iCoq: Regression Proof Selection for Large-Scale Verification Projects

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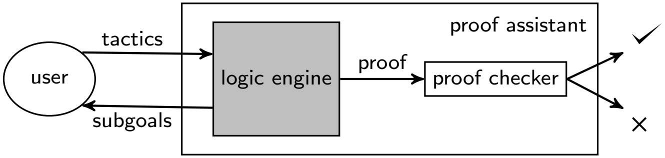
Verification Using Proof Assistants

1. encode definitions in (higher-order) formalism
2. prove propositions **interactively** using powerful **tactics**
3. check soundness of every low-level step



examples: Coq, HOL4, HOL Light, Isabelle/HOL, Lean, Nuprl, ...

Some Large-Scale Proof Assistant Projects

Project	**Year**	**Assistant**	**Check Time**	**LOC**
4-Color Theorem	2005	Coq	hours	60k
Odd Order Theorem	2012	Coq	hours	150k
Kepler Conjecture	2015	HOL Light	days	500k
CompCert	2009	Coq	tens of mins	40k
seL4	2009	Isabelle/HOL	hours	200k
Verdi Raft	2016	Coq	tens of mins	50k

problem: long proof checking times

Problem: Regression Proving in Evolving Projects

Typical **proving** scenario:

1. change definition or lemma statement
2. begin process of re-checking all proofs
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Typical **testing** scenario:

1. change method statements or method signature
2. begin process of re-running all tests
3. testing fails hours later (for seemingly unrelated test)

Regression Test Selection (RTS)

A regression test selection technique chooses, from an existing test set, tests that are deemed necessary to validate modified software.

Rothermel and Harrold, ACM TOSEM 6, 2 '97

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A regression proof selection technique chooses, from an existing proof set, proofs that are deemed necessary to verify modified theories.

Our Contribution

1. propose a regression proof selection (RPS) technique
2. implement RPS technique in tool, iCoq, which supports Coq
3. evaluate iCoq on revision histories of large Coq projects

Coq in a Nutshell

- based on a constructive dependent type theory (CiC)
- definitions + proofs programmed in Gallina/Ltac (`.v` files)
- coqc tool processes `.v` files, outputs terms (`.vo` files)

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Require Import Alternate.

Lemma alt_exists :
 forall l1 l2, exists l3, alt l1 l2 l3.
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- exists (a :: l1). apply alt_step.
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Qed.
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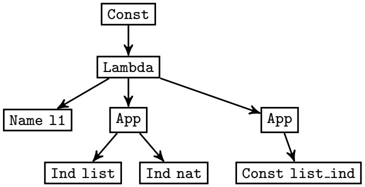
AltLem.v



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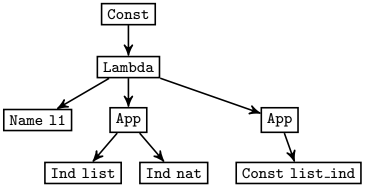

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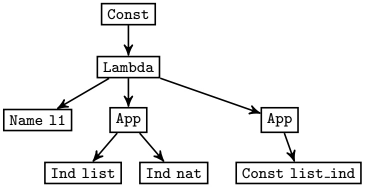

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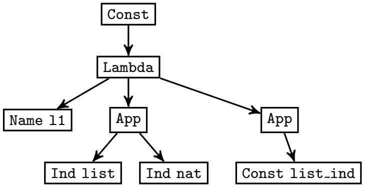

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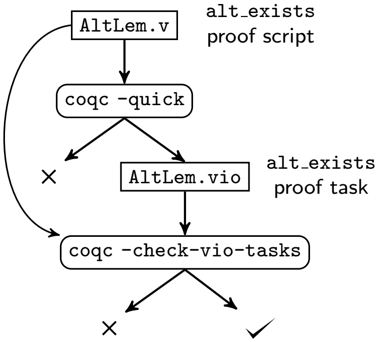
Coq v8.5 Asynchronous Proof-Checking Toolchain

- newly-added toolchain can produce `.vio` files without proofs
- `.vio` files contain proof tasks, checked asynchronously



Regression Proof Selection Technique

Three phases:

1. **analysis**: locate proofs affected by changes
2. **execution**: emit and run proof-checking commands
3. **collection**: find dependencies of modified definitions and lemmas+proofs

Key idea: maintain file and identifier **dependency graphs**

Example, revision 1

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Require Export List. Export ListNotations.

Fixpoint alternate l1 l2 : list nat :=
match l1 with
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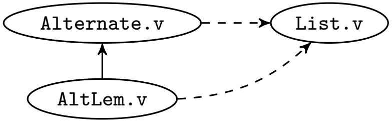
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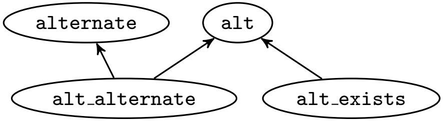

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Programmer now changes alternate.

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Change creates new revision.

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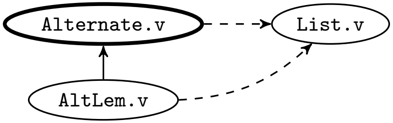
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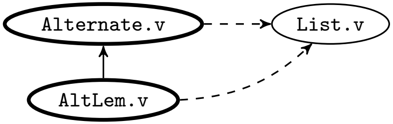
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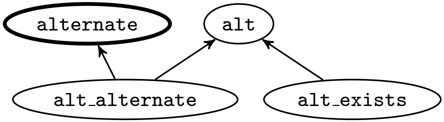

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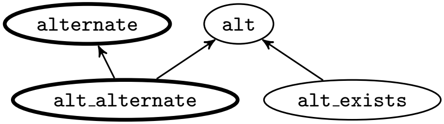

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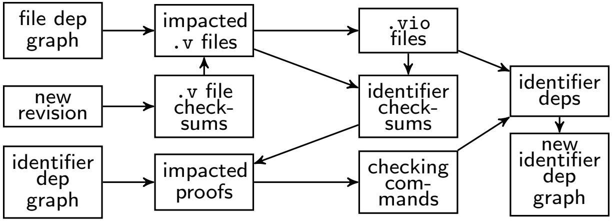
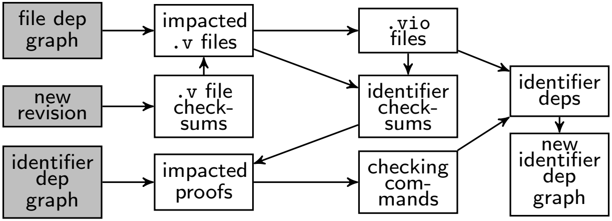
iCoq Components

Component	**Lang.**	**Description**
`coq-ast`	OCaml	compute digests of term ASTs
`coq-depends`	OCaml	extract dependencies from term ASTs
`coq-digest`	OCaml	compute digests of proof scripts
`coqc` extension	OCaml	proof-checking dependency extraction
graph builder	Java	construct/maintain dependency graphs
proof runner	bash	execute proofs

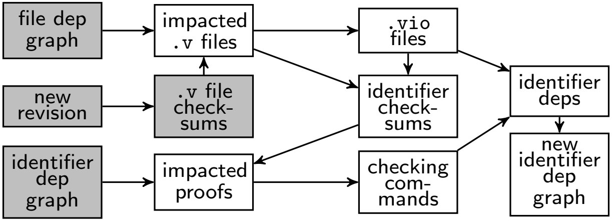
iCoq Workflow



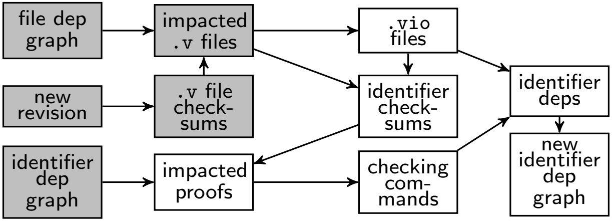
iCoq Workflow



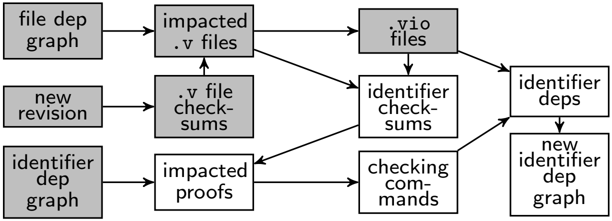
iCoq Workflow



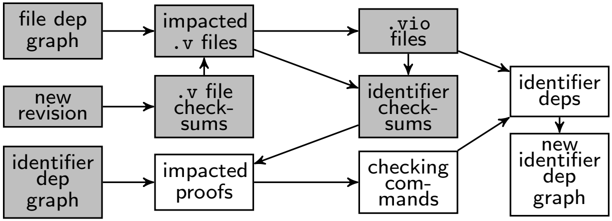
iCoq Workflow



iCoq Workflow



iCoq Workflow



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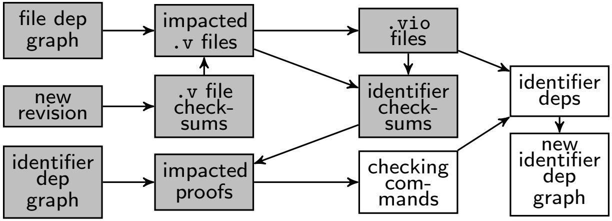
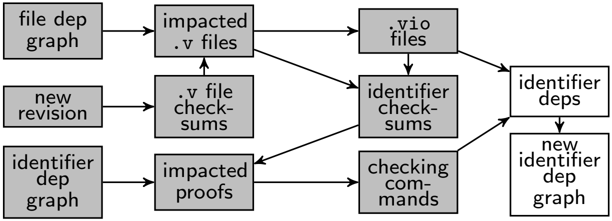
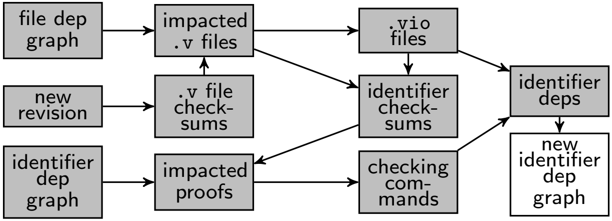


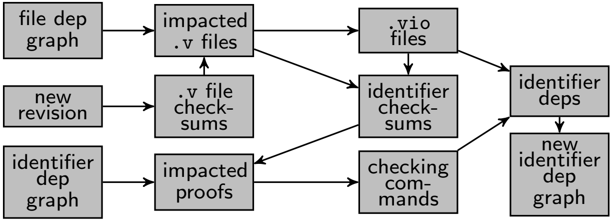
iCoq Workflow



iCoq Workflow



ICoq Workflow



Evaluation Research Questions

- RQ1 How effective is iCoq in terms of reduction in the number of checked proofs?
- RQ2 How effective is iCoq in terms of the proof checking time **inside** a CIS environment?
- RQ3 How effective is iCoq in terms of the proof checking time **outside** a CIS environment?

CIS: Continuous Integration Service (e.g., Travis CI)

Evaluation: Open Source Git-Based Projects

Project	**LOC**	**#Revisions**
CTLTCTL	0.6k	10
InfSeqExt	1.8k	10
StructTact	2.5k	10
WeakUpTo	1.8k	10
Flocq	25k	24
UniMath	43k	24
Verdi	54k	24

Evaluation Environments

1. **CI-Env** uses a CIS to check proofs (from scratch)
2. **LO-Env** uses local machine to check proofs (incrementally)

Experiments run on Intel Core i7-6700 CPU @ 3.40GHz with 16GB of RAM, running Ubuntu 14.04 LTS.

Dependency data always persisted between revision (cached).

RQ1: reduction in #proofs to check using ICoq

Project		**Proofs**		
		iCoq	**Total**	P^{sel}
Flocq	$\sum$	2164	22482	N/A
	Avg.	90.16	936.75	9.62
UniMath	$\sum$	853	17754	N/A
	Avg.	35.54	739.75	4.85
Verdi	$\sum$	4458	65413	N/A
	Avg.	185.75	2725.54	6.80

P^{sel}: proof selection percentage

RQ2: reduction in checking time using iCoq in CI-Env

Project		**CI-Env Time [s]**	
		coq_makefile	**iCoq**
Flocq	$\sum$	888.36	303.71
	Avg.	37.01	12.65
UniMath	$\sum$	12882.46	3742.88
	Avg.	536.76	155.95
Verdi	$\sum$	32528.57	3379.37
	Avg.	1355.35	140.80

end-to-end time in seconds, including all phases

RQ3: reduction in checking time using iCoq in LO-Env

Project		LO-Env Time [s] coq_makefile	LO-Env Time [s] iCoq
Flocq	$\sum$	297.97	261.62
	Avg.	12.41	10.90
UniMath	$\sum$	3783.52	1692.33
	Avg.	157.64	70.51
Verdi	$\sum$	8157.45	3130.96
	Avg.	339.89	130.45

end-to-end time in seconds, including all phases

Ratios of Total Times

Project	**CI-Env**	**LO-Env**
Flocq	2.92	1.13
UniMath	3.44	2.23
Verdi	9.62	2.60

Conclusion

- **technique**, regression proof selection, implemented in
- **tool**, iCoq, for Coq projects, giving
- **speedup** of up to 10× in CIS, 3× locally

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Resources:

- download iCoq: `http://cozy.ece.utexas.edu/icoq`
- Coq components: `https://github.com/proofengineering`

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