Modelling, analysing and verifying variability by means of Modal Transition Systems

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Outline

1. Aim and achievements of our research on variability
2. Running example: a family of coffee machines
3. Our Variability Model Checker VMC
4. Discussion and future work

Aim and achievements

Aim

- To develop a logical framework capable of dealing with variability (behavioural)
- To provide tools to support this framework with formal verification (model checking)

Main ingredient: Modal Transition Systems (Larsen et al.)

- Labelled Transition Systems distinguishing **may** (admissible) and **must** (necessary) transitions

ESEC/FSE'07, SPLC'08, VaMoS'09, VaMoS'10, iFM'10, ACoTA @ ASE'10, PLEASE @ ICSE'11, FMOODS/FORTE'11, SEW-34 @ FM'11, SPLC'11, demo @ iFM'12, tool @ FM'12, FMSPLE'12, demo @ SPLC'12, ISoLA'12,...

- v-ACTL: ACTL-like branching-time temporal logic (a.k.a. MHML)
- VMC: Variability Model Checker

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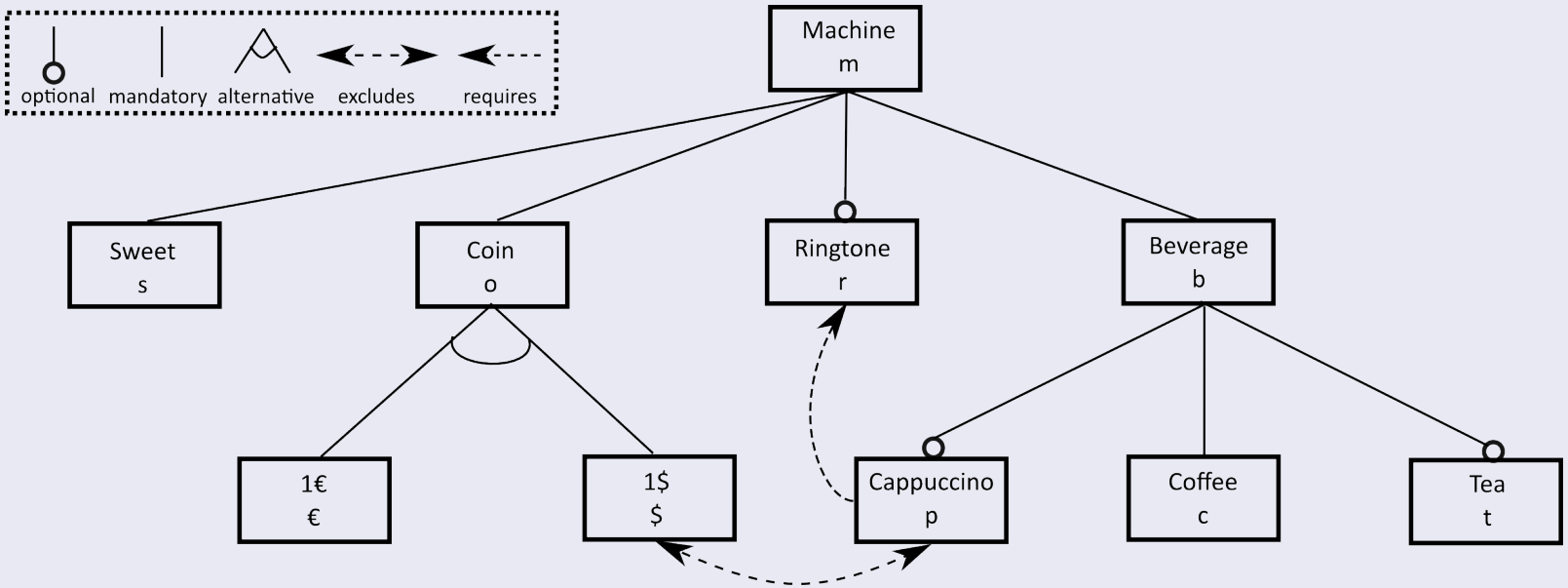
Running example: family of coffee machines

Feature-based constraints



Behavioural 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
- The machine returns to its idle state **after** the beverage is taken

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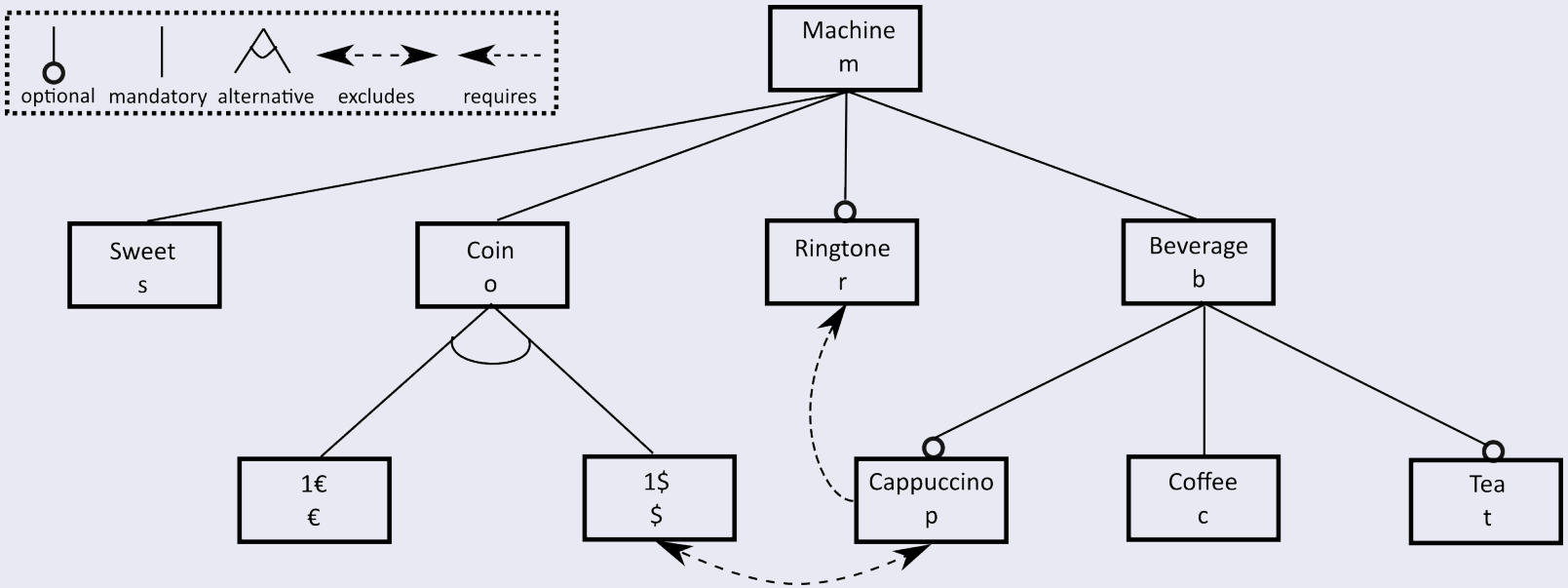

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Modal Transition Systems (MTSs)

Their use for behavioural modelling of SPLs due to Uchitel et al.

A behavioural model, amenable to model checking, able to formalize

- *shared behaviour*, common among all variants, and
- *variation points*, differentiating between variants

An LTS is obtained by including all (reachable) must transitions and a subset of the (reachable) may transitions—each selection is a variant (a.k.a. an implementation)

Limitation

MTSs cannot model **alternative** features nor **requires**/**excludes** CTC

Our solution

Additional variability constraints to single out the valid variants (and an algorithm to derive only—and possibly all—valid ones)

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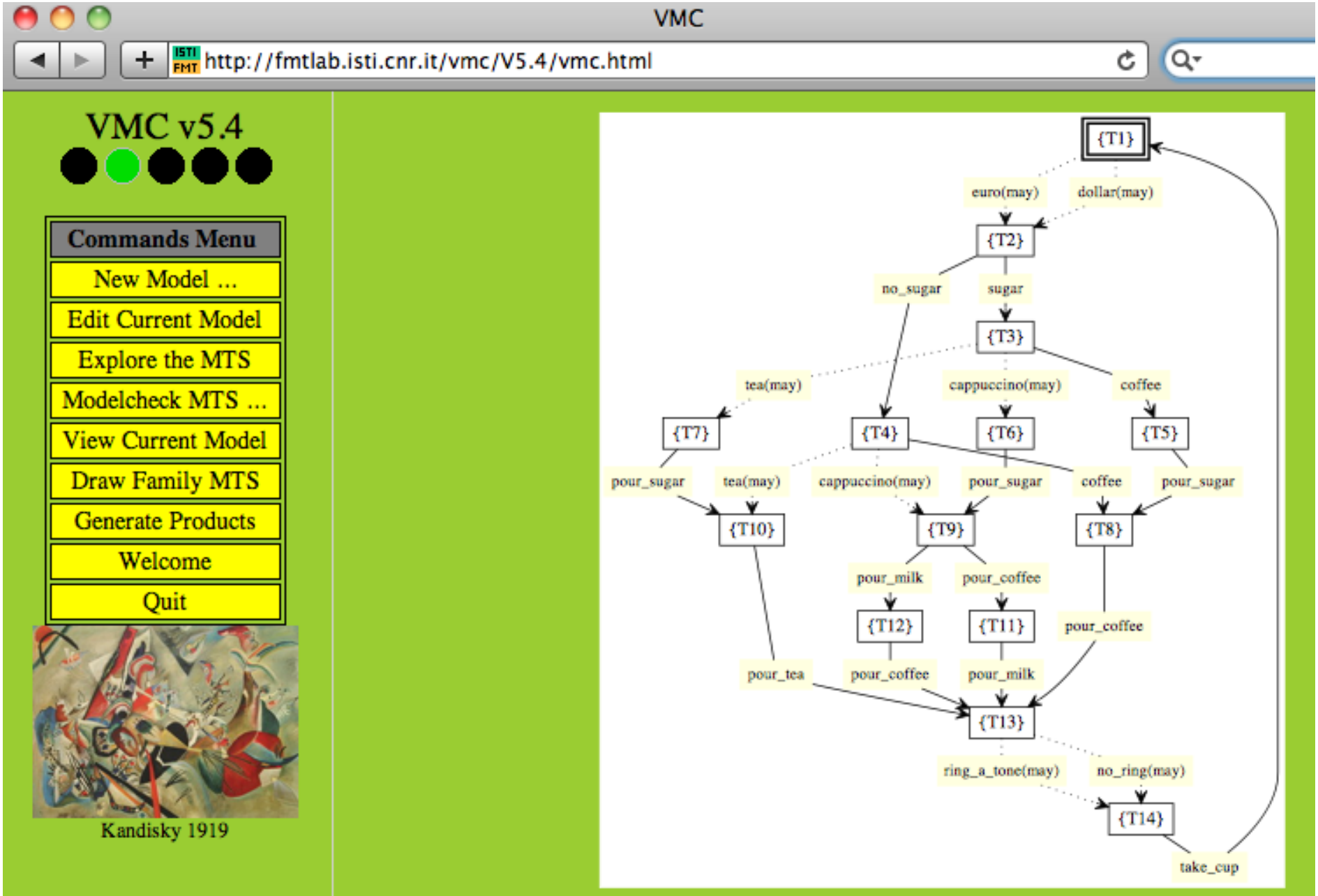
Coffee machine family: a possible MTS model



A valid European coffee machine

VMCP

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

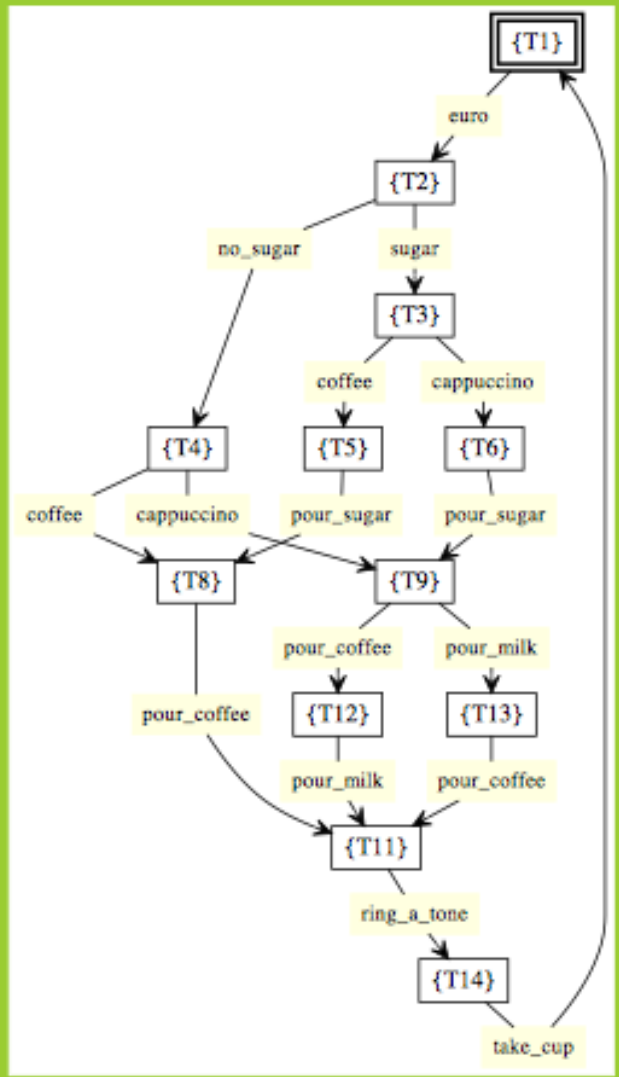
VMC | VMCP

VMCproduct
(on product)

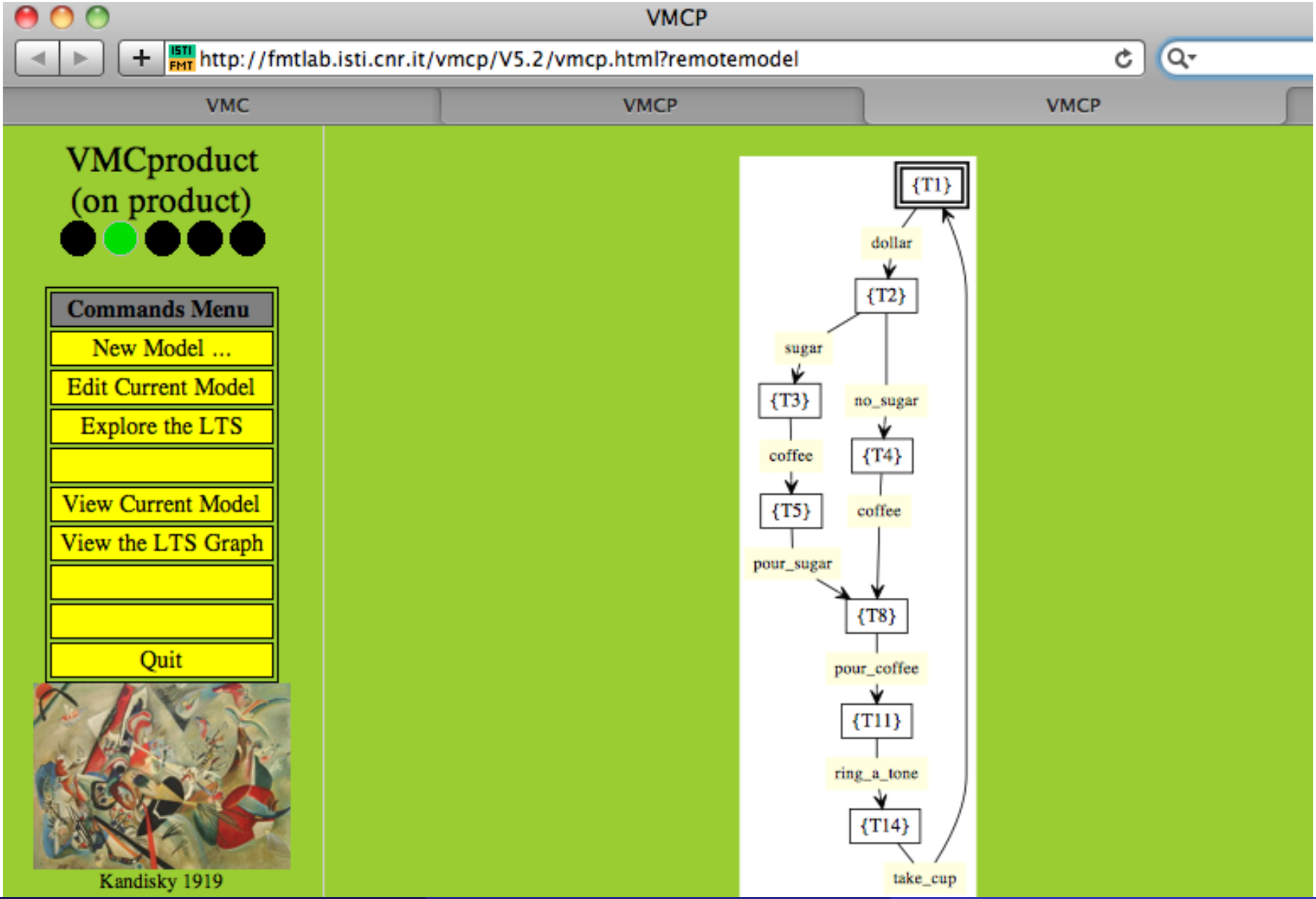
Commands Menu

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

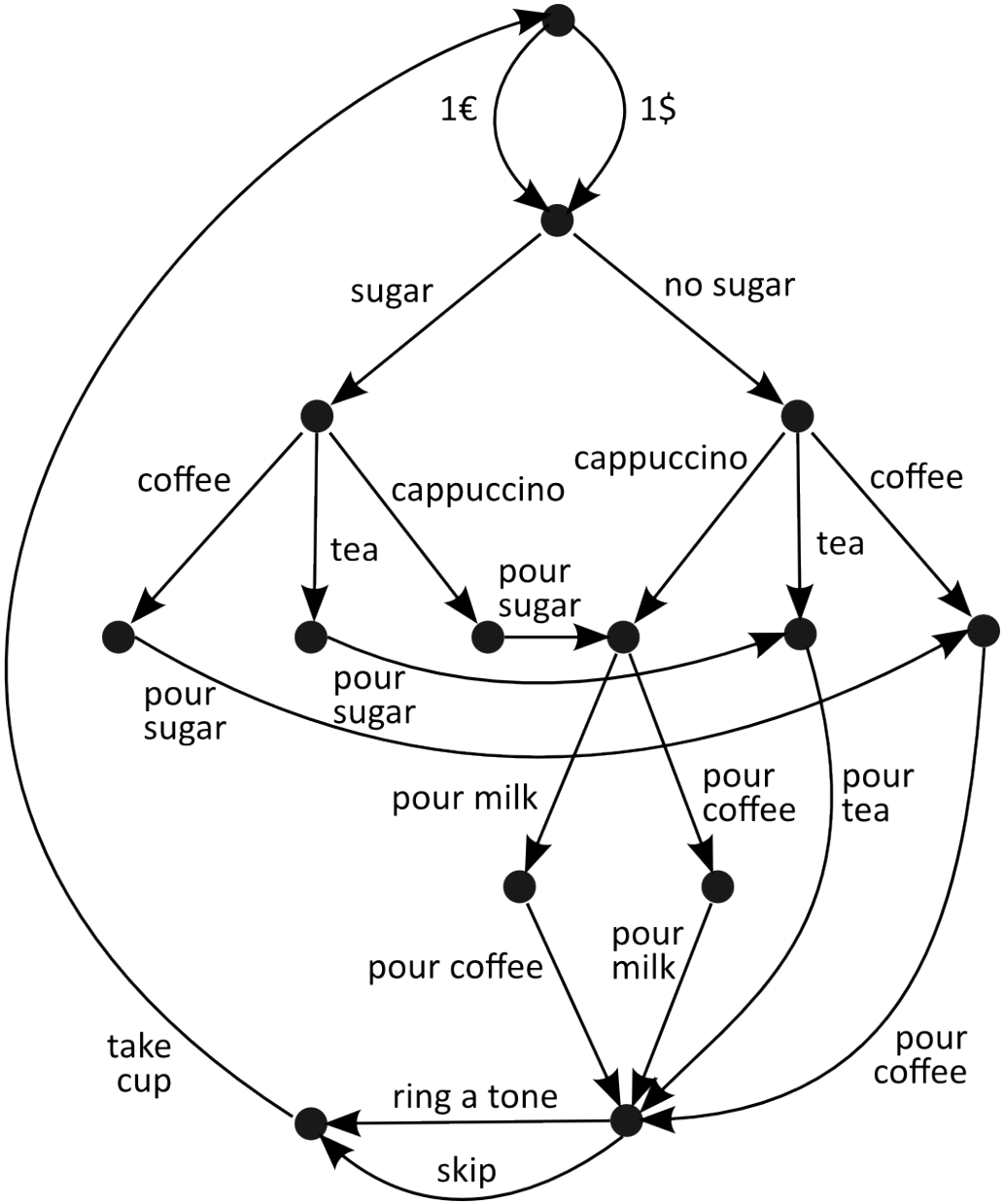
Kandisky 1919



A valid Canadian coffee machine



A variant LTS of above MTS that is not valid



v-ACTL: A logic interpreted over MTSs

Variability and action-based branching-time temporal logic

Based on action-based logic ACTL (De Nicola et al.), state-based logic CTL (Clarke et al.) and Hennessy-Milner Logic with Until (Larsen et al.)
Plus *deontic* interpretations of operators based on *must paths* in MTSs

Syntax of v-ACTL

$$\phi ::= true \mid \neg\phi \mid \phi \wedge \phi \mid \langle\varphi\rangle\phi \mid \langle\varphi\rangle^{\Box}\phi \mid [\varphi]\phi \mid [\varphi]^{\Box}\phi \mid E\,\pi \mid A\,\pi$$

$$\pi ::= \phi\ {}_{\varphi}U_{\varphi}\ \phi \mid \phi\ {}_{\varphi}U^{\Box}_{\varphi}\ \phi \mid \phi\ {}_{\varphi}W_{\varphi}\ \phi \mid \phi\ {}_{\varphi}W^{\Box}_{\varphi}\ \phi$$

Thus defines state formulae ϕ, path formulae π and action formulae φ (boolean compositions of actions) over set of atomic actions $\{a, b, \ldots\}$

Further operators

$F\phi$, $F_{\varphi}\ true$, $F^{\Box}_{\varphi}\ true$, $F^{\Box}\ \phi$, $AG\,\phi$, $AG^{\Box}\ \phi$, ...

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Tool: Variability Model Checker (VMC)

Modelling, analysing and verifying behavioural variability

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

- interactively explore the model (MTS)
- derive and explore (all) the model's valid variants (LTSs)
- visualize the model/variants graphically as MTS/LTSs
- verify branching-time temporal logic properties over MTSs/LTSs
- interactively explain why a property is (not) satisfied

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

Core is a command-line version of the model checker and of a variant generation procedure, both stand-alone executables written in Ada, so:

- easy to compile for Windows | Linux | Solaris | Mac OS X
- wrapped with a set of CGI scripts handled by a web server:
  - easy to build graphical html-oriented GUI
  - easy to integrate with graph drawing tools

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Family of coffee machines specified in VMC

VMC

http://fmtlab.isti.cnr.it/vmc/V5.4/vmc.html

VMC v5.4

Commands Menu
- New Model ...
- Edit Current Model
- Explore the MTS
- Modelcheck MTS ...
- View Current Model
- Draw Family MTS
- Generate Products
- Welcome
- Quit

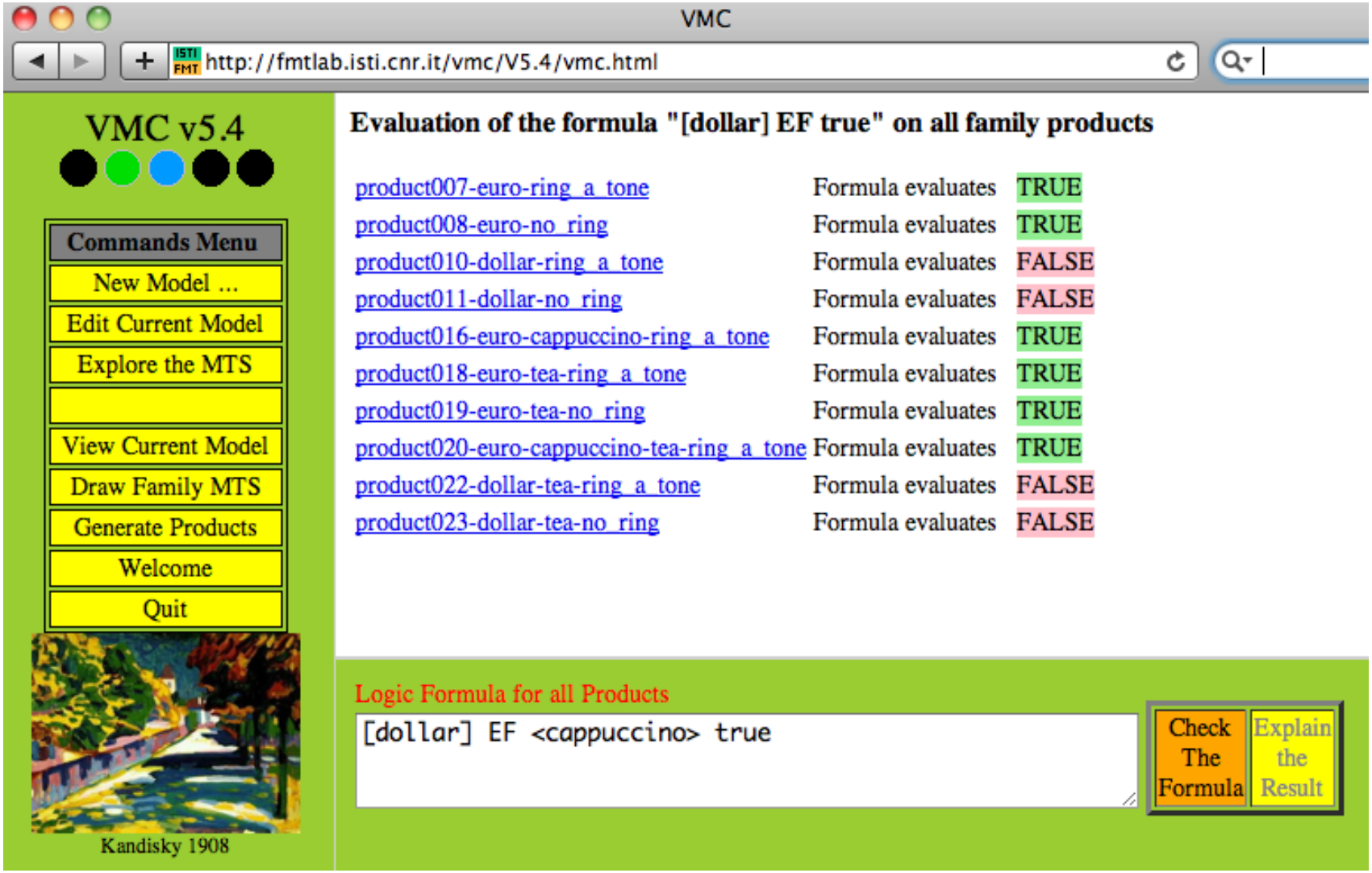
Kandisky 1908

```
T1 = euro(may).T2 + dollar(may).T2
T2 = sugar.T3 + no_sugar.T4
T3 = coffee.T5 + cappuccino(may).T6 + tea(may).T7
T4 = coffee.T8 + cappuccino(may).T9 + tea(may).T10
T5 = pour_sugar.T8
T6 = pour_sugar.T9
T7 = pour_sugar.T10
T8 = pour_coffee.T13
T9 = pour_coffee.T11 + pour_milk.T12
T10= pour_tea.T13
T11 = pour_milk.T13
T12 = pour_coffee.T13
T13 = ring_a_tone(may).T14 + no_ring(may).T14
T14 = take_cup.T1

net SYS = T1

Constraints {
   euro ALT dollar
   dollar EXC cappuccino
   cappuccino REQ ring_a_tone
   ring_a_tone ALT no_ring
}
```

A property verified over variants with VMC



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

VMC in relation to other model checkers

VMC itself is a product of a family of model checkers

- developed and highly optimized at ISTI–CNR during last decades
- on-the-fly: in general no need to generate/explore full state space
- capable of verifying properties specified in a CTL-like action- and state-based branching-time temporal logic

Products: FMC (input: CCS/CSP/LOTOS-like process algebras), UMC (input: UML state machines) & CMC (input: WS orchestration calculus)

Detailed comparison with MTSA, SNIP & SPLVERIFIER: SPLC'12

MTSA (D'Ippolito et al.): built on top of LTSA, i.e. also LTS-based, but no specific features for analysing variability

SNIP (Classen et al.): no GUI, but built-in support for feature diagrams and model-checking algorithms specifically tailored for SPLE

SPLVERIFIER (Apel et al.): does focus on features, but addressing the detection of feature interactions rather than variability

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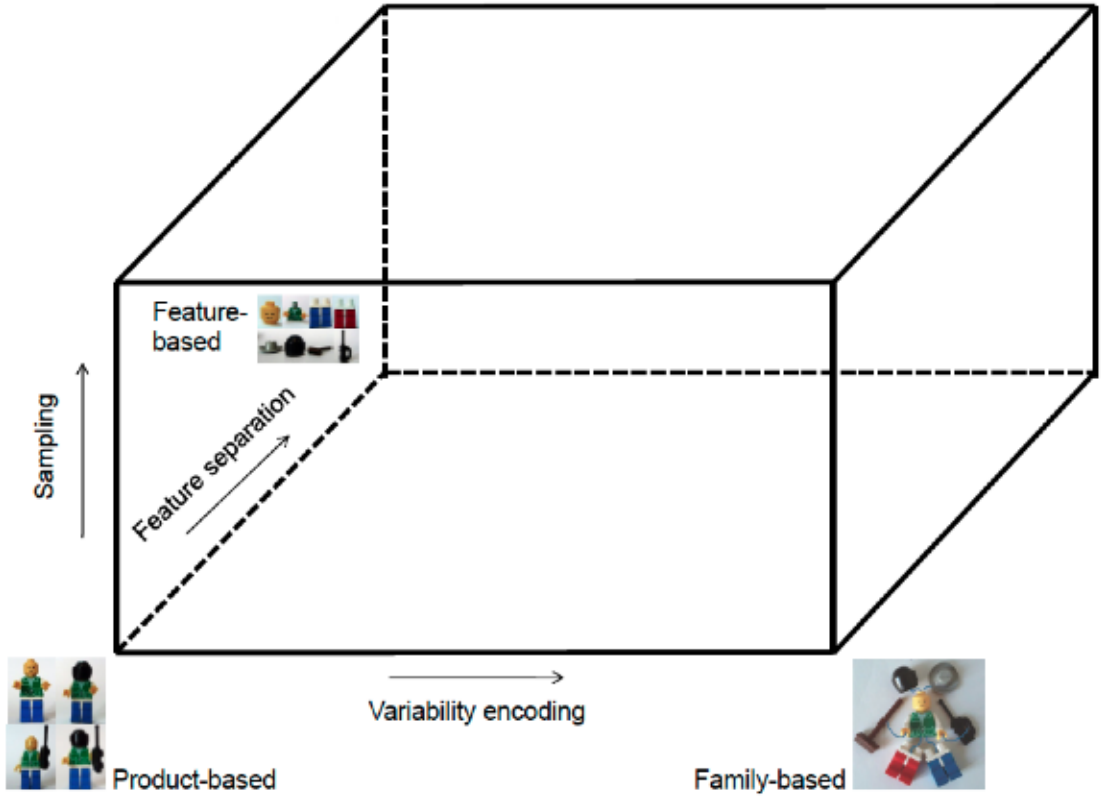
VMC's position in the PLA cube (Apel et al.)



From family-based to product-based analysis

VMC can also be used to model and analyse a subfamily or a specific subset of a family's valid variants by restrictions applied via constraints

Add constraint `coffee EXC dollar` to the family specification

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

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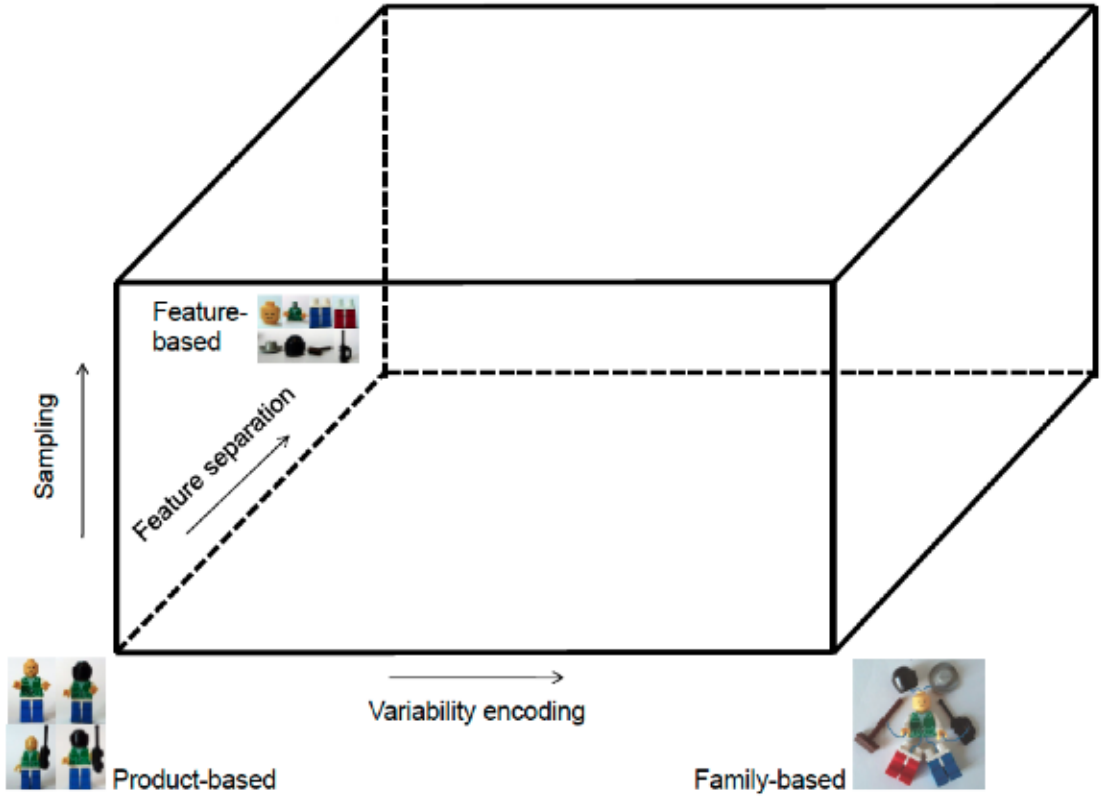

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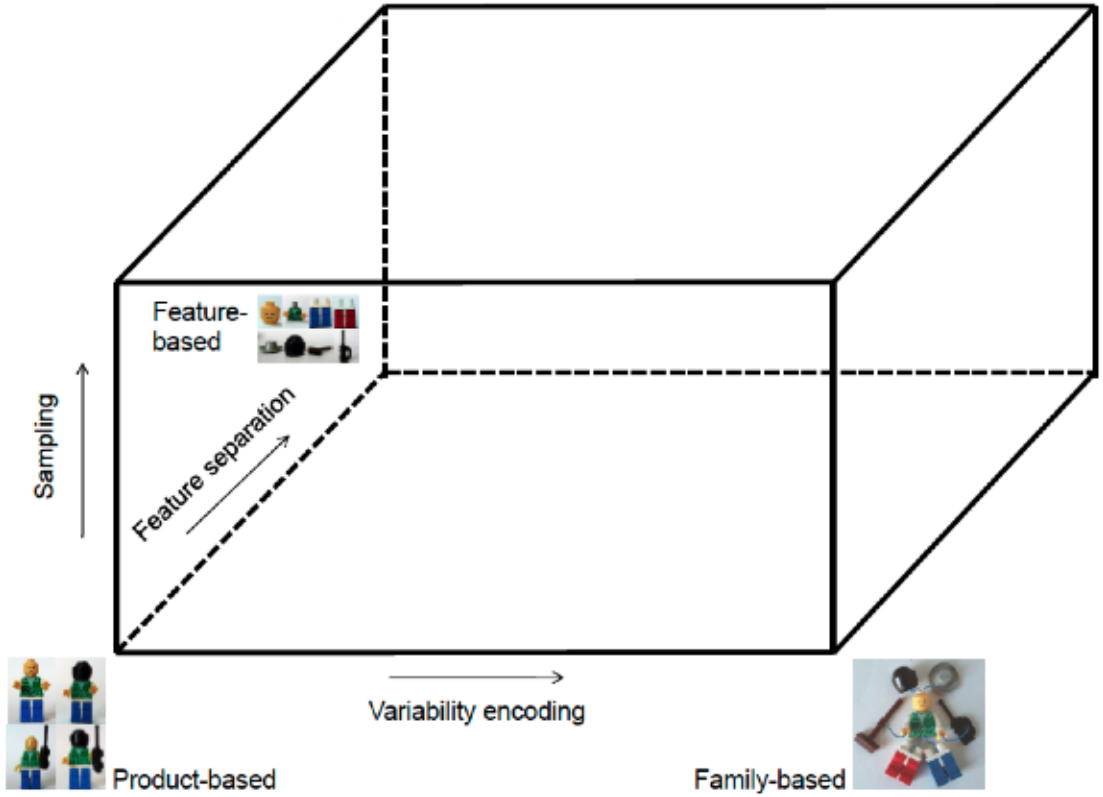

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Future work

1. Consider more expressive behavioural models (e.g. our (G)EMTSs)
2. Feature-based analysis, building on feature model composition (Acher et al.)
3. Confront with / learn from dynamic adaptation / reconfiguration, where all possible variants are often not known upfront