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Generating SPARK from Event-B

Providing Fundamental Safety and Security

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Outline of talk

- Background
  - Event-B, CamilleX & Event-B notation extensions (including Records)
  - Spark
- Overview -
  - why generate SPARK from Event-B
  - From abstract record structures to SPARK
- SPARK code generation
  - Overview of translation rules (inc. records)
- SBB Electronic Voting Case study
  - using latest CamilleX and Records
  - SBB final refinement -> SPARK specifications

Background - Event-B

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- Discrete transition systems
  - Variables representing states
  - Guarded events representing transitions
  - Contexts: Static part of the models (carrier sets, constants, etc.)
  - Machines: Dynamic part of the models (variables, events, etc.)
- First-order logic with set theory

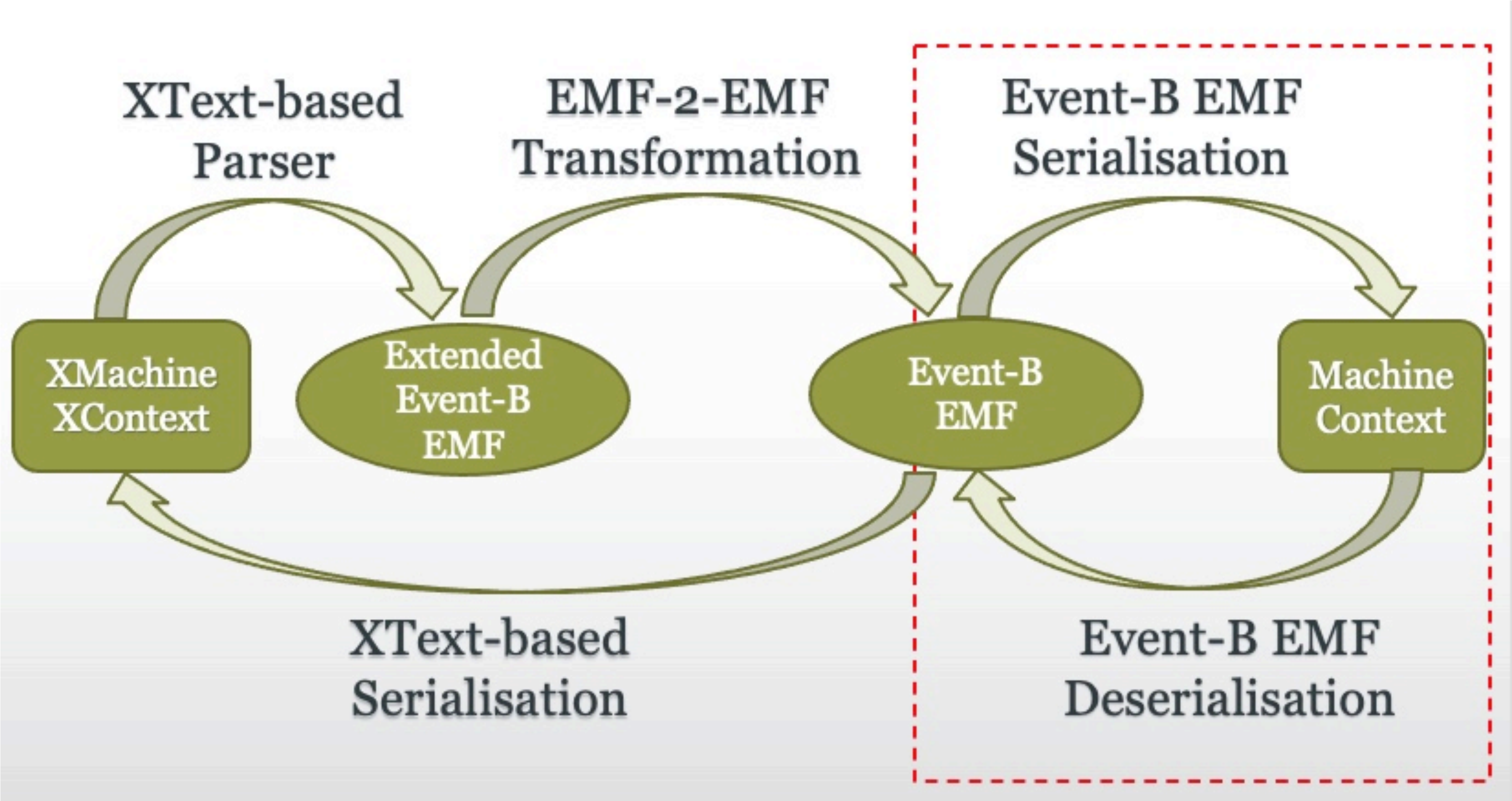
- Refinement
  - Start with a simple abstract model
  - Add detail and design in small steps

- Verification by automatic theorem provers
- Validation by model checking
- Model checker also useful for liveness and debugging

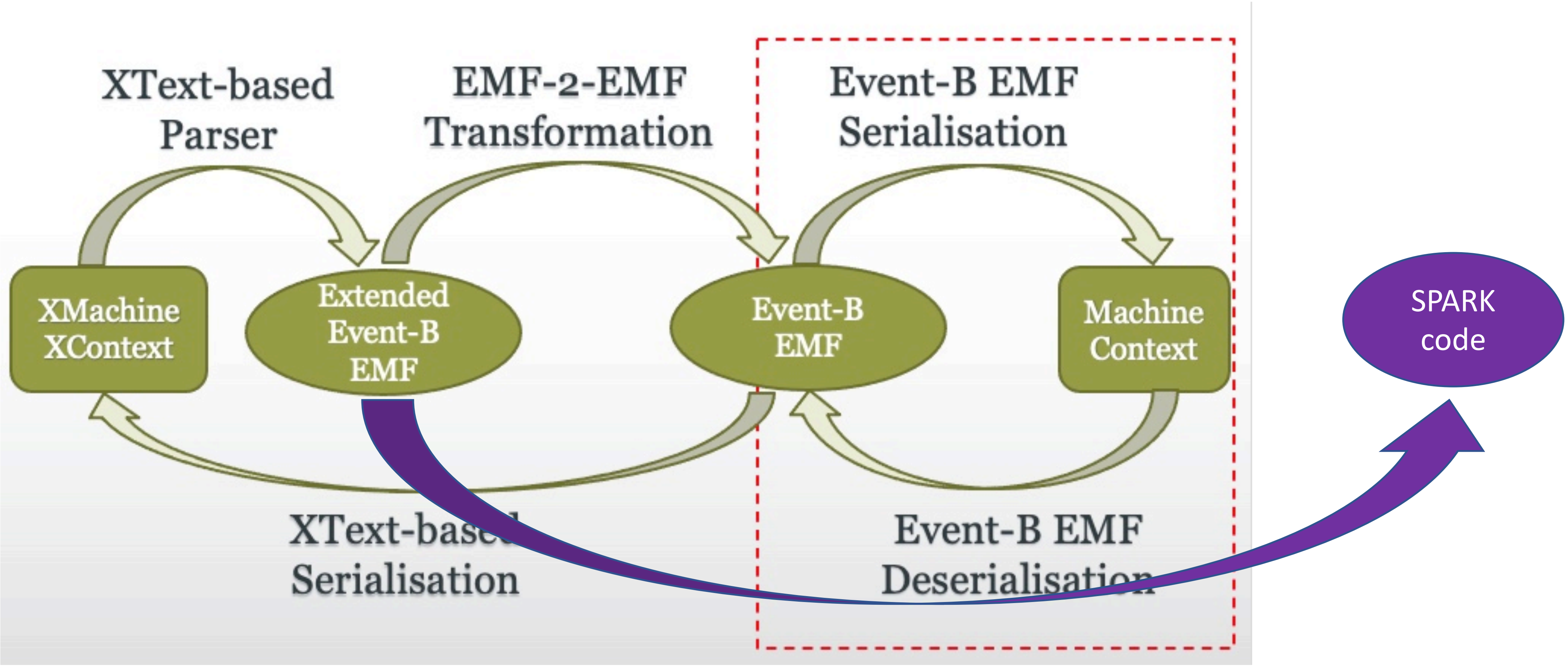
The Need for Textual Representation

- (True) Textual representation helps with teamworking
- Framework (e.g., XText) for developing IDE for DSLs.
- Design Principles:
  1. Reuse the existing Event-B tools of Rodin as much as possible.
  2. Support direct extension of the Event-B syntax to provide additional features.
  3. Provide compatibility with other kinds of ‘higher-level’ models that contribute to the overall model, e.g., UML-B diagrams.
- We make use of the Event-B EMF and EMF-2-EMF framework

The CamilleX Framework



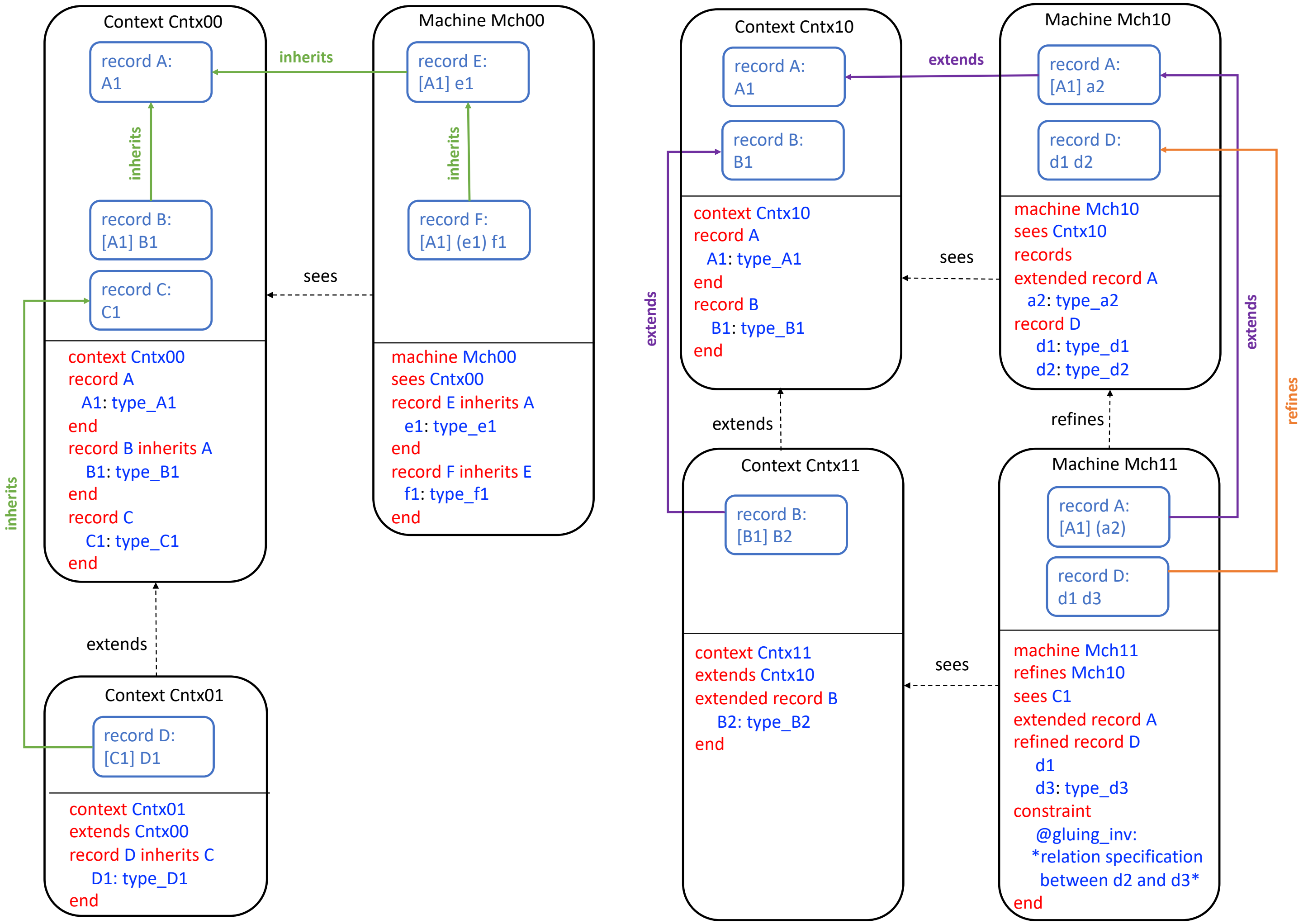
The CamilleX Framework



Records – an important extension to Event-B

- Inherits
  - Subtyping records
  - Implicit fields
- Refines
  - Replacing fields
  - Adding fields
- Extends
  - (Only) Adding fields
- Constraints
  - Properties of record instances

Ongoing research :
decomposition of records to prepare for translation to SPARK records



Background - SPARK

- Subset of Ada programming language
- Assertions, pre-conditions, post-conditions
- Targeted at highly reliable software
- Formal verification to prove the absence of runtime errors:
  - arithmetic overflow, buffer overflow and division-by-zero.
- Applied over many years
  - e.g. aircraft systems, control systems and rail systems.

Motivation

- Abstraction to isolate important properties
- Refinement to add detail and design
- Resulting in Validated and Verified models

- …But how can we ensure the code complies with the models

- Answer: generate Spark outline code
    - With pre/post-conditions that match events of the model
    - Assertions for run time checking

Steps : From abstract concept to Spark Implementation

- Abstract model of concept
- Refinements that introduce more detailed requirements
- Refinements that introduce design decisions
- Decomposition … *Controller* + Environment
- Refine *Controller* to prepare for code generation
- Generate SPARK from *Controller*

Overview of Event-B to SPARK Translation Rules

- Component Translation
  - (All) Context → specification package
    - Context extends → context packages use (and all extended context packages)
  - (Last) Refined Machine → specification and body packages
    - Machine sees context → use contexts packages (and all extended context packages)

```
machine mch_name sees ctx_name
```

```
with ctx_name; use ctx_name;
package mach_name
with SPARK_Mode => On
end mach_name;
```

```
package body mch_name with SPARK_Mode is ...
end mach_name;
```

Overview of Event-B to SPARK Translation Rules

- Constant Translation
  - Non function constants → constant, type depends on the axiom definitions

constants $const\_name$
axioms
$const\_name \in const\_type$
$const\_name = const\_value$

$$const\_name : \mathbf{constant}\ const\_type := const\_val;$$

  - Function type constant → function with return type depending on the range of the function and the function parameters are the domain of the Event-B function.

constants $cnst\_name$
axioms $cnst\_name \in dom \rightarrow ran$

$$\mathbf{function}\ cnst\_name\ (p\_dom :\ \mathbf{in}\ \ dom)\ \mathbf{return}\ ran;$$

Overview of Event-B to SPARK Translation Rules

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- Variable Translation
  - Variable → Global variable,
    - initialised according to the INITIALISATION event actions
- Record Translation
  - CamilleX Record → SPARK record
    - with all Event-B record fields (direct and implicit)

```
record rec_name
field_name : field_type
```

```
type rec_name is
field_name : field_type ;
end record;
```

Overview of Event-B to SPARK Translation Rules

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- Event Translation
  - Event → Procedure *(except Initialisation)*
  - Event Guard → Pre-condition
  - Event Action → Post-condition & Procedure body
  - Event Parameter → Procedure Parameter
    - (where output/input/in_out is deduced from guards and actions)
- Note that we have already proved invariants in the Event-B.. No need to translate invariants to SPARK
  - *Or is there! Some industrial partners have suggested that it may still be useful.. E.g. to catch problems caused by interrupts.*

Refinement of SBB example
From abstract concept to spark

- Ballot
- Paper (voter,vote)
- Paper (voter,vote,time)
- Paper (~~voter,vote~~,time,encrypted)
- Paper (~~voter,vote~~,time,encrypted, mac)
- Decompose -> smart ballot box + voters/attackers
- Refine SBB data towards arrays etc.
- Generate SPARK for SBB

Abstract notion of a ballot as a mapping from voters to vote
We only consider ideal situation of valid votes

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Replace ballet with its physical representation :
Paper - fields for voter and vote

This introduces the possibility of invalid papers.. Copying faking etc.

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Introduce new field : time

Voting papers can expire,
Reduces opportunity for validity threats

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Refine voter,vote with encrypted.

Provide confidentiality

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Introduce mac (algorithm for hashing)

Enables checking validity of vote..

E.g. if an attacker tries to alter the vote

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- Event-B model is a closed system
  - Some parts of model are the controller
  - Others the environment being controlled

Future work - How to decompose records sets e.g. only cast_papers are in the SBB system

Refinement of SBB example
From abstract concept to spark

- *Data Refinement from abstract SET into Array*
  - *Array can be modelled as a Total function from 0..n to set*
- *Event-B records can have optional fields SPARK we can only use total functions -*
  - *Define a null value for optional field so that all records are total*

- Ballot
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Refinement of SBB example
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Example: Application to Smart Ballot Box Model

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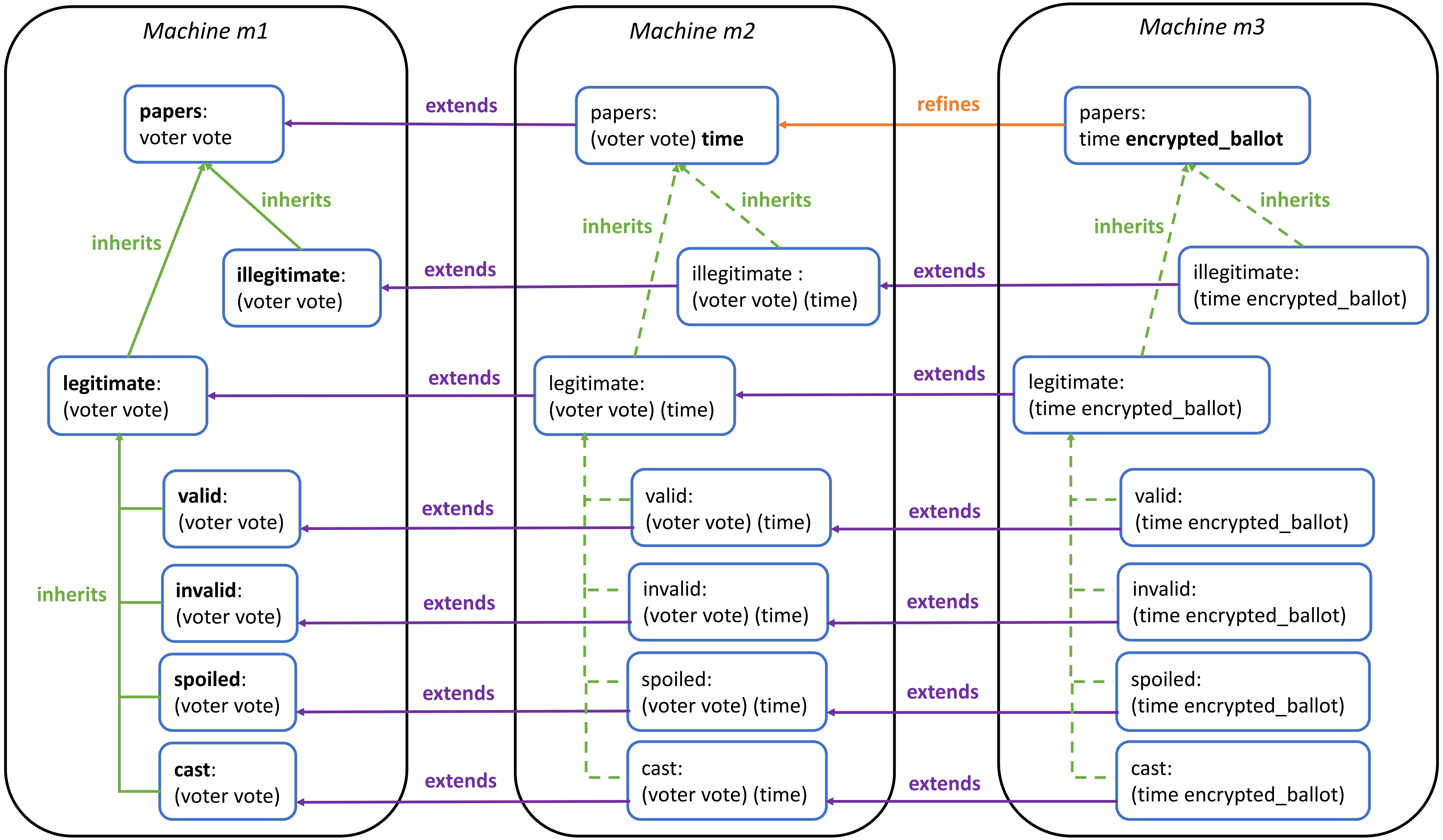
```
event cast_paper
refines cast_paper
any
paper
where
@grd1: paper ∈ BARCODE
@grd2: cast_count ∈ 0 .. max_votes −1
                    ....
then
@act1: cast_arr(cast_count)≔ paper
@act2: cast_count ≔ cast_count + 1
end
```

```
procedure cast(paper : in  barcode) with
Global => (Proof_In => ( spoiled_arr, curr_time, spoil_count),
In_Out => (cast_arr, cast_count)),
Pre => cast_count in 0 .. Max_Votes-1),
  and then not already_cast(paper)
                 ...
Post => already_cast(paper)
   and then cast_count = cast_count' old + 1);
```

```
procedure cast(paper : in  barcode) is
 begin
   cast_arr(cast_count) := paper;
   cast_count := cast_count + 1;
end cast;
```

QUESTIONS?

Case Study – SBB Electronic Voting



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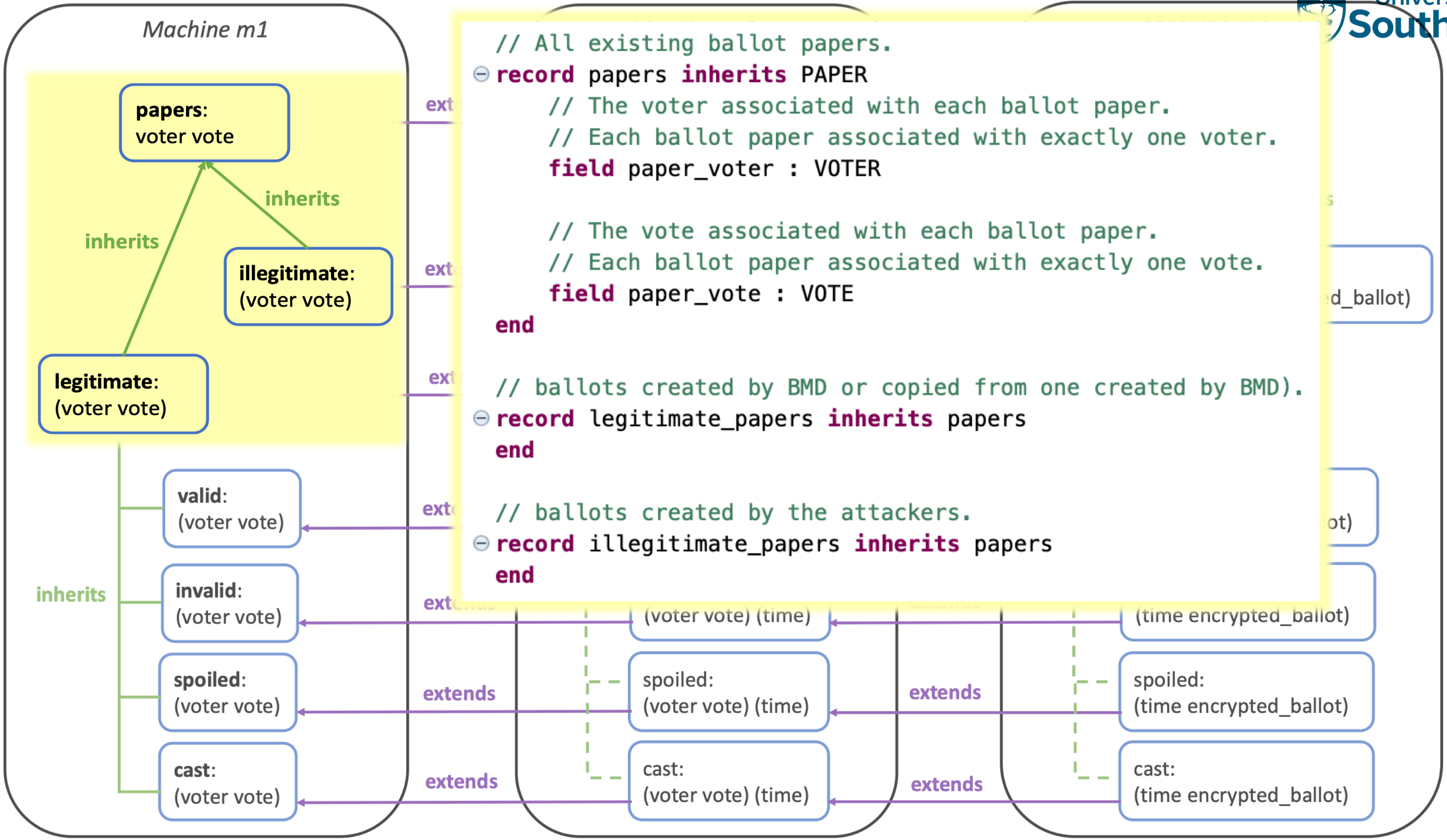
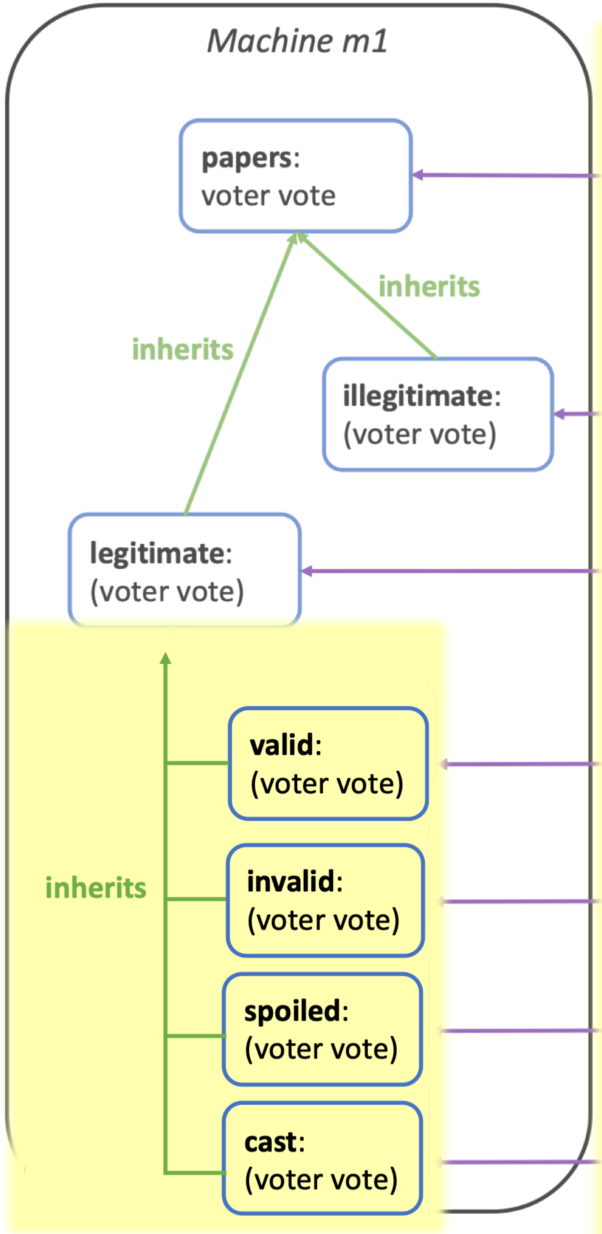
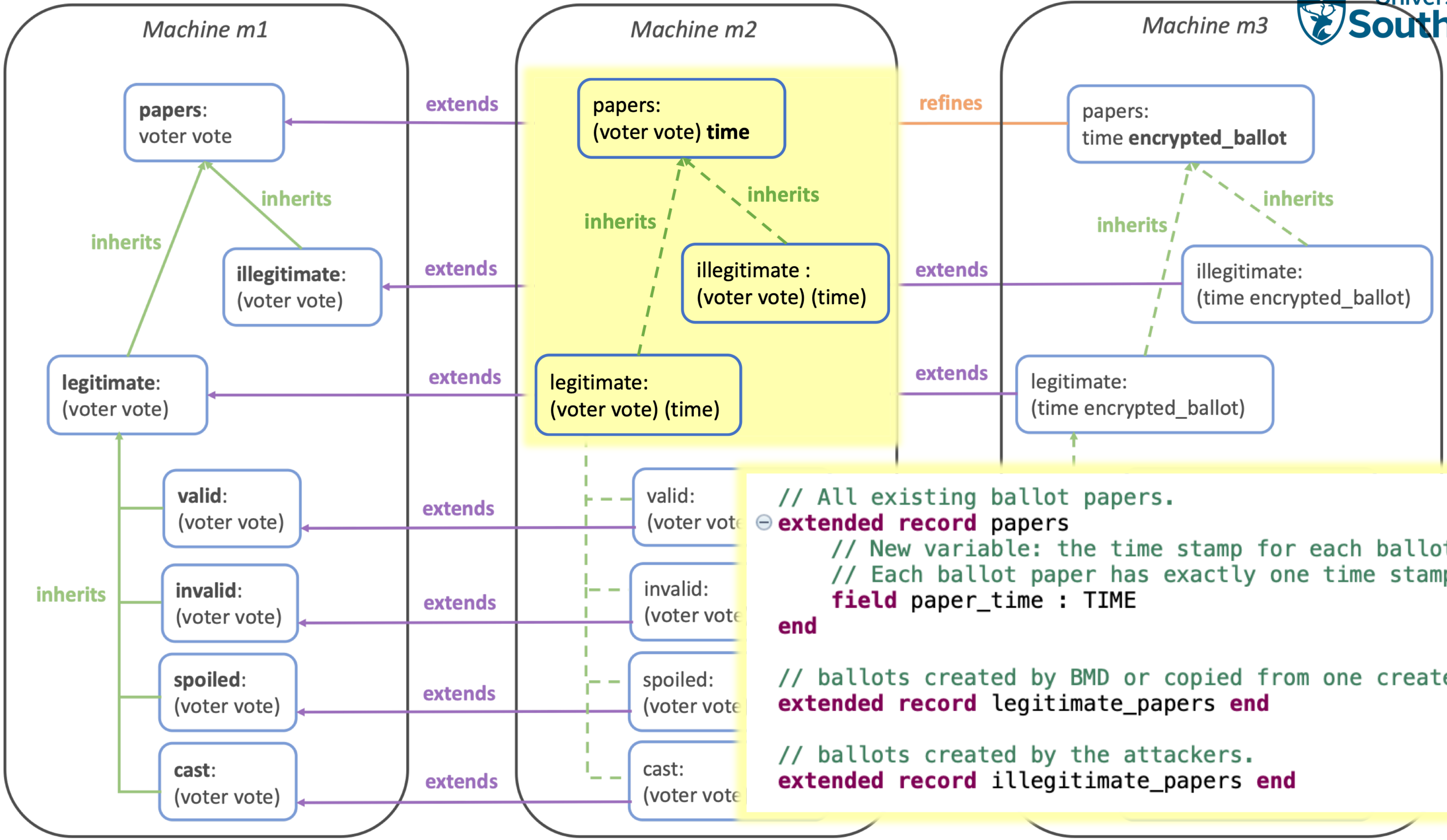


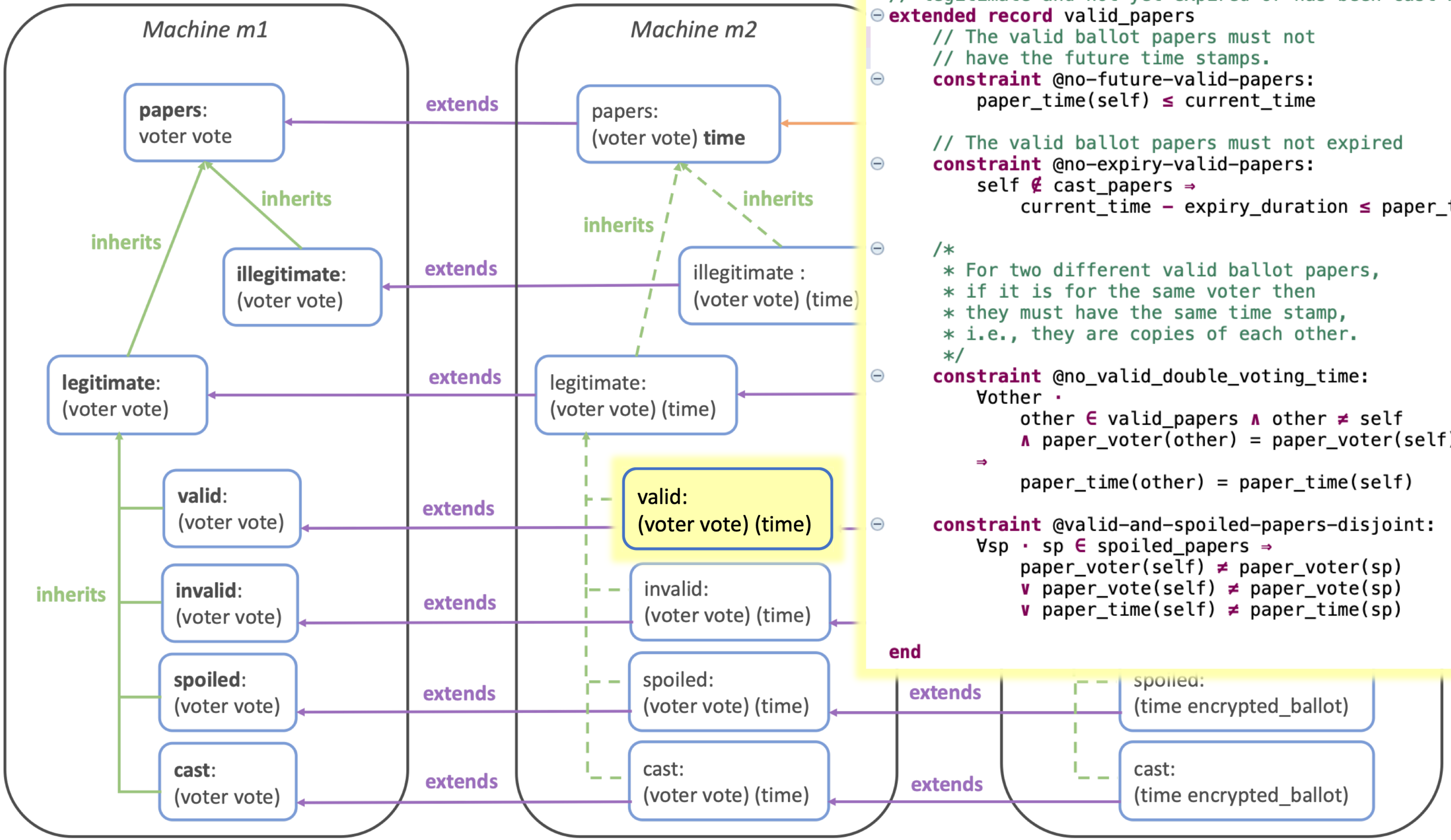

```
// All existing ballot papers.
record papers inherits PAPER
    // The voter associated with each ballot paper.
    // Each ballot paper associated with exactly one voter.
    field paper_voter : VOTER

    // The vote associated with each ballot paper.
    // Each ballot paper associated with exactly one vote.
    field paper_vote : VOTE
end

// ballots created by BMD or copied from one created by BMD).
record legitimate_papers inherits papers
end

// ballots created by the attackers.
record illegitimate_papers inherits papers
end
```



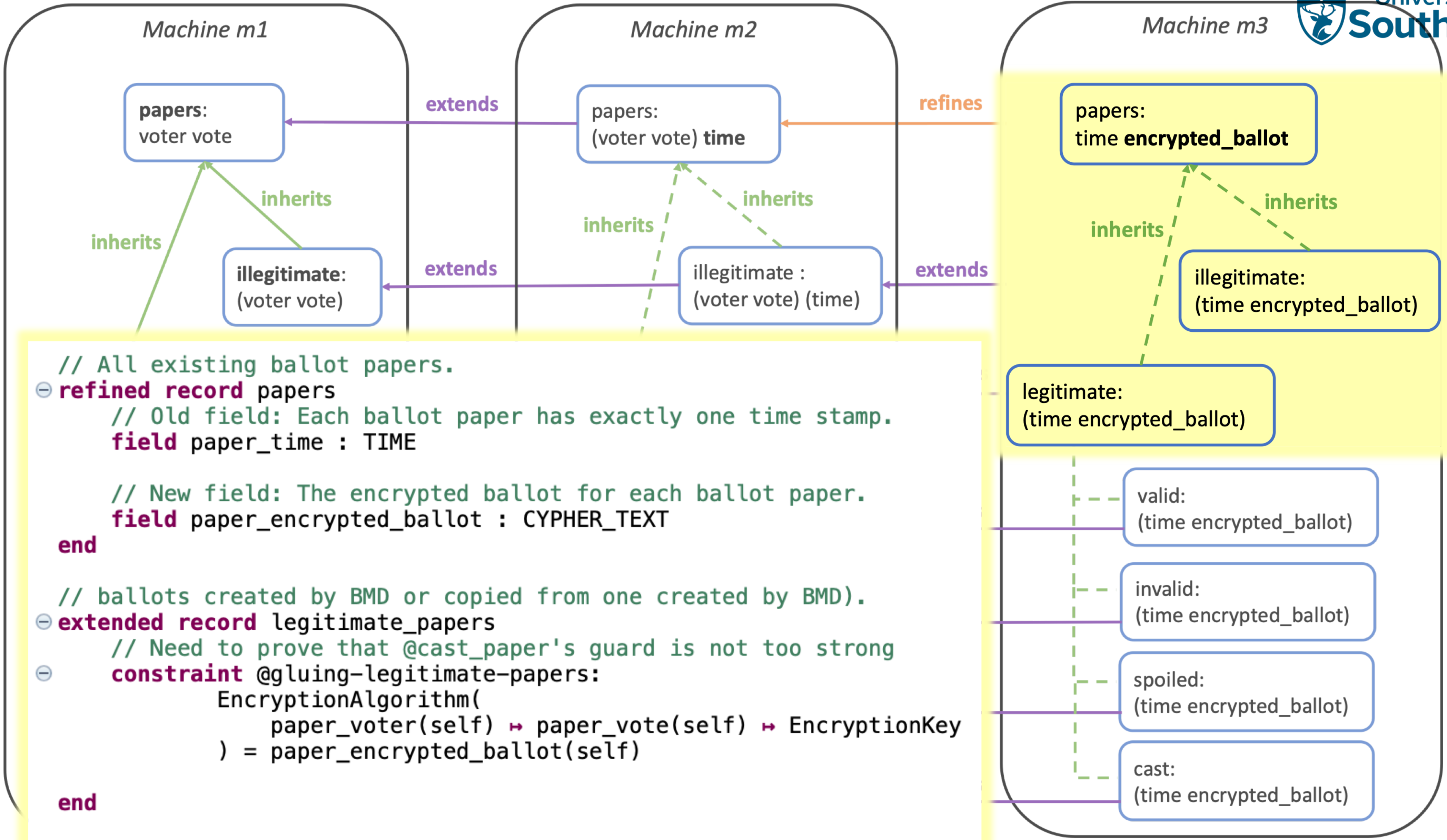

```
// The set of spoiled ballot paper.
record spoiled_papers inherits legitimate_papers
end

// legitimate and not yet expired or has been cast before expired or not spoiled
record valid_papers inherits legitimate_papers
    /*
     * For two different valid ballot papers, if it is for the same voter then
     * they must have the same vote, i.e., they are copies of each other.
     */
    constraint @no_valid_double_voting_vote:
        ∀other ·
            other ∈ valid_papers ∧ other ≠ self
            ∧ paper_voter(other) = paper_voter(self)
        ⇒
            paper_vote(other) = paper_vote(self)
end

// legitimate but becomes invalid since expired or a copy has been cast or
// spoiled.
record invalid_papers inherits legitimate_papers
end

// legitimate and already cast
record cast_papers inherits legitimate_papers
    /*
     * If a voter already cast a ballot paper, they cannot have any valid
     * ballot paper.
     */
    constraint @no_cast_double_voting_vote:
        paper_voter(self) ∉ paper_voter[valid_papers]
end
```




```
// All existing ballot papers.
extended record papers
    // New variable: the time stamp for each ballot paper
    // Each ballot paper has exactly one time stamp.
    field paper_time : TIME
end

// ballots created by BMD or copied from one created by BMD).
extended record legitimate_papers end

// ballots created by the attackers.
extended record illegitimate_papers end
```




```
// legitimate and not yet expired or has been cast before expired.
extended record valid_papers
    // The valid ballot papers must not
    // have the future time stamps.
    constraint @no-future-valid-papers:
        paper_time(self) ≤ current_time

    // The valid ballot papers must not expired
    constraint @no-expiry-valid-papers:
        self ∉ cast_papers ⇒
            current_time − expiry_duration ≤ paper_time(self)

    /*
     * For two different valid ballot papers,
     * if it is for the same voter then
     * they must have the same time stamp,
     * i.e., they are copies of each other.
     */
    constraint @no_valid_double_voting_time:
        ∀other ·
            other ∈ valid_papers ∧ other ≠ self
            ∧ paper_voter(other) = paper_voter(self)
        ⇒
            paper_time(other) = paper_time(self)

    constraint @valid-and-spoiled-papers-disjoint:
        ∀sp · sp ∈ spoiled_papers ⇒
            paper_voter(self) ≠ paper_voter(sp)
            ∨ paper_vote(self) ≠ paper_vote(sp)
            ∨ paper_time(self) ≠ paper_time(sp)

end
```




```
// All existing ballot papers.
refined record papers
    // Old field: Each ballot paper has exactly one time stamp.
    field paper_time : TIME

    // New field: The encrypted ballot for each ballot paper.
    field paper_encrypted_ballot : CYPHER_TEXT
end

// ballots created by BMD or copied from one created by BMD).
extended record legitimate_papers
    // Need to prove that @cast_paper's guard is not too strong
    constraint @gluing-legitimate-papers:
            EncryptionAlgorithm(
                paper_voter(self) ↦ paper_vote(self) ↦ EncryptionKey
            ) = paper_encrypted_ballot(self)

end

// ballots created by the attackers.
extended record illegitimate_papers end
```