

Verifying filesystems in the ACL2 theorem prover: an application to FAT32

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Abstract. We describe an effort to formally verify the FAT32 filesystem, based on a specification put together from Microsoft's published specification and the Linux kernel source code. We detail the proof approach we used and its pros and cons. We describe how this work is applicable to filesystems in general, and enumerate possible future applications of these techniques.

Keywords: interactive theorem proving, filesystems

1 Overview

Filesystems are ubiquitous in computing, and they have been of interest to the formal verification community for nearly as long as it has existed.

Here, we detail an effort to advance the state of the art by means of modelling the FAT32 filesystem at the binary level, and validating this model both through theorem proving and through co-simulation with the kernel implementation of FAT32. We begin with an overview of the model and the properties proved with examples; we proceed to a high-level explanation of the proof techniques used; and further we offer some insights about the low-level issues encountered while working the proofs. We end with some statistics pertaining to the magnitude of the proof effort and the running time of the proofs.

2 The model

At this point in development, we have six models of the filesystem, here referred to as 11 through 16 (see 1). Each new model *refines* a previous model, adding some features and complexity, and thereby approaching closer to a model which

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Table 1. Models and their features

11	The filesystem is represented as a tree, with leaf nodes for regular files and non-leaf nodes for directories. The contents of regular files are represented as strings stored in the nodes of the tree; the storage available for these is unbounded.
12	A single element of metadata, <i>length</i> , is stored within each regular file.
13	The contents of regular files are divided into blocks of fixed size. These blocks are stored in an external "disk" data structure; the storage for these blocks remains unbounded.
14	The storage available for blocks is now bounded. An allocation vector data structure is introduced to help allocate and garbage collect blocks.
15	Additional metadata for file ownership and access permissions is stored within each regular file.
16	The allocation vector is replaced by a file allocation table, per the official FAT specification.

is binary compatible with FAT32. Broadly, we characterise the filesystem operations we offer as either *write* operations, which do modify the filesystem, or *read* operations, which do not. In each model, we have been able to prove *read-over-write* properties which show that write operations have their effects made available immediately for reads at the same location, but also that they do not affect reads at other locations.

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Fig. 1. One kernel at x_s (*dotted kernel*) or two kernels at x_i and x_j (*left and right*) lead to the same summed estimate at x_s . This shows a figure consisting of different types of lines. Elements of the figure described in the caption should be set in italics, in parentheses, as shown in this sample caption.

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$$\psi(u) = \int_o^T \left[\frac{1}{2} (\Lambda_o^{-1}u, u) + N^*(-u) \right] dt . \quad (1)$$

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Example of a Computer Program

¹ The footnote numeral is set flush left and the text follows with the usual word spacing.

```

program Inflation (Output)
{Assuming annual inflation rates of 7%, 8%, and 10%,...
years};
const
  MaxYears = 10;
var
  Year: 0..MaxYears;
  Factor1, Factor2, Factor3: Real;
begin
  Year := 0;
  Factor1 := 1.0; Factor2 := 1.0; Factor3 := 1.0;
  WriteLn('Year 7% 8% 10%'); WriteLn;
  repeat
    Year := Year + 1;
    Factor1 := Factor1 * 1.07;
    Factor2 := Factor2 * 1.08;
    Factor3 := Factor3 * 1.10;
    WriteLn(Year:5,Factor1:7:3,Factor2:7:3,Factor3:7:3)
  until Year = MaxYears
end.

```

(Example from Jensen K., Wirth N. (1991) Pascal user manual and report. Springer, New York)

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