Getting Started with Isabelle/HOL

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Overview

1. What is a Formal Proof?
2. Automated versus Interactive Theorem Provers
3. The Isabelle/HOL Proof Assistant
4. Theory Documents
5. Isabelle/jEdit and Proof IDE

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Formal Proof

- Proof: demonstrate truth of a statement. Argument and evidence.
- Formal proof: turning logical conjectures into theorems.
- Conjecture: statement that a formula is true, without yet having a proof.
- Assume $x > 0$ then $x + 2 > 0$.
- Fermat's Last Theorem:

  Assume $n > 2$. Then:

  There are no three positive integers a, b, c with $a^n + b^n = c^n$.
- Proof shows how to formally derive conclusions from assumptions.
- By application of axioms, existing theorems, and deduction rules.

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Proof as Computation

- Analogy between proof and a function mapping inputs to outputs:

- Theorem provers and proof assistants help us in this process.
- Two main classes: automated and interactive theorem provers

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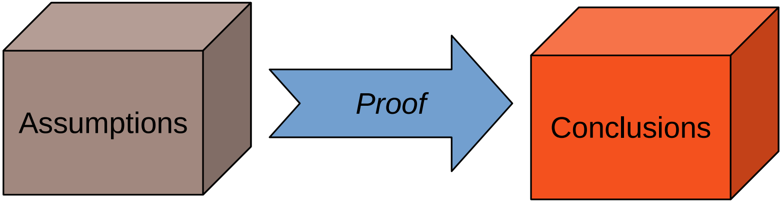

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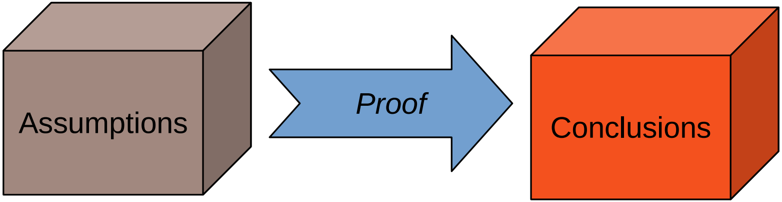

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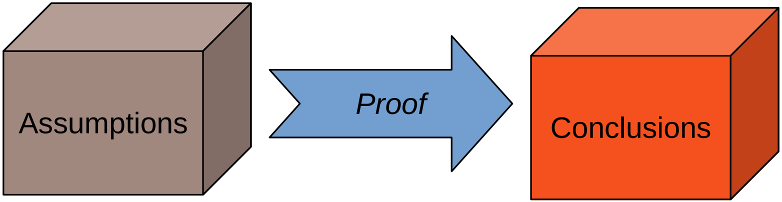

- Theorem provers and proof assistants help us in this process.
- Two main classes: automated and interactive theorem provers.

Overview

Automated Theorem Provers

- Automated theorem proving is an undecidable problem.

- Attractive push-button technology. Like model checkers
- SMT solvers (like Microsoft's Z3) prove arithmetic theorems etc
- Usually limited to first-order logic.
- Variables range over individuals not other predicates.
- In general, cannot handle induction, which requires higher order logic
- We need Interactive Theorem Provers (ITPs)

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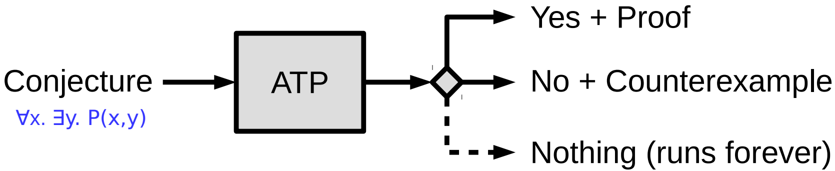

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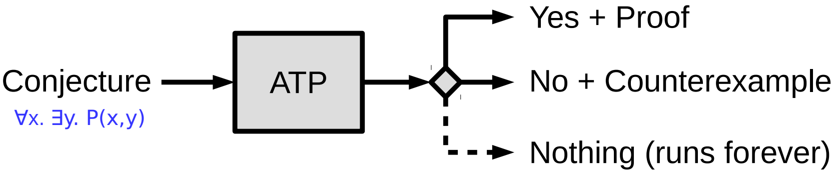

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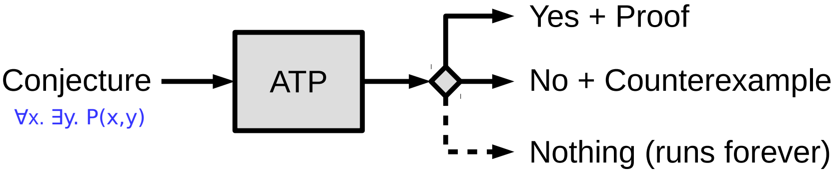

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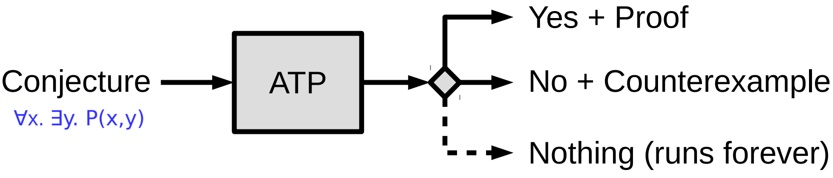

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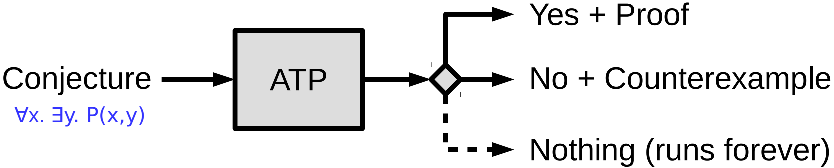

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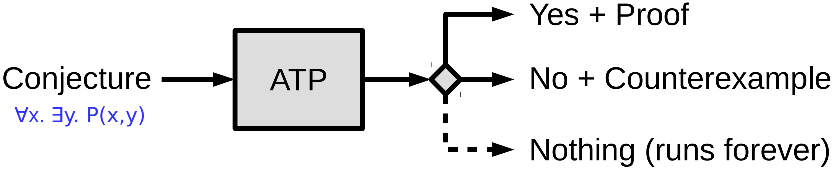

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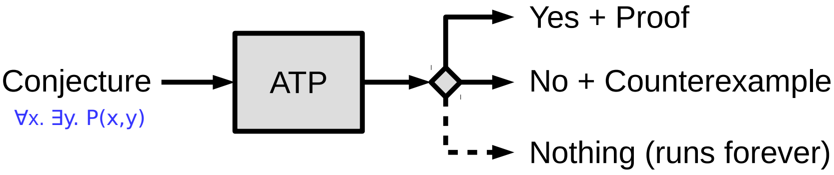

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Interactive Theorem Provers

- A proof is a script or program that acts on a proof state.
- Proof state: assumptions and outstanding conjectures ("subgoals").
- Proof tactics and deduction rules subdivide and eliminate proof goals.
- "Divide and conquer" approach to proof.
- Proof: game where winning condition is QED (no more subgoals).

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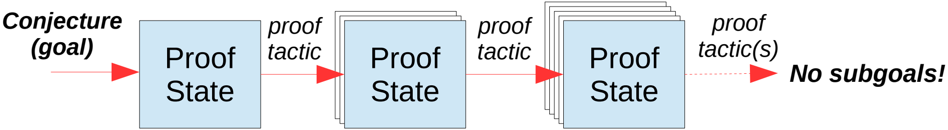

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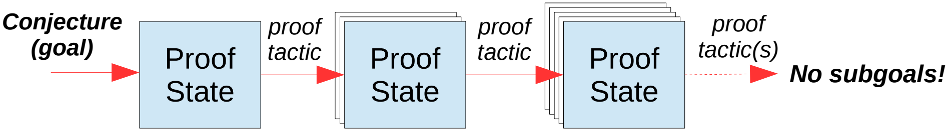

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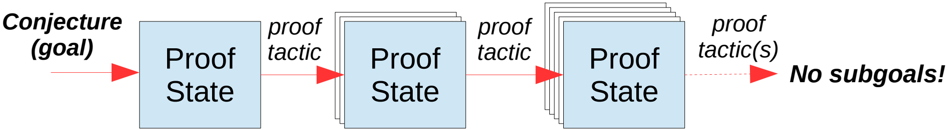

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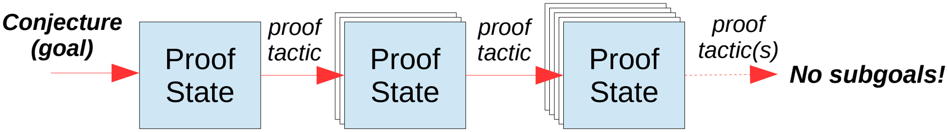

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- `isabelle.in.tum.de`
- Developed by Larry Paulson, Tobias Nipkow, Markarius Wenzel.
- HOL is a powerful functional specification language.
- Like Haskell: data structures, recursive functions, type classes, etc.
- Readable proofs in "natural deduction" style (Isar).
- Large online library of formalised mathematics.
- Archive of Formal Proofs `www.isa-afp.org/`.
- "Quantum and Classical Registers", "Category Theory for ZFC", ...
- Support for verified code generation.
- Implemented in the ML functional language and Scala.
- Program verification and assured software development.

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Assured Development with Isabelle

- Isabelle is more than an interactive theorem prover.
- Powerful automated tools (e.g., ATPs) used in system development.
- Flexible Proof IDE (PIDE) for programming, proof, and tool integration.
- Machine-checked document model with an extensible parser.
- Additional grammar categories support domain specific languages.
- Unicode symbols for type setting mathematics.
- Support for mixing formal and informal content.
- Plugins to interface with external tools (ATPs, SMT, CAS, etc.)
- An ideal platform for assured software development.

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Other Proof Tools

- There are many proof assistants besides Isabelle/HOL.
- Mathematically principled: Coq, Lean, Agda, Idris, Mizar.
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Mathematical Proofs in Isabelle/HOL

- Cantor's Theorem.
- Cardinality $\mathbb{P}\,A$ greater than cardinality A.

- Top 100 theorems online:
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Mathematical Proofs in Isabelle/HOL

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theorem Cantor:
  fixes f :: "'a ⇒ 'a set"
  shows "∃ S :: 'a set. S ∉ range f"
proof
  let ?S = "{x. x ∉ f x}"
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    assume "?S ∈ range f"
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    thus False
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      assume "y ∈ f y" assume "y ∈ ?S" then have "y ∉ f y" ..
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- Isabelle supports document-centric development approach.
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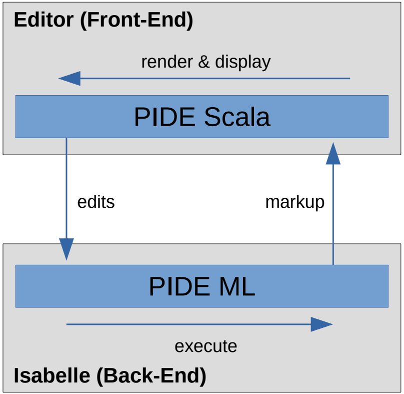

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- Outer Syntax:
- Definitional layer with simple combinatory parser
- Sequence or hierarchy of commands.
- Commands have a major keyword and several minor keywords.
- Can also refer to terms (inner syntax).

- Inner Syntax:
- Transition denoted by speech marks "..." or cartouche glyphs ‹...›.
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Overview

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3. The Isabelle/HOL Proof Assistant
4. Theory Documents
5. Isabelle/jEdit and Proof IDE

Isabelle/jEdit Interface Overview

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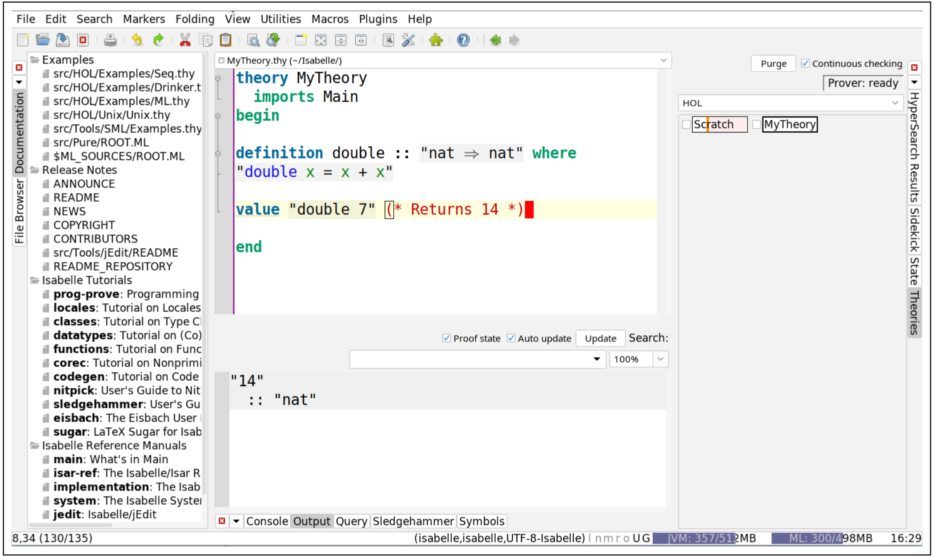

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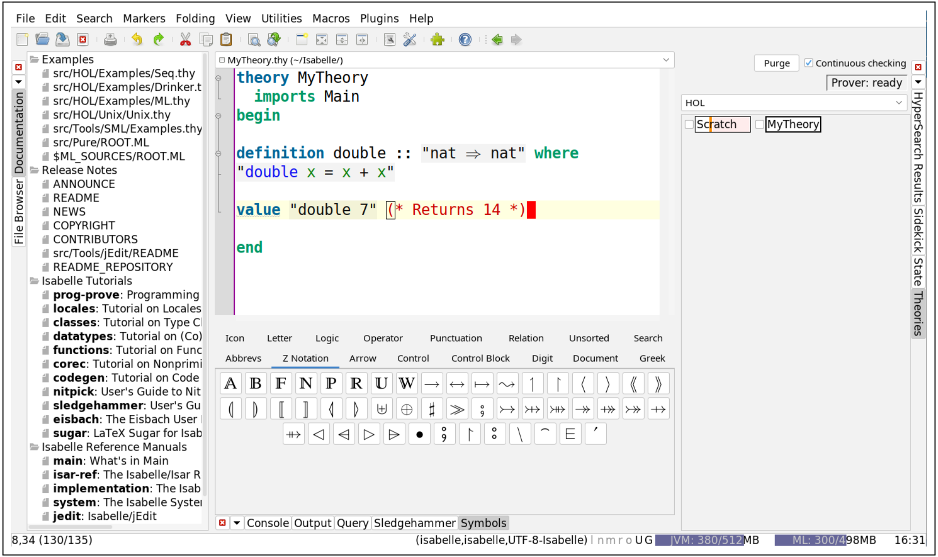

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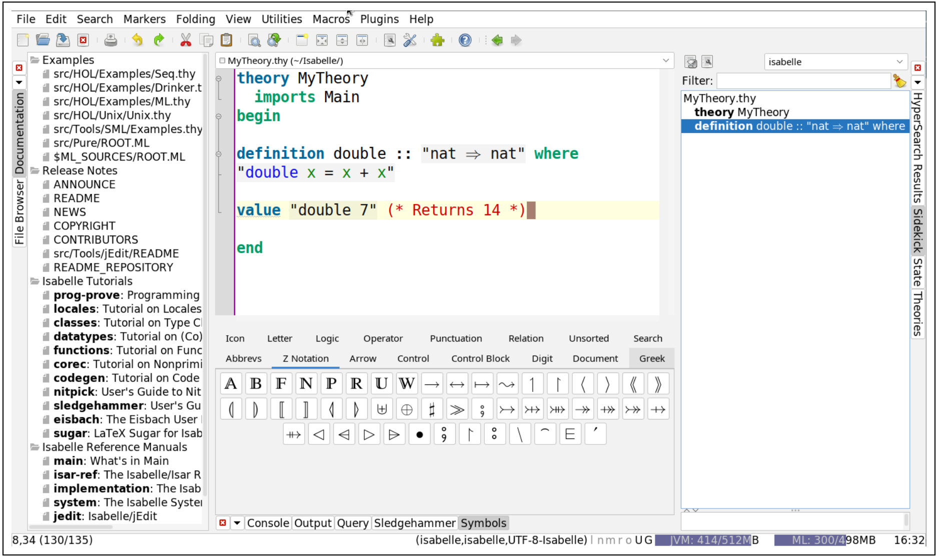

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- Isabelle/jEdit includes Unicode font with mathematical symbols
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- Autocompletion: partially typed symbol names appear in a list
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- Hovering the mouse over a symbol gives its name and abbreviations.
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Unicode Syntax

- Isabelle/jEdit includes Unicode font with mathematical symbols.
- In theory files use symbol code (similar to LaTeX markup).
- `\<alpha>` $\leadsto$ α, `\<forall>` $\leadsto$ $\forall$, `\<and>` $\leadsto$ $\wedge$, etc.

- Autocompletion: partially typed symbol names appear in a list
- Select and press `TAB` key.
- ASCII: `-->` $\leadsto$ $\longrightarrow$, `==>` $\leadsto$ $\Longrightarrow$, `\/` $\leadsto$ $\vee$, `(|` $\leadsto$ $\llparenthesis$, etc.
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Overview of Isabelle Documentation

- For more, see `isabelle.in.tum.de/documentation.html`
- Available within Isabelle/jEdit in the left-hand Documentation tab
- prog-prove: *Programming and Proving in Isabelle/HOL*
- Introduction to functional programming and Isar proofs.
- Part of the *Concrete Semantics* book by Nipkow and Klein.
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