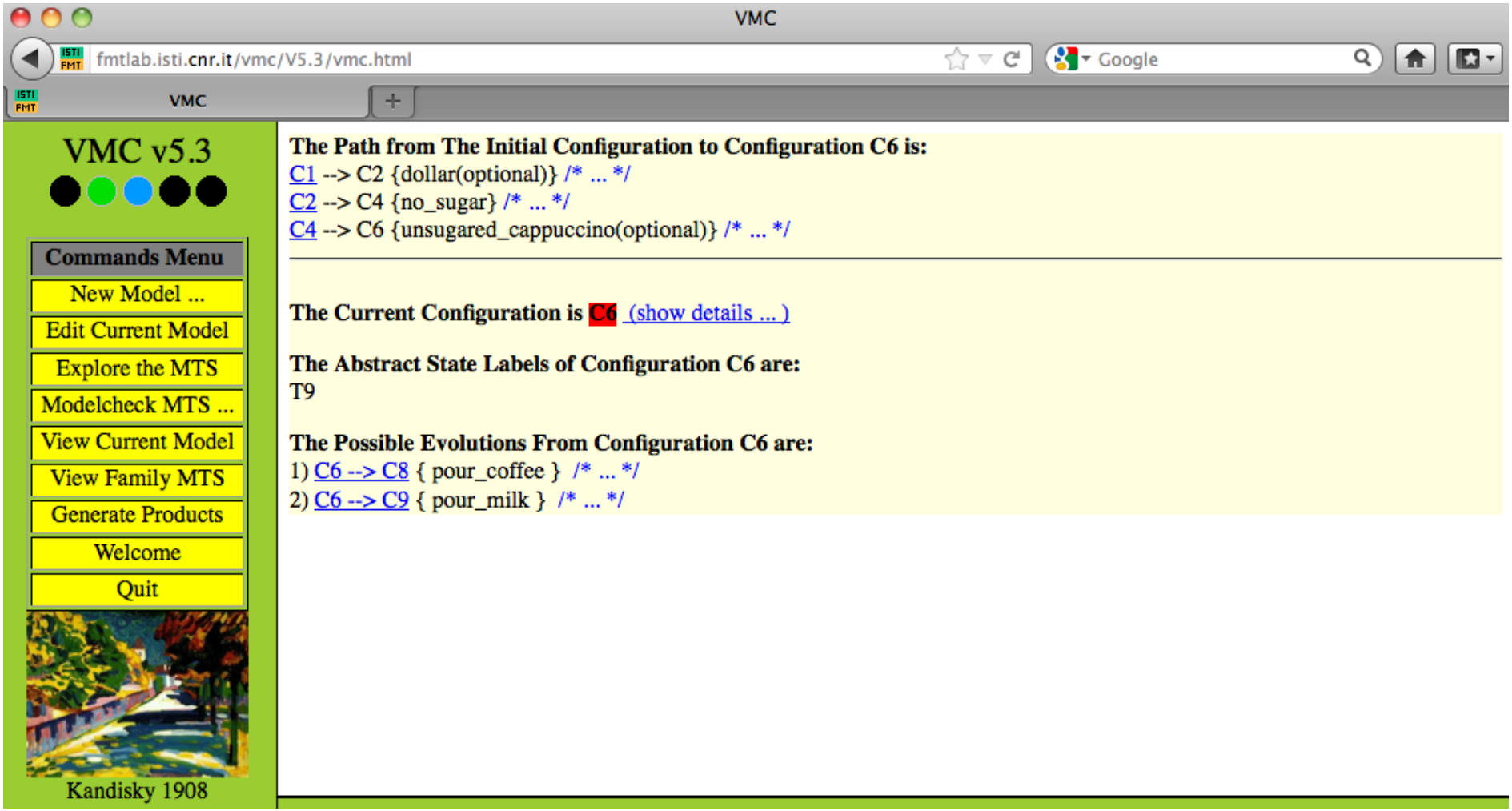


Permitted variability constraints ALTernative, EXCludes, REQuires, and IFF (shorthand for bilateral REQs) hide the logic formalization from user

Family/MTS of coffee machines visualized by VMC

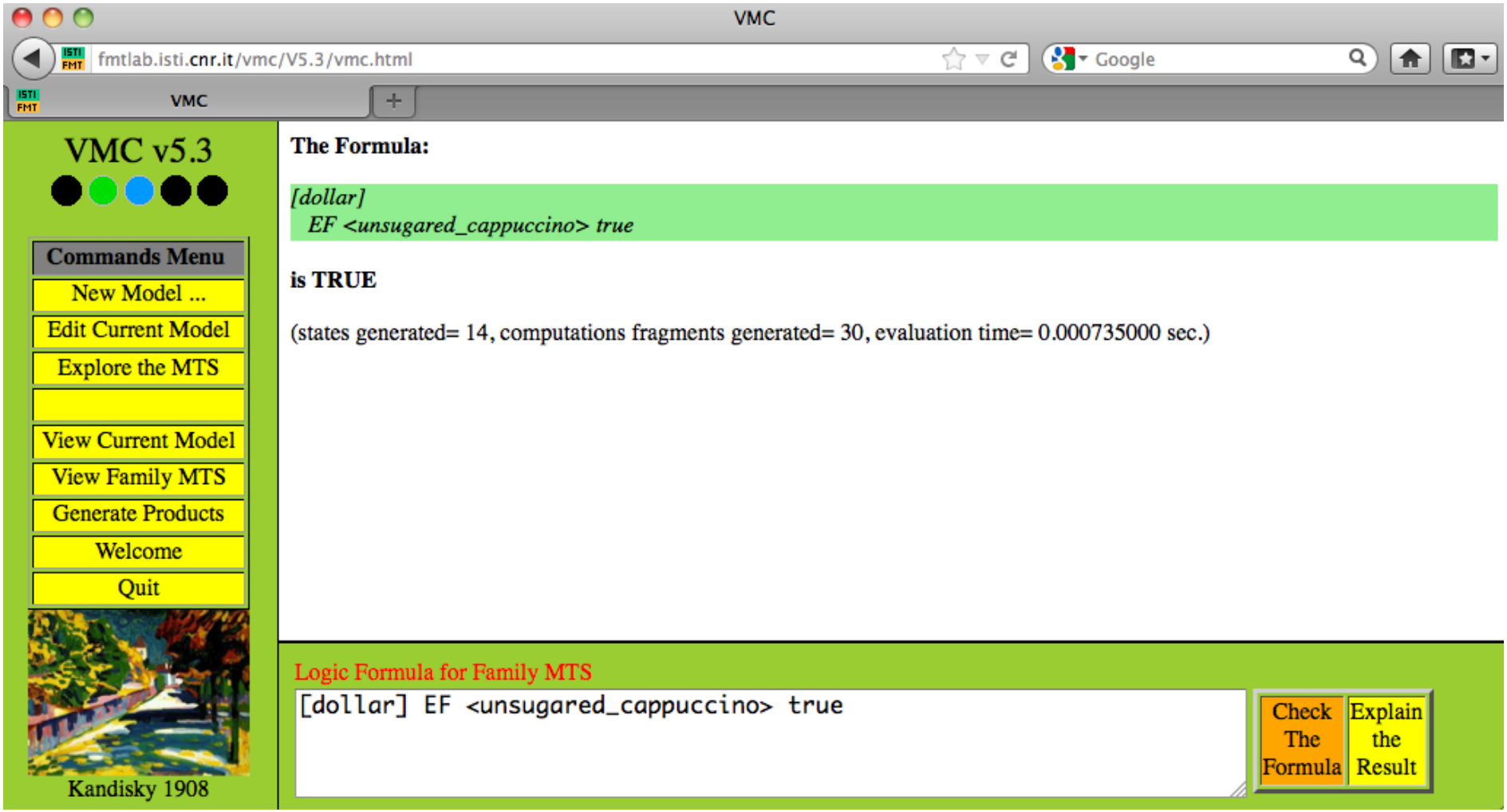


Family/MTS of coffee machines explored in VMC



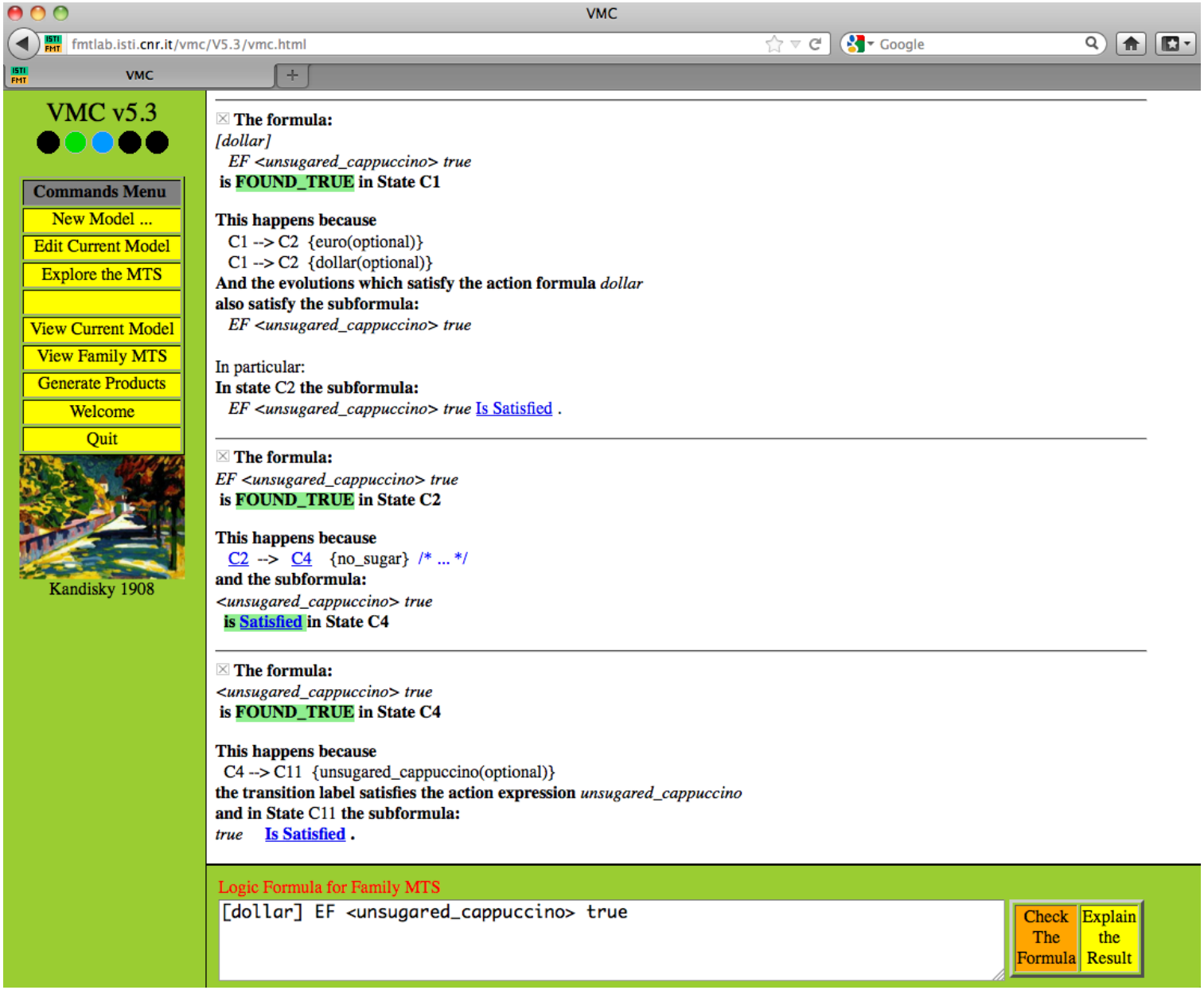
MTS model of coffee machine family actually permits a user to buy a cappuccino with a dollar, something which is forbidden for its products by the variability constraint `dollar EXC unsugared_cappuccino`

Outcome of a property verified over a family with VMC

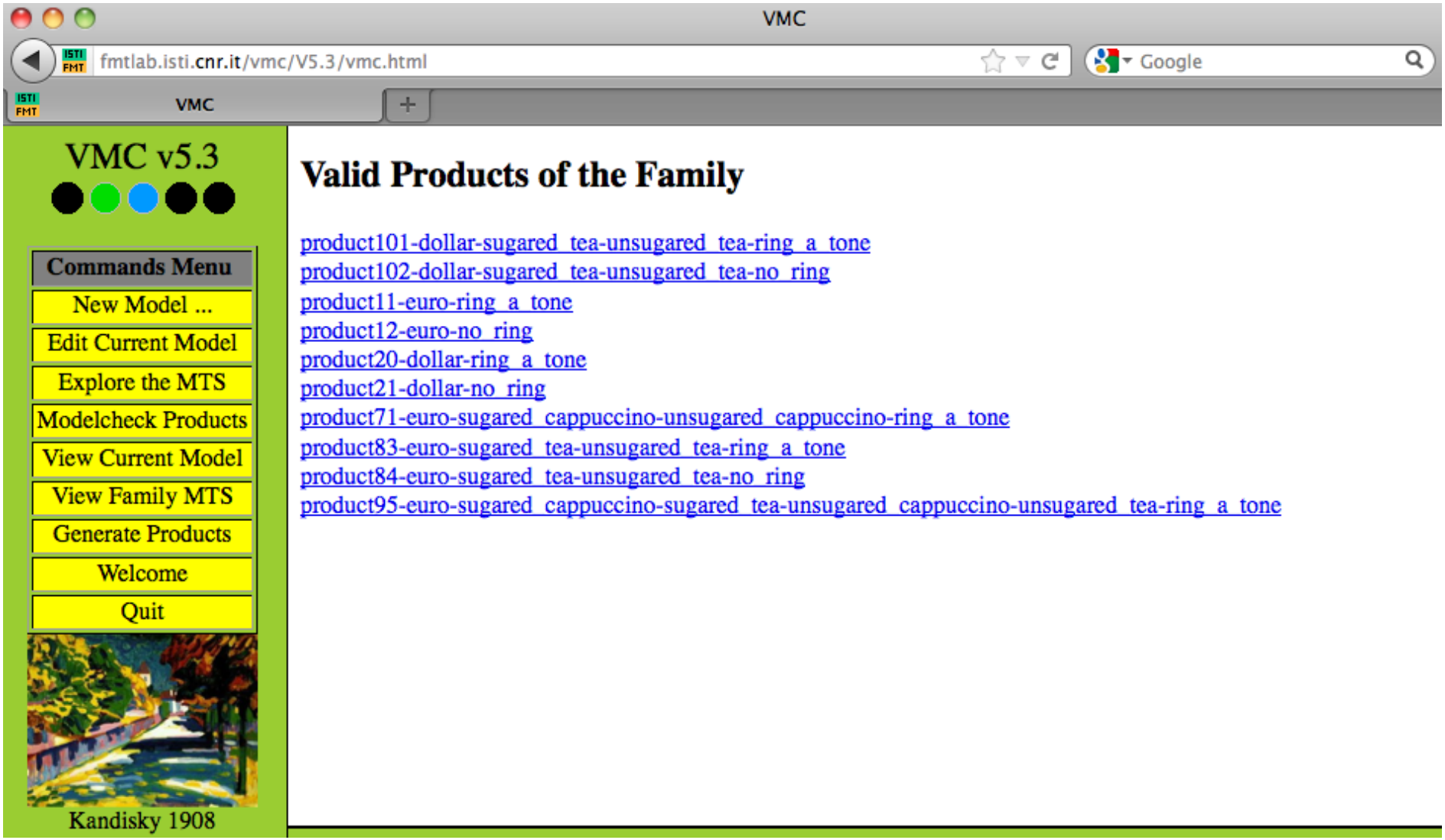


The formula expresses that every path through the MTS that starts with the insertion of a dollar, eventually leads to an unsugared cappuccino

Outcome of a property explained by VMC



Products of family of coffee machines derived by VMC



VMC indeed generates all 10 valid products/LTSs that are derivable from the family/MTS if the set of variability constraints is considered

Outcomes of a property verified over products with VMC

As required, no valid product (i.e. coffee machine) can deliver an (unsugared) cappuccino upon the insertion of a dollar!

Specification of one of the products derived by VMC

Clicking on a product, VMC opens a window with its textual encoding

Product/LTS on previous slide visualized by VMC

VMCP

fmtlab.isti.cnr.it/vmcp/V5.2/vmcp.html?remotemodel

VMC | VMCP

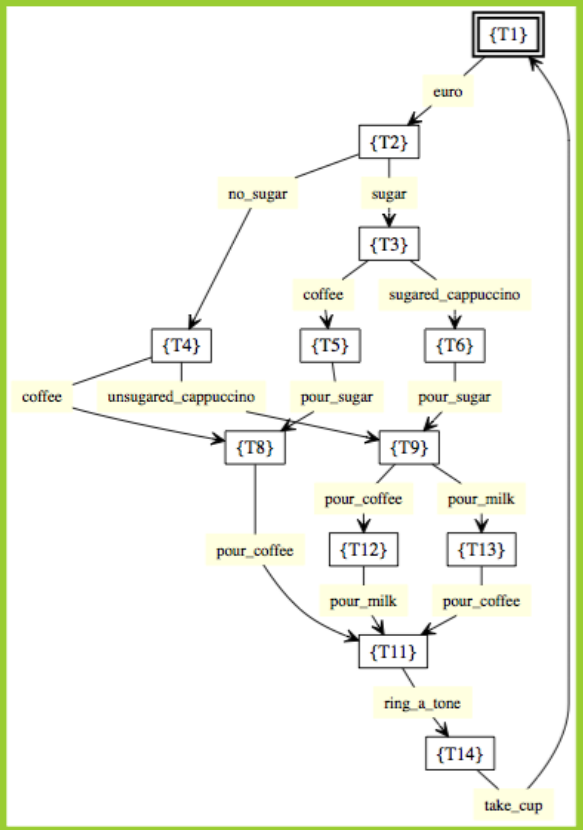
VMC v5.3
(on product)

Commands Menu
- New Model ...
- Edit Current Model
- Explore the LTS
- View Current Model
- View the LTS Graph
- Quit

Kandisky 1919

Product Model Evolutions Chart (LTS)

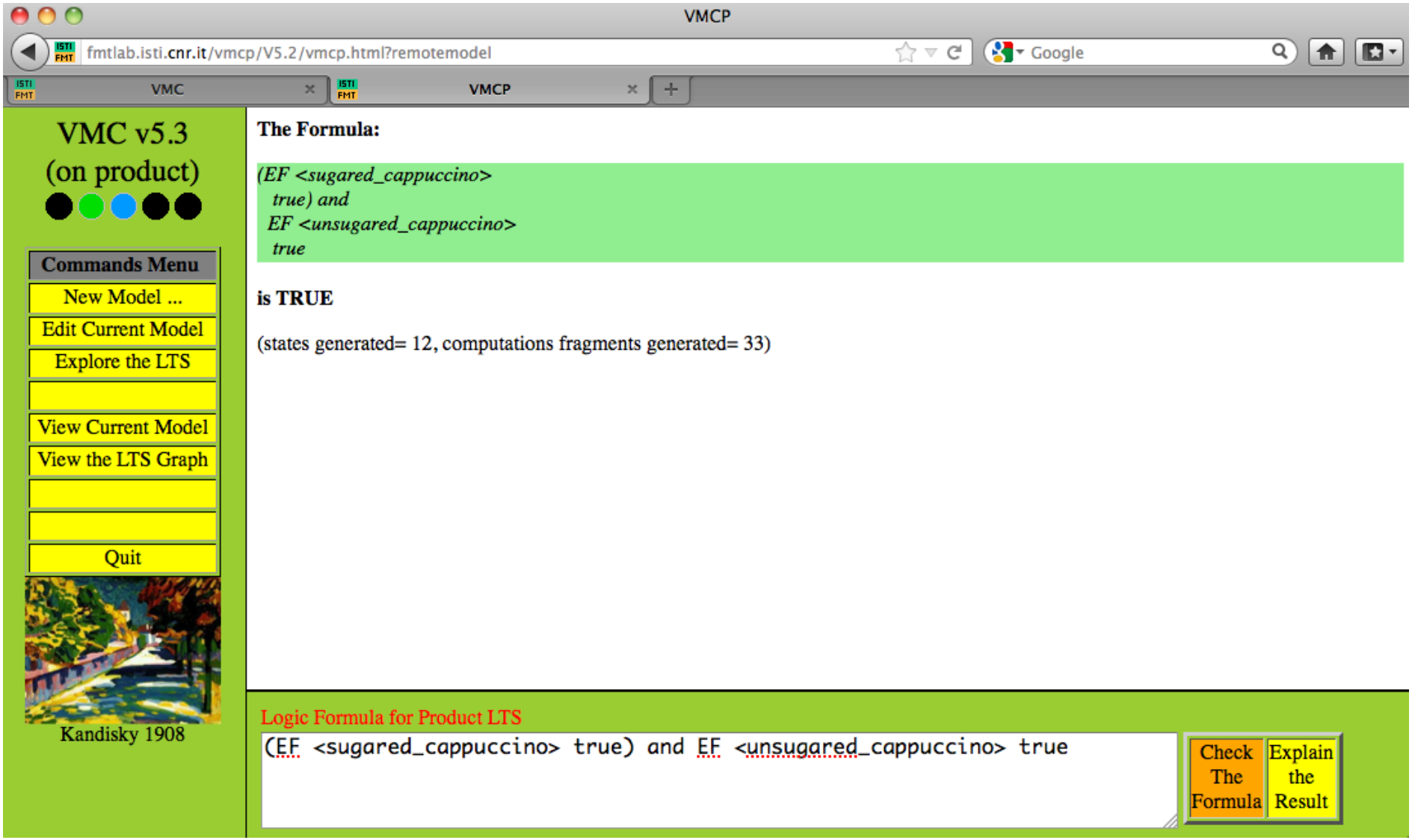
Zoom Out | Zoom In



View the graph in DOT format or as a PDF pdf picture or as plain SVG data.

The above graph shows the LTS product model evolutions, which by defintion contains only full edges.

Outcome of a property verified over a product with VMC



The formula expresses that in this particular LTS, there exists both a path to a sugared cappuccino and a path to an unsugared cappuccino

Outcome property on previous slide explained by VMC

VMCP

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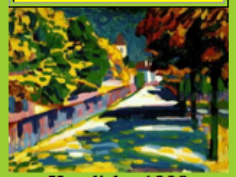

Kandisky 1908

The formula:
(EF <sugared_cappuccino> true) and
EF <unsugared_cappuccino> true
is FOUND_TRUE in State C1

This happens because the subformula:
EF <sugared_cappuccino> true
is Satisfied in State C1

And because the subformula:
EF <unsugared_cappuccino> true
is Satisfied in State C1

The formula:
EF <sugared_cappuccino> true
is FOUND_TRUE in State C1

This happens because
C1 --> C2 {euro} /* ... */
C2 --> C3 {sugar} /* ... */
and the subformula:
<sugared_cappuccino> true
is Satisfied in State C3

The formula:
EF <unsugared_cappuccino> true
is FOUND_TRUE in State C1

This happens because
C1 --> C2 {euro} /* ... */
C2 --> C4 {no_sugar} /* ... */
and the subformula:
<unsugared_cappuccino> true
is Satisfied in State C4

Logic Formula for Product LTS

```
(EF <sugared_cappuccino> true) and EF <unsugared_cappuccino> true
```

Check The Formula | Explain the Result

Discussion and future work

VMC can also be used to specify and analyze only specific subsets of a product family's valid products by applying restrictions via constraints

Add constraint `coffee EXC dollar` to the family specification

Only European coffee machines will be derived as valid products, which can then be analyzed both as a subset and individually

Future work required before possible application in industry

- A high-level language hiding all semantic details
  (investigate the relation between features and actions)
- A predefined taxonomy for exemplary logical properties
  (e.g. the specification patterns repository for LTL, (A)CTL, etc.)
- Scale to large, industrial-size product families
  (with many variation points and many features)

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Publicity: consider submitting to VaMoS 2013 in Pisa

Variability Modelling of Software-Intensive Systems (VaMoS'13)
7th International Workshop

Pisa, Italy, January 23–25, 2013

⇒ `http://www.vamos-workshop.net`

Submission deadline: November 4, 2012

PC chairs:

- Philippe Collet (Université Nice Sophia Antipolis, France)
- Klaus Schmid (Stiftung Universität Hildesheim, Germany)

Organized by our FMT lab at the CNR research area in Pisa