Tim Cosgrove

Outlin

ect Overv

Motivation

Dackgroun

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint

Indexing Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to Beagle

Results

Evaluation Metrics Beagle Comparisons Sample Position Comparisons

Conclusion

Term Indexing for the Beagle Theorem Prover

Tim Cosgrove

COMP4006 Honours Research Project

Research School of Computer Science, Australian National University

u4843619@anu.edu.au

Supervisor: Peter Baumgartner

October 14, 2013

Tim Cosgrove

Outline

First Order Logic

1 Project Overview Motivation

2 Background

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint Indexing

3 Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to Beagle

A Results

Evaluation Metrics Beagle Comparisons Sample Position Comparisons

6 Conclusion

Tim Cosgrove

Outlin

rainet Ovany

Motivation

Backgroui

First Order Logic Terminology The Beagle Theorem Prover Term Indexing

Indexing

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparisons Sample Position Comparisons

Conclusion

The Beagle Theorem Prover

 Beagle is a First-Order-Logic resolution theorem prover with equality, built to show off the capabilities of the Hierarchic Superposition with Weak Abstraction Calculus.

Tim Cosgrove

Outlin

roject Ovenzi

Motivation

Backgrou

First Order Log Terminology The Beagle Theorem Prove Term Indexing Fingerprint

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparisons Sample Positio Comparisons

Conclusion

The Beagle Theorem Prover

- Beagle is a First-Order-Logic resolution theorem prover with equality, built to show off the capabilities of the Hierarchic Superposition with Weak Abstraction Calculus.
- This calculus is capable of *hierarchic reasoning* by incorporating a *background prover*.
- Background provers act as a black box which can instantly prove known facts. For example integer arithmetic.

Tim Cosgrove

Outlin

roject Overvi

Motivation

Backgrou

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint

Implementatio

Implementing Fingerprint Indexing Indexing Applications Tailoring to Beagle

Resul

Metrics
Beagle
Comparisons
Sample Positio
Comparisons

Conclusion

The Beagle Theorem Prover

- Beagle is a First-Order-Logic resolution theorem prover with equality, built to show off the capabilities of the Hierarchic Superposition with Weak Abstraction Calculus.
- This calculus is capable of *hierarchic reasoning* by incorporating a *background prover*.
- Background provers act as a black box which can instantly prove known facts. For example integer arithmetic.
- The calculus is carefully constructed with a process known as weak abstraction in order to ensure consistency and completeness.

Tim Cosgrove

Outline

roject Ovenzi

Motivation

Backgroui

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

D . . II

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Extensions to Beagle

- Beagle has some major shortcomings which prevent it being more than a proof of concept.
- In particular, it lacks an efficient manner of locating terms for inference

Tim Cosgrove

Outlin

oject Oveni

Motivation

Backgrou

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Position Comparisons

Conclusion

Extensions to Beagle

- Beagle has some major shortcomings which prevent it being more than a proof of concept.
- In particular, it lacks an efficient manner of locating terms for inference
- Enter 'Term Indexing', a method for efficiently managing and collecting these terms.

Tim Cosgrove

Motivation

First Order Logic

Terminology

The Beagle

Term Indexing

Indexing

Implementing Indexing Indexing

Tailoring to

Evaluation

Metrics

Terminology Used in this Presentation

First Order Logic

Tim Cosgrove

Outline

Project Overv

Motivation

First Order Logic

Terminology

The Beagle

Term Indexing

Fingerprint

Indexing

Implementatio

Implementing

Fingerprint Indexing Indexing

Applications
Tailoring to

D . . II

Evaluation

Metrics

Comparisons
Sample Positi

Comparisons

Conclusion

Terminology Used in this Presentation

- First Order Logic
- Positions

Tim Cosgrove

Outline

Project Over Motivation

D. I

First Order Logic

Terminology
The Beagle

Theorem F

Term Indexing

Fingerprint Indexing

Implementation

Implementing

Fingerprint Indexing

Indexing Applications Tailoring to

Result

Evaluation Metrics

Comparisons
Sample Position

Sample Position Comparisons

Conclusion

Terminology Used in this Presentation

- First Order Logic
- Positions
- Substitutions:
 - s is 'unifiable' with t: $\sigma s = \sigma t$
 - s 'subsumes' t : $\sigma s = t$

Tim Cosgrove

Outlin

Project Overvi

IVIOLIVACIOII

First Order Logic

Terminology
The Beagle

Theorem Prover Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing

Applications
Tailoring to

D....la.

Evaluatio Metrics

Sample Position

Conclusion

The Superposition Calculus

Normal Superposition rule

Positive Superposition

$$\frac{I \approx r \lor C \qquad s[u] \approx t \lor D}{(s[r] \approx t \lor C \lor D)\sigma}$$

Where (i) $\sigma = \text{simple mgu } (l, u)$, and (ii) u is not a variable.

Tim Cosgrove

Outlin

Project Overv Motivation

First Order Logic

The Beagle Theorem Prover Term Indexing

Term Indexir Fingerprint Indexing

Implementati

Fingerprint Indexing Indexing

Application Tailoring to

D 1

Evaluation Metrics

Comparisons
Sample Positi

Sample Position Comparisons

Conclusion

The Hierarchic Superposition with Weak Abstraction Calculus

 Extension of the Superposition Calculus to accommodate hierarchic reasoning.

Positive Superposition

$$\frac{I \approx r \lor C \qquad s[u] \approx t \lor D}{\mathsf{abstr}((s[r] \approx t \lor C \lor D)\sigma)}$$

Where (i) $\sigma = \text{simple mgu } (I, u)$,

- (ii) u is not a variable,
- (iii) $r\sigma \times l\sigma$.
- (111) 10 2 10
- (iv) $t\sigma \not\succeq s\sigma$,
- (v) / and u are not pure background terms,
- (vi) $(l \approx r)\sigma$ is strictly maximal in $(l \approx r \lor C)\sigma$,
- and (vii) $(s \approx t)\sigma$ is strictly maximal in $(s \approx t \vee D)\sigma$.

Tim Cosgrove

Outline

Project Overvie

Motivation

Backgroui

First Order Logic Terminology The Beagle

Term Indexing Fingerprint

Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Term Indexing Techniques

 Term indexers aim to collect all FOL terms which potentially match a 'query' term.

Tim Cosgrove

Outlin

Project Overvi

Backgroun

First Order Logic Terminology The Beagle Theorem Prover

Term Indexing Fingerprint Indexing

Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparisons Sample Position Comparisons

Conclusion

Term Indexing Techniques

- Term indexers aim to collect all FOL terms which potentially match a 'query' term.
- Top-Symbol Hashing.
- Discrimination Trees.
- Path Indexing.

Tim Cosgrove

Outlin

Project Overvi

Motivation

First Order Logic Terminology The Beagle

Term Indexing

Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Fingerprint Indexing

• Maintain a collection of *fingerprints* for terms.

Tim Cosgrove

Outline

Project Overvi

Motivation

First Order Logic Terminology The Beagle

Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Fingerprint Indexing

- Maintain a collection of *fingerprints* for terms.
- A term fingerprint is an array over $F \cup \{A, B, N\}$, the *Fingerprint Features*.

Tim Cosgrove

Outline

Project Overvie

Motivation

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementation

Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Positio

Conclusion

Fingerprint Indexing

- Maintain a collection of *fingerprints* for terms.
- A term fingerprint is an array over F ∪ {A, B, N}, the Fingerprint Features.

Table: Fingerprint Feature comparison tables for *unification* (left) and *subsumption* (right)

	f_1	f_2	Α	В	N
f_1	Υ	N	Υ	Υ	N
f_2	N	Υ	Υ	Υ	N
Α	Y	Υ	Υ	Υ	N
В	Y	Υ	Υ	Υ	Υ
N	N	N	N	Υ	Υ

	f_1	f_2	Α	В	Ν
f_1	Υ	N	N	N	N
f_2	N	Υ	N	N	N
Α	Υ	Υ	Υ	N	N
В	Υ	Υ	Υ	Υ	Υ
N	N	2	N	Ν	Y

Tim Cosgrove

Outline

Motivation

First Order Logic Terminology The Beagle

Term Indexing
Fingerprint
Indexing

Implementation

Implementin
Fingerprint
Indexing
Indexing
Applications
Tailoring to

Result

Metrics
Beagle
Comparisons
Sample Positio

Conclusion

Fingerprint Indexing

- Maintain a collection of *fingerprints* for terms.
- A term fingerprint is an array over $F \cup \{A, B, N\}$, the *Fingerprint Features*.

Table: Fingerprint Feature comparison tables for *unification* (left) and *subsumption* (right)

	f_1	f ₂	Α	В	N
f_1	Υ	N	Υ	Υ	N
f_2	N	Υ	Υ	Υ	N
Α	Υ	Υ	Υ	Υ	N
В	Υ	Υ	Υ	Υ	Υ
N	N	N	N	Υ	Υ

	f_1	f_2	Α	В	N
f_1	Υ	N	N	N	N
f_2	N	Υ	N	N	N
Α	Y	Υ	Υ	N	N
В	Y	Υ	Υ	Υ	Υ
N	N	2	N	N	Υ

Schulz, Stephan: Fingerprint Indexing for Paramodulation and Rewriting.
 In: Lecture Notes in Computer Science volume 7364 pp. 447–483 (2012).

Tim Cosgrove

Outlin

Project Overv

Motivation

First Order Logic Terminology

Theorem Prove

Fingerprint Indexing

Implementatio

Implementing Fingerprint

Indexing Indexing Applications

Tailoring to

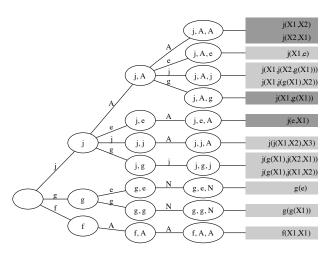
Result

Evaluation Metrics

Sample Posit

. . .

Fingerprint Indexing – Example Fingerprint Index



Tim Cosgrove

Outlin

roject Overvie

Motivation

Backgroui

First Order Logic Terminology The Beagle

Term Indexing

Fingerprint Indexing

Implementatio

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle

Sample Positio

Conclusion

Why Fingerprint Indexing?

New and not thoroughly tested technique.

Tim Cosgrove

Outline

Project Overvi

IVIOLIVALION

Dackgroui

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementation

Implementing
Fingerprint
Indexing
Indexing
Applications
Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Why Fingerprint Indexing?

- New and not thoroughly tested technique.
- Currently showing very promising results.

Tim Cosgrove

Outline

Project Overvi

. .

First Order Logic Terminology

Theorem Prove Term Indexing

Fingerprint Indexing

Implementatio

Implementatio

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle

Sample Position Comparisons

Conclusion

Why Fingerprint Indexing?

- New and not thoroughly tested technique.
- Currently showing very promising results.
- Highly customisable and configurable.

Tim Cosgrove

Outline

Project Overvi

Motivation

Rackground

First Order Logic Terminology

The Beagle

Term Indexing

Indexing

Implementatio

Implementing Fingerprint Indexing

Indexing Applications Tailoring to

Result

Evaluation Metrics

Sample Position

Comparisons

Conclusion

Creating the Fingerprint Index

• Addition of terms.

Tim Cosgrove

Outlin

Project Overvi

Motivation

Backgrour

First Order Logic Terminology The Beagle

Term Indexis

Fingerprint Indexing

Implementation

Fingerprint Indexing

Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparisons

Comparisor

Creating the Fingerprint Index

- Addition of terms.
- Requires an Fingerprint generation along with implementation and traversal of the Index tree structure.

Tim Cosgrove

Outlin

Project Overvi

Motivation

Backgroui

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing

Indexing Applications Tailoring to

Result

Evaluation Metrics

Comparisons
Sample Position

Sample Position Comparisons

Conclusion

Creating the Fingerprint Index

- Addition of terms.
- Requires an Fingerprint generation along with implementation and traversal of the Index tree structure.
- Retrieval of terms.

Tim Cosgrove

Outlin

Project Overvi

Motivation

Backgrou

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementation

Fingerprint Indexing Indexing

Applications
Tailoring to

Result

Evaluatio Metrics

Comparisons
Sample Position

Conclusion

Creating the Fingerprint Index

- Addition of terms.
- Requires an Fingerprint generation along with implementation and traversal of the Index tree structure.
- · Retrieval of terms.
- Requires implementation of the comparison tables and a more complex Index traversal algorithm.

Tim Cosgrove

Outlin

Project Overvi

Motivation

Backgrour

First Order Logic Terminology The Beagle Theorem Prover Term Indexing

Fingerprint Indexing

Implementing

Fingerprint Indexing

Indexing Applications Tailoring to

Results

Evaluation Metrics Beagle Comparison

Sample Positio

Conclusion

Beagle's Main Procedure

Maintain two Clause Sets, new and old.
 Remove Clauses from new one at a time, simplify them and then attempt inference rules.

Tim Cosgrove

First Order Logic Terminology Indexing

Implementing

Indexing Applications

Tailoring to

Beagle's Main Procedure

- Maintain two Clause Sets. new and old. Remove Clauses from *new* one at a time, simplify them and then attempt inference rules.
- Two key areas of improvement (O(n)) operations:
 - Inferences via the Superposition rules.
 - Simplifying Clauses.

Tim Cosgrove

First Order Logic

Indexing Applications

Indexing Superposition

Positive Superposition

$$\frac{I \approx r \lor C \qquad s[u] \approx t \lor D}{\mathsf{abstr}((s[r] \approx t \lor C \lor D)\sigma)}$$

Where (i) $\sigma = \text{simple mgu } (I, u)$,

- (ii) u is not a variable.
- (iii) $r\sigma \not\succeq l\sigma$,
- (iv) $t\sigma \times s\sigma$.
- (v) I and u are not pure background terms,
- (vi) $(l \approx r)\sigma$ is strictly maximal in $(l \approx r \lor C)\sigma$,
- and (vii) $(s \approx t)\sigma$ is strictly maximal in $(s \approx t \vee D)\sigma$.

 Requires that we index all subterms. Furthermore we must implement two separate cases for from and into.

Tim Cosgrove

First Order Logic Terminology

Indexing

Indexing

Applications Tailoring to

Indexing Simplification

- Simplification rules exist to implement special cases of the rules in the Hierarchic Superposition with Weak Abstraction Calculus.
- These special cases allow redundant Clauses to be removed; preventing clutter in the inference process.

Tim Cosgrove

First Order Logic Terminology

Indexing

Applications

Indexing Simplification

- Simplification rules exist to implement special cases of the rules in the Hierarchic Superposition with Weak Abstraction Calculus.
- These special cases allow redundant Clauses to be removed; preventing clutter in the inference process.
- The two main simplification rules used by Beagle are *Negative* Unit Simplification and Demodulation

Tim Cosgrove

Outlin

Project Overvi

Backgroun

Terminology
The Beagle
Theorem Prov
Term Indexing
Fingerprint
Indexing

Implementatio

Indexing Indexing

Applications Tailoring to

Results

Metrics
Beagle
Comparisons
Sample Position
Comparisons

Conclusion

Indexing Simplification

- Simplification rules exist to implement special cases of the rules in the Hierarchic Superposition with Weak Abstraction Calculus.
- These special cases allow redundant Clauses to be removed; preventing clutter in the inference process.
- The two main simplification rules used by Beagle are *Negative Unit Simplification* and *Demodulation*
- These rules operate only on *unit Clauses*, so using our current index clogged with subterms is inefficient.
- The rules also require checking for subsumption, which requires implementing a new comparison table for Fingerprint Indexing.

Tim Cosgrove

Outline

Project Overvie

Rackgroup

First Order Logic Terminology

The Beagle Theorem Prover

Term Index

Fingerprint Indexing

Implementatio

Implementing

Fingerprint Indexing

Indexing Applications

Tailoring to

Results

Evaluation

Beagle Comparisons

Sample Position

Conclusion

Indexing Negative Unit Simplification

Negative Unit Simplification

$$\frac{1 \not\approx r \qquad s \approx t \vee C}{C}$$

Where (i) $\exists \sigma$ s.t. $(l \approx r)\sigma \equiv s \approx t$.

The clause $s \approx t \vee C$ may be removed.

Tim Cosgrove

Outlin

Project Overv

Backgroun

First Order Logic Terminology The Beagle Theorem Prover Term Indexing

Fingerprint Indexing

Implementatio

Fingerprint

Indexing Applications

Applications
Tailoring to

Results

Metrics
Beagle
Comparisons
Sample Positio

Conclusion

Indexing Negative Unit Simplification

Negative Unit Simplification

$$\frac{1 \not\approx r \qquad s \approx t \vee C}{C}$$

Where (i) $\exists \sigma$ s.t. $(l \approx r)\sigma \equiv s \approx t$.

The clause $s \approx t \vee C$ may be removed.

- Searching for valid subsuming Literals is extremely time consuming.
- Requires an index capable of matching Equations rather than Terms.

Tim Cosgrove

Outline

Project Overvi

Motivation

Backgroun

First Order Logic Terminology

The Beagle Theorem Pro

Term Indexin

Indexing

Implementation

Implementing Fingerprint

Indexing Applications

Tailoring to

Results

Evaluation

Beagle

Sample Position

Conclusion

Indexing Demodulation

$$\frac{I \to r \qquad s[u] \approx t \vee D}{s[r\sigma] \approx t \vee D}$$

Where $I\sigma = u$

The clause $s[u] \approx t \vee D$ may be removed.

Tim Cosgrove

Outline

Project Overvi

Motivation

Backgroun

First Order Logic Terminology

Theorem P

Fi----i-

Indexing

Implementation

implementatio

Fingerprint Indexing

Indexing Applications Tailoring to

Danislan

Evaluation

Comparisons
Sample Position

Sample Position Comparisons

Conclusion

Indexing Demodulation

• For a simple example, with a Literal $X \to f(a)$ we may replace all occurrences of X with f(a).

Tim Cosgrove

Outline

Project Overv

Backgroun

First Order Logic Terminology The Beagle Theorem Prover Term Indexing

Indexing

Implementatio

Implementing Fingerprint

Indexing Applications Tailoring to

Decide

Evaluation
Metrics
Beagle
Comparisons
Sample Position
Comparisons

Conclusion

Indexing Demodulation

Demodulation
$$\frac{l \to r \qquad s[u] \approx t \lor D}{s[r\sigma] \approx t \lor D}$$
 Where $l\sigma = u$ The clause $s[u] \approx t \lor D$ may be removed.

- For a simple example, with a Literal $X \to f(a)$ we may replace all occurrences of X with f(a).
- Like in Negative Unit Simplification, the most costly operation is searching for subsuming / Terms.
- We must perform this search for every possible subterm u of s.

Tim Cosgrove

Outlin

Project Over

Motivation

First Order Logic Terminology The Beagle Theorem Prover

Indexing Implementatio

Fingerprint Indexing Indexing Applications

Applications
Tailoring to

Beagle

Evaluatio

Beagle Comparisons Sample Position

Conclusion

Fingerprint Indexing for the Hierarchic Superposition with Weak Abstraction Calculus

 The Hierarchic Superposition with Weak Abstraction Calculus imposes many restrictions on what can be used for inference.

Tim Cosgrove

Outlin

Mativation

Motivation

First Order Logic Terminology The Beagle Theorem Prover

Term Indexin Fingerprint Indexing

Implementatio

Fingerprint Indexing Indexing

Applications
Tailoring to

Beagle

Evaluatio Metrics

Comparisons Sample Positi

Comparisons

Conclusion

Fingerprint Indexing for the Hierarchic Superposition with Weak Abstraction Calculus

- The Hierarchic Superposition with Weak Abstraction Calculus imposes many restrictions on what can be used for inference.
- We may take advantage of some of these conditions to increase the effectiveness of Fingerprint Indexing.

Tim Cosgrove

Outlin

Motivation

Background

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint Indexing

Implementation

Fingerprint Indexing Indexing Applications

Tailoring to Beagle

Evaluation Metrics Beagle

Sample Position Comparisons

Conclusion

Fingerprint Indexing for the Hierarchic Superposition with Weak Abstraction Calculus

- The Hierarchic Superposition with Weak Abstraction Calculus imposes many restrictions on what can be used for inference.
- We may take advantage of some of these conditions to increase the effectiveness of Fingerprint Indexing.

Table: Fingerprint comparison table for unification; extended by considering the term hierarchy.

	f_1	f ₂	Α	В	N	f_1+	f_2+	A+	B+
f_1	Υ	N	Υ	Υ	N	N	N	N	N
f ₂	N	Υ	Υ	Υ	N	N	N	N	N
A	Y	Υ	Υ	Υ	N	Υ	Y	Υ	Υ
В	Y	Υ	Υ	Υ	Υ	Υ	Υ	Υ	Υ
N	N	N	N	Υ	Υ	N	N	N	Y
f_1+	N	N	Υ	Υ	N	Υ	N	Υ	Υ
f ₂ +	N	N	Υ	Υ	N	N	Y	Y	Υ
A +	N	N	Υ	Υ	N	Y	Y	Y	Υ
B+	N	N	Υ	Υ	Υ	Y	Υ	Υ	Y

Tim Cosgrove

Outlin

Project Overv

Motivatio

First Order Logic Terminology

The Beagle Theorem Proved Term Indexing

Fingerprint Indexing

Implementatio

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics

Beagle Comparisons

Metrics for Analysing Indexing Performance

• Total run time - Need to be careful to consider all factors.

Tim Cosgrove

Outline

Project Overvi

Backgroun

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementatio

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle

Sample Positions
Comparisons

Conclusion

Metrics for Analysing Indexing Performance

- Total run time Need to be careful to consider all factors.
- False Positives Relevant, but can be misleading depending on number of positions being sampled.

Tim Cosgrove

Outlin

Project Overv

Backgroun

First Order Logi Terminology The Beagle Theorem Prove Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics

Comparisons
Sample Positio

Conclusion

Metrics for Analysing Indexing Performance

- Total run time Need to be careful to consider all factors.
- False Positives Relevant, but can be misleading depending on number of positions being sampled.
- Run time per Inference Most accurate measure of performance.
 Must still take care when interpreting.

Tim Cosgrove

Outline

Motivation

First Order Logic Terminology

The Beagle Theorem Prove Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications

Applications
Tailoring to
Beagle

Results

Beagle Comparisons

Sample Positio Comparisons

Conclusion

Comparing Varieties of Beagle

Table: Totalled inference counts and indexing statistics for various versions of beagle.

	Inf	erence Cou	ınts	Indexing Results		
Version	Sup Demod NegUnit		TotalFound	SupFP	SimpFP	
Unmodified 1	414216	29097	1826	0	0	0
Standard	162881	41414	2452	61884768	15525	39778148
Enhanced	146861	35326	1960	58119897	17641	39916687

Table: Totalled timing results for various versions of beagle.

		Time Spent (seconds)							
Version	Indexing	Retrieving	Sup	Demod	NegUnit	Total			
Unmodified 1	0	0	730.44	9.44	31.99	5623.21			
Standard	28.4	38.73	254.17	41.66	3.18	381.36			
Enhanced	18.74	17.58	168.79	30.56	2.12	259.02			

¹This version failed to solve two out of the fifty problems within 8 hours.

Tim Cosgrove

Outlin

oject Overv

Motivation

Backgroui

First Order Logic Terminology The Beagle Theorem Prover Term Indexing

Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics

Beagle Comparisons

Sample Positi

Conclusion

Time Spent Per Inference

Table: Superposition time for the 6 most extreme problem examples.

Version	Superposition	Demodulation	NegUnit Simplification
Unmodified	1.7ms	0.3ms	17.5ms
Standard	1.5ms	1.0ms	1.3ms
Enhanced	1.1ms	0.8ms	1.0ms

Tim Cosgrove

Outline

Project Overvie

First Order Logic

Terminology
The Beagle
Theorem Pro

Term Indexir Fingerprint Indexing

Indexing

impiementatio

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluatio Metrics Beagle

Comparisons Sample Posit

Conclusion

Time Spent Per Inference

Table: Superposition time for the 6 most extreme problem examples.

Version	Superposition	Demodulation	NegUnit Simplification
Unmodified	1.7ms	0.3ms	17.5ms
Standard	1.5ms	1.0ms	1.3ms
Enhanced	1.1ms	0.8ms	1.0ms

• Most typical application of Demodulation is a Literal like $X \to f(a)$. X will match anything, making fingerprint indexing a waste of time.

Tim Cosgrove

Outline

Project Overv

Backgrou

First Order Logic Terminology The Beagle

Term Indexing Fingerprint Indexing

Implementation

Implementing
Fingerprint
Indexing
Indexing
Applications
Tailoring to

Result

Beagle Comparisons

Sample Positio

Conclusion

Time Spent Per Inference

Table: Superposition time for the 6 most extreme problem examples.

Version	Superposition	Demodulation	NegUnit Simplification
Unmodified	1.7ms	0.3ms	17.5ms
Standard	1.5ms	1.0ms	1.3ms
Enhanced	1.1ms	0.8ms	1.0ms

- Most typical application of Demodulation is a Literal like X → f(a). X will match anything, making fingerprint indexing a waste of time.
- When excluding PUZ037-1.p we have 0.29, 0.39 and 0.31 milliseconds per Demodulation.

Tim Cosgrove

Outlin

Duniant O.

Project Ove Motivation

Backgroup

First Order Logic Terminology The Beagle

Theorem Prove Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Recult

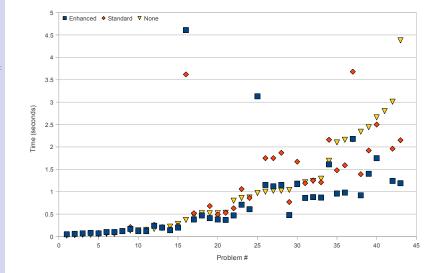
Evaluation Metrics Beagle

Comparisons Sample Positi

Sample Positio Comparisons

C---!--

Runtimes under 5 seconds



Tim Cosgrove

Outlin

Project Overv

Motivation

Backgroun

First Order Logic Terminology The Beagle Theorem Prover Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

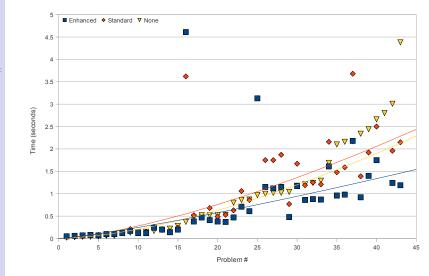
Evaluation Metrics

Beagle Comparisons Sample Positi

Sample Position Comparisons

C---!--

Runtimes under 5 seconds



Tim Cosgrove

Motivation

First Order Logic Terminology The Beagle

Term Indexing

Indexing

Implementing Indexing Indexing

Tailoring to

Evaluation Metrics

Beagle Comparisons

Results Analysis

Table: Superposition time for the 6 most extreme problem examples.

Problem	Enhanced	Standard	Unmodified
DAT050=1.p	17.53	31.54	48.62
DAT039=1.p	13.2	22.51	130.77
DAT040=1.p	14.49	21.29	190.71
DAT038=1.p	12.53	24.04	294.86
DAT043=1.p	18.67	26.08	N/A
DAT048=1.p	17.65	35.77	N/A

Tim Cosgrove

Outline

Project Overv

Motivatio

Backgrou

First Order Logic Terminology

The Beagle Theorem Pro

Fingerprint Indexing

Implementatio

Implementin Fingerprint Indexing

Indexing
Indexing
Applications
Tailoring to

Resul

Evaluatio Metrics Beagle

Comparisons Sample Posit

Conclusion

Results Analysis

Table: Superposition time for the 6 most extreme problem examples.

Problem	Enhanced	Standard	Unmodified
DAT050=1.p	17.53	31.54	48.62
DAT039=1.p	13.2	22.51	130.77
DAT040=1.p	14.49	21.29	190.71
DAT038=1.p	12.53	24.04	294.86
DAT043=1.p	18.67	26.08	N/A
DAT048=1.p	17.65	35.77	N/A

 When taking number of inferences into account for DAT038=1.p we observe 1.2 milliseconds per superposition for the full implementation versus 2.2 milliseconds per superposition for unindexed beagle.

Tim Cosgrove

Outline

Project Overvi

Motivation

Dackgroui

First Order Logic Terminology The Beagle

Theorem Prove

Fingerprin

Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics

Beagle Compariso

Sample Position Comparisons

Conclusion

Fingerprint Sampling Varieties

• Reasoning. Cite shulz and FP/Speed balance

Tim Cosgrove

Outline

Project Overvie

Motivation

Dackgroui

First Order Logic Terminology The Beagle Theorem Prover

Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Results

Evaluation Metrics

Comparisons

Sample Position Comparisons

Conclusion

Fingerprint Sampling Varieties

- Reasoning. Cite shulz and FP/Speed balance
- Different position samples

Tim Cosgrove

Outline

Project Overvi Motivation

First Order Logic Terminology The Beagle

The Beagle Theorem Prov Term Indexing Fingerprint Indexing

Implementing Fingerprint Indexing

Indexing
Indexing
Applications
Tailoring to
Beagle

Resu

Beagle Comparisons Sample Position Comparisons

Conclusion

Fingerprint Sampling Varieties

Table: Totalled inference counts and indexing statistics for various Fingerprint sampling sets.

	Inf	erence Cou	ınts	Inde	xing Result	ts
Sample Set	Sup	Demod NegUni		TotalFound	SupFP	SimpFP
FP3W	162218	42402	2472	13913606	69429	1815992
FP4M	147798	35709	1963	13469779	26847	1851515
FP6M	144505	35326	1959	12601762	16406	1694731
FP7	159055	41005	2440	13011130	21281	1596575
FP8X2	159385	40876	2438	12819184	11229	1602033

Table: Totalled timing results for various Fingerprint sampling sets.

			Time Spent (seconds)							
	Sample Set	Indexing	Retrieving	Sup	Demod	NegUnit	Total			
Ī	FP3W	11.52	14.02	170.37	9.26	1.78	237.75			
	FP4M	13.09	14.12	164.95	9.51	1.82	230.68			
	FP6M	16.82	16.5	159.93	10.78	2.11	229.59			
	FP7	19.98	18.74	170.83	12.37	2.37	249.22			
	FP8X2	45.56	32.59	181.43	21.45	4.06	294.8			

Tim Cosgrove

Outlin

Project Overvie

Motivation

Backgrou

First Order Logic Terminology The Beagle Theorem Prover

Term Indexing Fingerprint Indexing

Implementation

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons Sample Position

Conclusion

Fingerprint Sampling Varieties

 The Hierarchic Superposition with Weak Abstraction Calculus is a

Tim Cosgrove

Outlin

Project Ovendi

Motivation

Backgroup

First Order Logic Terminology

The Beagle Theorem Prover Term Indexing

Fingerprint Indexing

Implementatio

а

Implementing Fingerprint Indexing Indexing Applications Tailoring to

Result

Evaluation Metrics Beagle Comparisons

Sample Position Comparisons

Conclusion

Fingerprint Sampling Varieties

• The Hierarchic Superposition with Weak Abstraction Calculus is