A Versatile, Sound Tool for Simplifying Definitions

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Outline

OUTLINE

Introduction

Our "Five Ws and one H" (cf. Wikipedia "Five Ws"):

- WHAT: A tool, `simplify-defun`, that transforms definitions into simpler versions
- WHO/WHERE: Used in APT project at Kestrel Institute
- WHY: Carry out rewriting transformations and simplify results from other APT program transformations
- HOW: Employ the ACL2 simplifier (and various other utilities, including `make-event`)
- WHEN: Older version is in supporting materials; soon (we hope) to move the "real" version to the community books

Introduction (2)

Improvements vs. related (but simpler) tool presented in 2003 ACL2 Workshop include:

- More robust and flexible
  - Many more options, e.g., for simplifying specified subterms
  - Used hundreds of times so far
- `Simplify-defun` is an event form (via `make-event`) that can thus go into a book
- Uses community book `misc/expander.lisp`, which has been improved in support of this project

Outline

BASIC EXAMPLES

Let's start by seeing a few examples.

- Later in the talk we will touch briefly on how `simplify-defun` works, but not here.

[DEMO]

- We will follow file `demo.lsp` in the supporting materials directory `books/workshops/2017/coglio-kaufmann-smith/support/` with corresponding log file `demo-log.txt`.

Basic Examples

Some features not demoed in depth:

- simplifying measure and guard
- mutual-recursion (with syntax for associating an option with a specific clique member)
- transforming recursive to non-recursive or vice versa
- flexibility for matching subterms
- more aspects of directed-untranslate
- ...

The paper describes two applications of `simplify-defun` in the use of APT. Let's turn now to one of those.

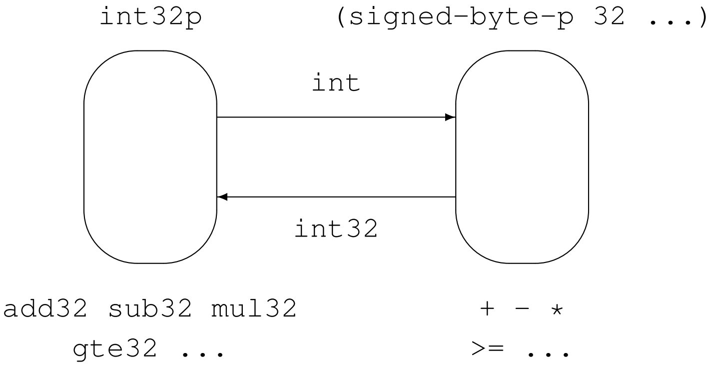
Outline

Bounded vs. Unbounded Integers

- Popular programming languages like C and Java typically use bounded integer types and operations
- Requirements specifications typically use unbounded integer types and operations
- To verify code against specifications, or to synthesize verified code from specifications, often it must be proved that bounded and unbounded integers are “equivalent” under given conditions
- The following slides consider a code verification scenario, but a similar approach should apply to a code synthesis scenario

AN ACL2 MODEL OF BOUNDED INTEGERS

Consider an ACL2 model of 32-bit two's complement integers (e.g., bit vectors), isomorphic to the ACL2 integers in $[-2^{31}, 2^{31})$, with associated modular operations:



REPRESENTATION OF BOUNDED INTEGER EXPRESSIONS IN ACL2

Java code like

```
if (d >= 0) { d += 2 * (b - a); }
else { d += 2 * b; }
```

can be represented via ACL2 terms like

```
(if (gte32 d (int32 0))
    (add32 d (mul32 (int32 2) (sub32 b a)))
  (add32 d (mul32 (int32 2) b)))
```

(see paper).

Rules to Convert Bounded to Unbounded Integer Operations

```
(defthmd add32-to-+
  (equal (add32 x y)
         (int32 (+ (int x) (int y)))))
(defthmd sub32-to--
  (equal (sub32 x y)
         (int32 (- (int x) (int y)))))
(defthmd mul32-to--
  (equal (mul32 x y)
         (int32 (* (int x) (int y)))))
(defthmd gte32-to-<=
  (equal (gte32 x y)
         (>= (int x) (int y))))
```

RESULT OF APPLYING THE OPERATION CONVERSION RULES

```
(if (>= (int d)
        (int (int32 0)))
    (int32 (+ (int d)
              (int
               (int32 (* (int (int32 2)
                              (int
                               (int32
                                (- (int b)
                                   (int a))))))))))
  (int32 (+ (int d)
            (int
             (int32
              (* (int (int32 2))
                 (int b))))))))
```

Rule to Eliminate the Conversions

```
(defthm int-of-int32
  (implies (signed-byte-p 32 x)
           (equal (int (int32 x)) x)))
```

While the operation conversion rules are unconditional, this rule is conditional: relieving its hypothesis amounts to proving that the bounded integer operations do not wrap arouund.

RESULT OF APPLYING THE CONVERSION ELIMINATION RULE

```
(if (>= (int d) 0)
    (int32 (+ (int d)
              (* 2 (- (int b) (int a)))))
  (int32 (+ (int d) (* 2 (int b)))))
```

The hypotheses are relieved automatically in this case, given the context where the expression appears (see paper).

The remaining `int` conversions at the leaves and `int32` conversions at the roots can be eliminated via APT's isomorphic data transformations, which changes the representation of `a`, `b`, `d`, and result from `int32p` to `(signed-byte-p 32 ...)`.

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IMPLEMENTATION OVERVIEW

How does simplify-defun expand into an event? Recall our first example.

```
ACL2 !>(defun f1 (x)
         (if (zp x) 0 (+ 1 1 (f1 (+ -1 x)))))
.....
 F1
ACL2 !>(simplify-defun f1)
(DEFUN F1{1} (X)
       (DECLARE (XARGS ...))
       (IF (ZP X) 0 (+ 2 (F1{1} (+ -1 X)))))
ACL2 !>:pe f1-becomes-f1{1}
           3:x(SIMPLIFY-DEFUN F1)
              \
>              (DEFTHM F1-BECOMES-F1{1}
                       (EQUAL (F1 X) (F1{1} X))
                       :HINTS ...)
```

AT A HIGH LEVEL

```
ACL2 !>:trans1 (simplify-defun f1)
 (WITH-OUTPUT
  :GAG-MODE NIL :OFF :ALL :ON ERROR
  (PROGN
   (MAKE-EVENT ...)
   (VALUE-TRIPLE :INVISIBLE)))
ACL2 !>
```

The `make-event` call (above) generates an `encapsulate` form. What is that form?

```
ACL2 !>(simplify-defun f1 :show-only t)
 (ENCAPSULATE NIL
  (SET-INHIBIT-WARNINGS "theory")
  (SET-IGNORE-OK T)
  (SET-IRRELEVANT-FORMALS-OK T)
  (LOCAL (INSTALL-NOT-NORMALIZED F1))
  (LOCAL (SET-DEFAULT-HINTS NIL))
  (LOCAL (SET-OVERRIDE-HINTS NIL))
  (DEFUN
       F1{1} (X)
       (DECLARE (XARGS :NORMALIZE NIL
                       :GUARD T
                       :MEASURE (ACL2-COUNT X)
                       :VERIFY-GUARDS NIL
                       :HINTS (("Goal" :USE (:TERMINATION-THEOREM F1))
                               '(:IN-THEORY (DISABLE* F1 (:E F1) (:T F1))))))
       (IF (ZP X) 0 (+ 2 (F1{1} (+ -1 X)))))
  (LOCAL
   (PROGN
    (MAKE-EVENT (LET ((THY ...))
                  (LIST 'DEFCONST
                        '*F1-RUNES*
                        (LIST 'QUOTE THY))))
    (DEFTHM F1-BEFORE-VS-AFTER-0
            (EQUAL (IF (ZP X) 0 (+ 1 1 (F1 (+ -1 X))))
                   (IF (ZP X) 0 (+ 2 (F1 (+ -1 X)))))
            ...)
    (COPY-DEF F1{1} ...)
    (DEFTHM F1-BECOMES-F1{1}-LEMMA
      (EQUAL (F1{1} X) (F1 X))
      :HINTS ...)))
  (DEFTHM F1-BECOMES-F1{1}
          (EQUAL (F1 X) (F1{1} X))
          :HINTS ...))
ACL2 !>
```

EXPANSION

What did we just see?

(encapsulate nil
 [prelude]
 [local events] ; *these do the work*
 [new defun form]
 ['becomes' theorem])

Let's look at local events....

Local events (1)

```
(DEFTHM F1-BEFORE-VS-AFTER-0
  (EQUAL (IF (ZP X) 0 (+ 1 1 (F1 (+ -1 X))))
         (IF (ZP X) 0 (+ 2 (F1 (+ -1 X)))))
  :INSTRUCTIONS ((:IN-THEORY *F1-RUNES*) ...)
  :RULE-CLASSES NIL)

(COPY-DEF F1{1}
          :HYPS-FN NIL
          :HYPS-PRESERVED-THM-NAMES NIL
          :EQUIV EQUAL)
```

LOCAL EVENTS (2)

```
(DEFTHM F1-BECOMES-F1{1}-LEMMA
  (EQUAL (F1{1} X) (F1 X))
  :HINTS
  (("Goal"
    :BY ; from the copy-def call
    (:FUNCTIONAL-INSTANCE F1{1}-IS-F1{1}-COPY
                          (F1{1}-COPY F1))
    :IN-THEORY
    (UNION-THEORIES (CONGRUENCE-THEORY WORLD)
                    (THEORY 'MINIMAL-THEORY))
   '(:USE
     (F1-BEFORE-VS-AFTER-0 F1$NOT-NORMALIZED))))
```

Let's look at the key events for functional instantiation and then the corresponding proof obligation.

```
(DEFTHM F1{1}-IS-F1{1}-COPY
  (EQUAL (F1{1} X) (F1{1}-COPY X))
  :HINTS ...
  :RULE-CLASSES NIL)
(DEFTHM F1{1}-COPY-DEF
  (EQUAL (F1{1}-COPY X)
         (IF (ZP X)
             '0
             (BINARY-+ '2 (F1{1}-COPY (BINARY-+ '-1 X)))))
  :HINTS ... :RULE-CLASSES ((:DEFINITION ...)))
(DEFTHM F1-BECOMES-F1{1}-LEMMA
  (EQUAL (F1{1} X) (F1 X))
  :HINTS (("Goal" :BY (:FUNCTIONAL-INSTANCE
                        F1{1}-IS-F1{1}-COPY
                        (F1{1}-COPY F1)))
          ...))

; proof obligation from functional instantiation:
(EQUAL (F1 X)
       (IF (ZP X) 0 (+ 2 (F1 (+ -1 X)))))
```

Note links below to new features in ACL2 or books.

Need	How need is met
prove termination	appeal to previous function's *unnormalized* body (**install-not-normalized**) and **:termination-theorem**
verify guards	appeal to previous function's **:guard-theorem**
support assumptions	require a proof that assumptions are preserved on recursive calls
preserve structure	use **directed-untranslate**
use context	simplify and flatten assumptions, **IF** tests
suppress output	turn off warnings; return and print only the new definition
ease debugging	**:show-only t**, **:verbose t**
control	patterns, hints, . . .
support redundancy	use an ACL2 table
automate reasoning	functional instantiation, theories, . . .

Outline

CONCLUSION

- `Simplify-defun` is *sound*, in that it generates events for ACL2 to prove
- We are using it heavily as part of the APT tool suite for transforming programs and program specifications.
- `Simplify-defun` is coming soon to the community books under `kestrel/`.
  - Its `:XDOC` documentation explains the many options, which have been developed as needed.
- More details are (of course) in the paper.

Thanks!