Coq Proof Assistant: Propositions and Proofs

Mirco Kocher

Logic and Theory Group
Institute of Computer Science and Applied Mathematics
Universität Bern

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Overview

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Truth table

$(P \to Q)$

- Classical logic
- Assign to every variable a denotation true or false
- Formula is valid iff true in all cases
- Question "is the proposition P true?"

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$(P \rightarrow Q)$

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- Obtain a proof of Q from a proof of P
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- Question "what are the proof of P (if any)?"

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Hypothesis

`Hypothesis h:P`

- Local declaration
- *h* is the name of the hypothesis
- P is its statement
- Synonymous to
  `Variable h:P`
- Use
  `Hypotheses`
  or
  `Variables`
  to declare several at a time

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Axiom

`Axiom x:P`

- Global declaration
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Environment contains axioms

Context contains hypotheses

$E, \Gamma \vdash \pi : P$

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Goals and Tactics

Goals: what needs to be proven

Goal: $E, \Gamma \vdash P$
Construct a proof of P. Should be a well-formed term t in the environment E and context Γ
Term t is called a *solution*

Tactics: commands to decompose this goal into simpler goals

g ist input goal and g_1, g_2, ..., g_k are output goals
Possible to construct a solution of g from the solutions of goals g_i

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intros

Goal: $(P \to Q) \to (Q \to R) \to (P \to R)$

`intros H H' p`

- Transform the task of construction a proof into proving R with those hypotheses added
- $H : P \to Q$
- $H' : Q \to R$ and
- $p : P$
- New subgoal: R

Simplifies the statement to prove and increases the resources available

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apply

Subgoal: R

Hypothesis $H' : Q \rightarrow R$ and $H : P \rightarrow Q$

`apply H'`

- Use the hypothesis H' to advance our proof
- Argument has to be a premise and a conclusion
- Creates new goal for the premise
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Applying hypothesis H gives the new subgoal P

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assumption

Subgoal: P

Hypothesis $p : P$

`assumption`

- Statement to proof is exactly statement of hypothesis p
- Succeeds without generating any new goal

`No more subgoals`

Proof complete

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Proof complete

Finish

`Qed`

- Saves the theorem's name, statement and proof term
- Displays the sequence of tactics.

```
intros H H' p.
apply H'.
apply H.
assumption.
```

`Print theorem-name`

- Shows the proof like any *Gallina* definition

```
theorem-name = fun (H:P -> Q)(H':Q -> R)(p:P) => H' (H p)
 : (P -> Q) -> (Q -> R) -> P -> R
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Transitivity

$$(P \to Q) \to (Q \to R) \to (P \to R)$$

One Shot

Not all the details for the proof is needed

A few automatic tactics are able to solve this goal

```
Theorem transitivity : (P->Q) -> (Q->R) -> P -> R.
Proof.

auto.
Qed.
```

Good usage requires the command Proof after Theorem or Lemma

Makes the proof documents more readable

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exact

The exact tactic takes any term (with right type) as argument

The whole proof could be given as an argument

```
Theorem delta : (P->P->Q) -> P -> Q.
Proof.

exact (fun (H:P->P->Q)(p:P) => H p p).
Qed.
```

Or even shorter:

```
Theorem delta : (P->P->Q) -> P -> Q.
Proof (fun (H:P->P->Q)(p:P) => H p p).
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Modus Ponens

apply tactic uses the Modus Ponens

$$\textbf{App}\ \frac{E,\Gamma \vdash t : P \to Q \qquad E,\Gamma \vdash t' : P}{E,\Gamma \vdash tt' : Q}$$

Term t : $P_1 \to P_2 \to ... \to P_n \to Q$
Goal : $P_k \to P_{k+1} \to ... \to P_n \to Q$

`apply t`

generates k-1 goals with statements $P_1, ..., P_{k-1}$

if new goals have solution $t_1, t_2, ..., t_{k-1}$
solution is $t\ t_1\ t_2\ ...\ t_{k-1}$ for initial goal

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is the same as

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intro v_1, intro v_2, ..., intro v_n
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intro v_1 takes the first implication as a hypothesis called v_1

Proof Theorem K : $P \to Q \to P$
Goal is $P \to Q \to P$

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intro p.
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Hypothesis $p : P$ and new Goal $Q \to P$

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Handling

`Show i`

Display goal *i* with complete context
Coq displays the goals after each proof step

`Undo n`

Go back *n* steps and try an alternative if goal can not be solved

`Restart`

Go back to the beginning of the proof

`Abort`

Abandon the proof

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Simple composing

Combine tactics without stopping at intermediary subgoals

Goal: $P \to Q \to (P \to Q \to R) \to R$

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intros p q H; apply H; assumption.
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Like chess: forsee results of tactics

If any tatcic fails, then the whole combination fails

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Combine tactics without stopping at intermediary subgoals

Goal: $P \rightarrow Q \rightarrow (P \rightarrow Q \rightarrow R) \rightarrow R$

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intros p q H; apply H; assumption.
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Tactics can generate multiple subgoals

Goal: $(P \to Q \to R) \to (P \to Q) \to (P \to R)$

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intros H H' p; apply H; [assumption | apply H'; assumption].
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Two subgoals P and Q

First is solved with assumption
Other one first has to apply H' and then use assumption

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If a tactic fails automatically use another tactic

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intros H p; apply H; (assumption || intro H').
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If assumption fails, then intro H' is used

A tactic can be left unchanged to finish every subgoal in one go

Goal: $(P \to Q) \to (P \to R) \to (P \to Q \to R \to T) \to P \to T$

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intros H H0 H1 p.
apply H1; [idtac | apply H | apply H0]; assumption
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Tactic that always fails

Goal: $(P \rightarrow Q) \rightarrow (P \rightarrow Q)$

`intro X; apply X; fail.`

This combination succeeds; there are no more subgoals after "apply X"

Goal: $((P \rightarrow P) \rightarrow (Q \rightarrow Q) \rightarrow R) \rightarrow R$

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"try tac" behaves like "tac || idtac"

tac is either applied or the subgoal is left unchanged

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Even though they are valid in classical logic

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Truth table shows it is a valid formula

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