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The NTF format for non-classical logics

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TPTPTP 2024, Nancy, France

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Goal

TPTP is the standard in (classical) theorem proving

Our goal: 'gracefully' extend to non-classical logics

- Minimal syntactic changes
- Uniform syntax for all non-classical logics
- Consistency throughout TPTP dialects
- User-friendly syntax
  (easy reading and writing of problems)
- Developer-friendly syntax
  (easy parsing, minimal no. of cases to consider)

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This talk: Describe extensions to TPTP (focus on language)

Typed first-order logic (TXF): Recap on TPTP syntax

```
tff(dog_decl,type, dog: $tType ).
tff(human_decl,type, human: $tType ).
tff(owner_of_decl,type, owner_of: dog > human ).
tff(bit_decl,type, bit: (dog * human * $int) > $o ).
tff(hates_decl,type, hates: (human * human) > $o ).

tff(hate_the_multi_biter_dog,axiom,
   ! [D: dog,H: human,N: $int] :
     ( ( H != owner_of(D) & bit(D,H,N) & $greater(N,1) )
     => hates(H,owner_of(D)) ) ).
```

Higher-order logic (THF): Recap on TPTP syntax

```
thf(dog_decl,type, dog: $tType ).
thf(human_decl,type, human: $tType ).
thf(owner_of_decl,type, owner_of: dog > human ).
thf(owns_decl,type, owns: human > dog > $o ).

thf(owns_defn,definition,
   ( owns = ( ^ [H: human,D: dog] : ( H = ( owner_of @ D ) ) ) ) ).

thf(hate_the_multi_biter_dog,axiom,
   ! [Huddle: dog > $o]: ?[Group: human > $o]:
    ![D: dog]: ? [H: human]:
    ( (Huddle @ D) & (Group @ H) & (owns @ H @ D) ) ).
```

Extend languages with new operator:

- New kind of connective:

```
| { connective_name }
```

- `connective_name` is either TPTP-defined: e.g. `{ $necessary }`, `{ $possible }`, `{ $knows }`, ...
- or `connective_name` is system-defined: e.g. `{ $$future }`, `{ $$obligation }`, `{ $$permission }`, ...

Resulting language: NTF (non-classical typed form)

- Non-classical typed extended first-order form (NXF)
  - first-order-like application style:

```
{ connective_name } @ (a,b)
```

- Non-classical typed higher-order form (NHF)
  - canonical higher-order application style (curried):

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NTF: Non-Classical TPTP

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Non-Classical TPTP

Example in NXF:

```
tff(possible_dog_bit_owner,axiom,
   {$dia} @ (? [D: dog] : bit(D,owner_of(D),1)) ).

tff(jon_says_necessary_truth,axiom,
   ! [S: $o] : ( says(jon,S) => {$box} @ (S) ) ).
```

Example in NHF:

```
thf(possible_jon_owns_biter,axiom,
   ! [D: dog] :
    ( ( bit @ D @ jon @ 1 )
    => ( {$dia} @ ( owns @ jon @ D ) ) ) ).

thf(jon_says_he_must_feed_odie,axiom,
   says @ jon @ ({$box} @ (feeds @ jon @ odie)) ).
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Parameterized connectives

Optional parameters: Every NCL connective may be parameterized

- For logics with families of operators, e.g. ...
  - multi-modal logics: $\Box_i$
  - term-modal logics: $[t]\varphi$
  - propositional dynamic logic: $[p \cup q]\varphi$
  - epistemic logic: $K_A\varphi$, $C_{\{A,B,C\}}\phi$, ...

Representation: key-value arguments

```
{ connective_name(param1 := value1, param2 := value2, ...) }
```

- ... where the params are functors,
- and the values are arbitrary terms

Allow hashed (#ed) index value as first argument:

```
{ connective_name(#index, param1 := value1, param2 := value2, ...) }
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Parameterized exmaples

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tff(alice_knows_its_possible_odie_bit_jon,axiom,
   {$knows(#alice)} @ ({$dia} @ (bit(odie,jon,1)) ).
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```
tff(jon_says_common_knowledge,axiom,
   ! [S: $o] :
     ( says(jon,S) => {$common($agents:=[alice,bob,claire])} @ (S) ) ).
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thf(alice_knows_jon_owns_a_dog,axiom,
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     ? [D: dog] : ( owns @ jon @ D ) ).
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thf(alice_and_bob_know_jon_might_lie,axiom,
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Note on representation in TPTP

A note on the format

- NTF is a result of different deliberate design decisions:
  - Minimal parser extensions if TXF (or THF) is already supported
  - Prolog parsing compability (long-standing principle)
  - Syntax should be general enough to cover many (complicated) NCLs
  - Distinction of object-language and meta-language components

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Advantages:
(1) n-ary operators remain n-ary: `{$box(#i)} @ (phi)` for $\Box_i \varphi$

(2) operators always use the same number of arguments (also in case NCL has e.g. indexed and unindexed box)

(3) no typing issues (meta-level objects – like index *i* – may not be part of the term/formula language)

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  - Syntax should be general enough to cover many (complicated) NCLs
  - Distinction of object-language and meta-language components
- NTF clearly is (a bit) more complex than single-purpose languages
  - If we only need to support (indexed) modal operators, things are syntactically simpler
  - If we only need to support unary (binary) NCL operators, things are syntactically simpler
  - ...

Object-level syntax is not enough

From which logic does the formula $p \vee q$ come from?

Classical logic? Wrong! I meant intuitionistic logic.

From which logic does the formula $\Box\phi \rightarrow \phi$ come from?

Modal logic **K**? Wrong! I meant **S5** ...

- Formula syntax alone not enough to let ATP systems know which logic we're in
- Introduce: Logic specification

> tff(*formula_name*, logic, *logic_name* == [*properties*]).

where ...

- *logic_name* is the name of the logic family,
- *properties* is a comma-separated sequence of key-value pairs

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As a start: Focused on (quantified) modal logics

Examples

Example formulas of modal logics

Mono-modal:

- $\Box \text{raining} \rightarrow \Diamond \text{raining}$
- $\forall P\, (\Diamond \text{rich}(P) \vee \Diamond \neg \text{rich}(P))$
- $\neg \Box (\exists X\, \text{rich}(X))$

Multi-modal:

- $\Box_a \text{raining} \rightarrow \Diamond_b \text{raining}$
- $\forall P\, (\Diamond_b \text{rich}(P) \vee \Diamond_b \neg \text{rich}(P))$
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Representation in TPTP

Connectives (mono-modal)

- `{ $box }`
- `{ $dia }`

Connectives (multi-modal)

- `{ $box(#i)}`
- `{ $dia(#i)}`

Examples from above:

```
tff(1, axiom, { $box } @ (raining) => { $dia } @ (raining) ).
tff(2, axiom, ![P]: ( { $dia } @ (rich(P)) | ~({ $dia } @ (rich(P))) ).
tff(3, axiom, ~ { $box } @ ( ? [X]: rich(X) ) ).
```

We also offer user-friendly names: `{ $necessary }`, `{ $possible }`, `{ $knows }`, ...

Quantified Modal Logics in TPTP

Representation in TPTP

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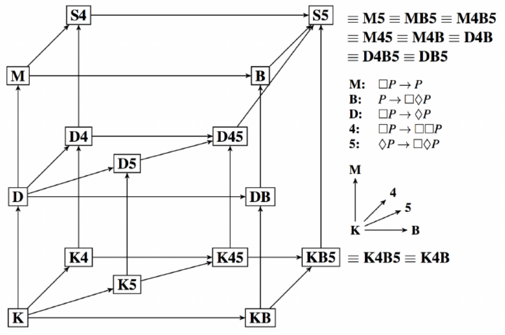
We also offer user-friendly names: `{ $necessary }`, `{ $possible }`, `{ $knows }`, ...

Modal logic: A family of many different logics

- Many parameters exist to create more specific modal logics
- Popular example: Properties of the box operator



Logic dimensions of modal logic

1. **Axiomatization of $\Box_i$**
2. **Quantification domains**
3. **Rigid/flexible designation of symbols**
4. **Term locality**

Logic dimensions of modal logic

1. **Axiomatization of $\Box_i$**
   - What properties does the box operators have?
   - Depending on the application domain

   Some popular axiom schemes:

Name	Axiom scheme	Condition on R_i	Corr. formula
K	$\Box_i(s \supset t) \supset (\Box_i s \supset \Box_i t)$	—	—
B	$s \supset \Box_i \Diamond_i s$	symmetric	$wR_iv \supset vR_iw$
D	$\Box_i s \supset \Diamond_i s$	serial	$\exists v.wR_iv$
T/M	$\Box_i s \supset s$	reflexive	wR_iw
4	$\Box_i s \supset \Box_i \Box_i s$	transitive	$(wR_iv \land vR_iu) \supset wR_iu$
5	$\Diamond_i s \supset \Box_i \Diamond_i s$	euclidean	$(wR_iv \land wR_iu) \supset vR_iu$
...	...	...	...

2. **Quantification domains**

3. **Rigid/flexible designation of symbols**

4. **Term locality**

Logic dimensions of modal logic

1. **Axiomatization of $\Box_i$**
   - What properties does the box operators have?
2. **Quantification domains**
   - What is the meaning of $\forall$?
   - Several popular choices exist
     (1) Varying domains: No restrictions
     (2) Constant domains: $\mathcal{D}_w = \mathcal{D}_v$ for all worlds $w, v \in W$
     (3) Cumulative domains: $\mathcal{D}_w \subseteq \mathcal{D}_v$ whenever $(w, v) \in R^i$
     (4) Decreasing domains: $\mathcal{D}_w \supseteq \mathcal{D}_v$ whenever $(w, v) \in R^i$
3. **Rigid/flexible designation of symbols**
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1. **Axiomatization of $\Box_i$**
   - What properties does the box operators have?
2. **Quantification domains**
   - What is the meaning of $\forall$?
3. **Rigid/flexible designation of symbols**
   - Do all constants $c \in \Sigma$ denote the same object at every world?
   - Several popular choices exist
     (1) Flexible constants: $\mathcal{I}_w$ may vary for each world w
     (2) Rigid constants: $\mathcal{I}_w(c) = \mathcal{I}_v(c)$
     for all worlds $w, v \in W$ and all $c \in \Sigma$
4. **Term locality**

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   - Do all constants $c \in \Sigma$ denote the same object at every world?
4. **Term locality**
   - What is the domain for the interpretation of terms t?
   - At least two common possibilites:
     (1) Local terms: Interpretation of t at world w is an element of $\mathcal{D}_w$
     (2) Global terms: Interpretation of t at world w is some element from $\bigcup_{w \in W} \mathcal{D}_w$

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$\longrightarrow$ many different logics

Use logic specification to encode specific logic

> `tff(`*formula_name*`, logic, $modal == [` *properties* `] ).`

- `$modalities` for the properties of $\Box_i$
- `$domains` for the properties of $\mathcal{D}_w$
- `$designation` for the properties of $\mathcal{I}_w$
- `$terms` for the locality properties

Allowed values:

Use logic specification to encode specific logic

```
tff(formula_name, logic, $modal == [ properties ] ).
```

- `$modalities` for the properties of $\Box_i$
- `$domains` for the properties of $\mathcal{D}_w$
- `$designation` for the properties of $\mathcal{I}_w$
- `$terms` for the locality properties

Allowed values:

`$modalities`: `$modal_system_`X or [`$modal_axiom_`Y_1`,...,$modal_axiom_`Y_n] for ...
$X \in \{K, KB, K4, K5, K45, KB5, \ldots, S4, S5\}$,
$Y_i \in \{K, T, B, D, 4, 5, C, \ldots\}$.

`$domains`: `$constant`, `$varying`, `$cumulative`, `$decreasing`

`$designation`: `$rigid`, `$flexible`

`$terms`: `$global`, `$local`

Example

Simple example:

```
tff(simple_spec,logic,
    $modal == [
      $designation == $rigid,
      $domains     == [ $constant, some_user_type == $varying ],
      $terms       == $global,
      $modalities  == $modal_system_S5 ] ).
```

More complex example:

```
tff(complex_spec,logic,
 $modal == [
   $designation == [ $flexible, sun == $rigid ],
   $domains     == [ $constant,
                        planet_type == $varying],
   $terms       == $local,
   $modalities  == [ $modal_system_K,
                     {$box(#1)} == $modal_system_KB,
                     {$box(#2)} == [ $modal_axiom_K,
                                     $modal_axiom_4 ] ] ).
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TPTP integration

- TPTP v9.0.0 contains 147 NTF (monomodal logic) problems: 132 NXF + 15 NHF
- TPTP4X utility for NTF
- proof verification via GDV
- AGMV model verifier
- IDV derivation viewer (for NTF)
- IIV interpretation viewer for Kripke models
- `scala-tptp-parser` package available

Automation of modal logics

Existing translations to bridge to ...

- KSP
- nanoCoP-M
- MleanCoP
- any TFF/THF reasoner via Logic Embedding Tool

State of TPTP and tool support

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Possible (exotic?) future

Dynamic epistemic logics (PAL)

- Does $[\varphi!]\varphi$ hold?

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tff(c1, conjecture, {$box($announce := phi)} @ (phi) ).
```

- Does $[\varphi!]\,(C_{a,b,c}\,\varphi)$ hold?

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tff(c2, conjecture, {$box($announce := phi)} @ ({common($agents := [a,b,c])} @ (phi)) ).
```

Term modal logics

- Does $\Box_{f(x)}\varphi$ hold?

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```

Of course, concrete syntax needs to be discussed.

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Summary

- NTF: Generic NCL syntax extension of the TPTP
  - Current focus: Modal logic
- NTF problems in TPTP v9.0.0
- Solutions as usual in the TSTP
- Many TPTP tools and infrastructure extended to NTF
- More logics to come (with <u>your</u> help?)

Not discussed here:

- There exist means of automation for the presented logics
  - Based on shallow semantical embedding to HOL
- Recent experients for quantified modal logics (QMLTP): Competitive performance wrt. native modal logic provers