Panel Discussion Slides FM@Scale Workshop

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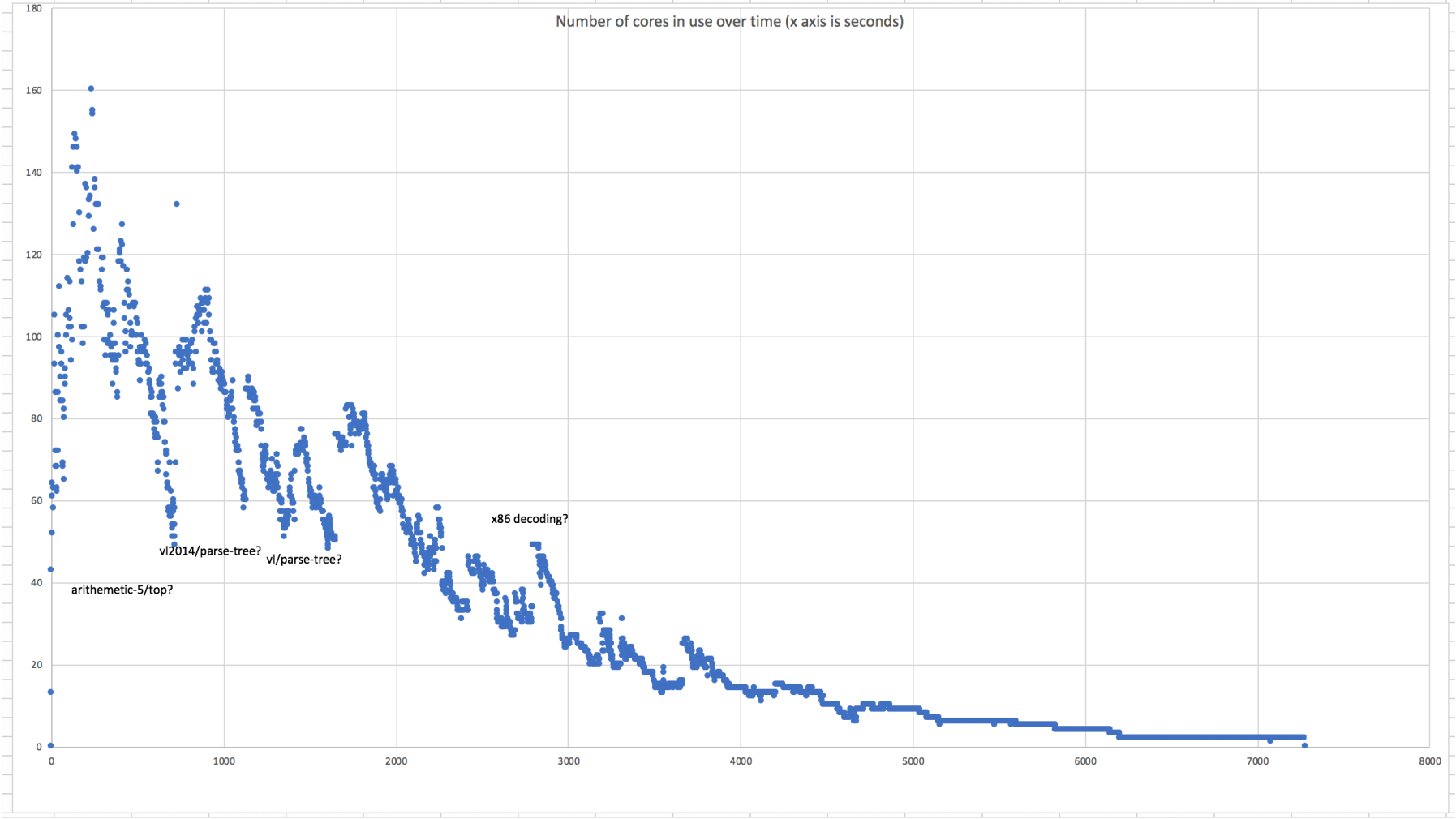
A Large Formal System: ACL2 and its Community Libraries

- ACL2 (together with its libraries) contains:
  - ~8,000 files
  - ~124,000 definitions
  - ~150,000 theorems
- Kestrel adds
  - ~1,200 files
  - ~18,000 definitions
  - ~19,000 theorems
- Both repos include lemma libraries, tools, and many worked examples
- This all takes quite a few CPU hours to certify (see next slide)
- Frequent changes
  - https://github.com/acl2/acl2 has ~13900 commits in ~5 years
  - Kestrel's main ACL2 repository has ~13500 commits in ~6 years
  - Both see several commits per day
- We keep all this stuff working continuously.
  - Prevents bit-rot
  - Test changes and detects errors, bad decisions, bad rules

Numbers of Cores in Use During a Build of ACL2's Libraries

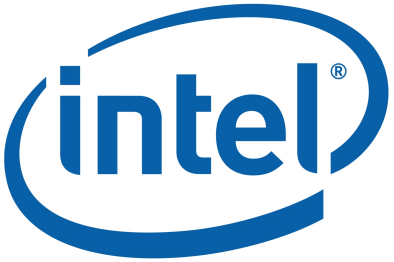


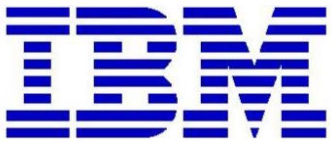
Things that Enable Scale

- Lots of engineering on the prover over 30 years
  - Handle huge industrial designs
- Certificates
  - When ACL2 processes a file, it stores a "certificate"
  - When including a certified file, the proofs are *not* replayed
- Automated regression testing
- Lots of cores
  - My testing uses a 112-core machine
  - Many large Axe / Android / MUSE proofs take ~1hour each
- Good documentation
- Avoiding name clashes
- Working with several simultaneous copies
  - On git, people push to one of four testing branches
    - When any testing branch certifies, the changes are automatically pushed to master
  - I keep ~8 copies of things, so I can test various change sets independently.
- Striving for robustness
  - Avoid brittle proofs hints that depend on, e.g., subgoal numbering

ACL2 Theorem Prover (github.com/acl2)

- Automated, industrial-strength theorem prover
- Used by many companies





Axe: A more scalable rewriter

- Axe is based on ACL2 and includes a rewriter, prover, and equivalence checker
- Key difference: terms are represented as structure-shared DAGs
- Makes symbolic execution much faster
- Crucial for unrolling crypto code (for equivalence checking)

- The Axe Rewriter operates directly on DAGs.
- Have to approximate the context of overarching IFs (may be exponentially many paths to a node).

Example: Blowfish encryption with 448-bit key

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Showing info for DAG:

220723 unique nodes

69047228901642606968385420273829908180338998181151845513142481776128402892495749820425309705176191290762906645508817492017063796957109632222111807817496907058452142384006862813099562777337809764057286201236097348363302715537393373523693696373721931998284267400957454427205743555998357925242650106258287677115990519078241732852362054463216293540771281830529716817153267956527529096963172057094931709614419697759399123176055108497414762235821932024289667959141426814517967295494213344839245765424464878210404596340021932238275231019602584636935302617935710149455420349192829327985776591389242189194947144387442662504213479477055257765079244636325514870117628393279927809569105285445380840985188380380543962845049546975688313492287110259829919665693299035027542325290600083689389668032005888630304154300333723752059619849084848775964443874647591862071243961560053995038346090131509985813531665618846681742441373095521054768419843412240387094627644092452849204146985937148081231850705757068301303387947971612277436289181796552510513003488019982541566207253709317534785541553313760328004589353701163621393076544481184168686529177109281229990164495998847328550868869000484327044459089380396857134866977916073205977908519577906523805151741689843776193417950339176684329817640919730374815812438742571241614336447670726354736223615930385341043906022330340750150129403571360237123250704101693637498980233783740717545304901171889033432060512908454132440152364716980840607907191337769247963997529156722625827362602818968816409517153275833488483525913317913214361643818591191645463621625794113072311383551457416873646801545935247541782844608550463717162992785923609858927329752689444888599149802075662898526118923028417206615489285531381453257262261860106664473857648438046684988189732775688025194596973227404964721439308067198182974265528423405743353452046387062363954341311458850932253358080263803666303790015497177683458624463762581449922687481875811230031324908109315472167682563912799692051302907603175523879101113162595297117779997774377106660622933028103592168211158380963321797081105795794712739084108858888264946762191410852459002785228813117329588094596618809574845453965723662548891411139708846483631974926068037811505057454040176774281020031485277725876065091234804895000783815271866514081827525026631432837968665370663013696648026347590566948019180137798975878259285052059086733635158151479806822652959792472770406483632832289663489070231968880520385260406170855633964297945826245629482480613050815526869070435443266799097507807527978194568955760027221913079986270080698679505580441607170035959573443777987716457876372528005539929510769860909903052798449806882421978368106892488208698980947549377264997090479569582048774435578932059131275752566222868122828503583118085730992751776513225192838784976639123947031739801301083211871193922090631248139279687881268261766140732628285680400486665806658932847855324822599619356068377797596646568719019681235659126119805911824254844422279470831811699016066580360469140334458448947442403773294610419188823706744379019854960788952455009282450198019617145270261468345950264617334709408920406175809339406882772407382947227258260382493567058570855815349631348093051256120208511029314877713825922401428516068925047121655054777535363325192169757535912105270901204887477287603075565875566156812030268129563946837710627585646135190155611223194205771216041315277988575248726285574668930802363015706804552941527205387787767316933368409453729394091842712165857190785540673246395278459727431003309698163567436167456838519717812651570846770512050755215579080712722417437813932921609964445239588383110517883262042131685698633265165681179870611124746063824675943770372739006767080724403554677555274239276467872850296348011811308824142880102502207188184515388905432471711628416570984364076362758677087253160728050772780230631882680211228194184094920747984519879327006649734517143567494716401790604842565134689573903276968965033240579179189199491817078528324146268719364654911672896515866356883985537771073355002767038342703930046590110336413286173392129118985784262221090355077593068153761514469413641851432022165952474656184559589960435222454488712747606337273769743761903891439721315403564140238995459227879036243990476313036929545112656840831104351313106409523258130355465719856917329487703363702526539360632682515290548533814648737899748509430229413848813904491757078253047317758060309044127669569796655276623685200661921492979162694898039474837376491472999874728994765775423505340602155114843845426799330142471358712509530543740288484453892827901308079341192244360941781595848573579179780825879904504574527440321965325291448020885070994572481730345225308441974442477877479319829247835426265863117858139068629339076917486756684108638626702229736758165065186072175631396658166819173623441684617882100817602915426879245345263105884152105992772637814702659865215574685010328660304685806121183906569549494977554523793688658597359386029489410861164062064057857792951051843979464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```

total nodes

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```
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220723 unique nodes

690472289016426069683854202738299081803389981811518455131424817761280963222
211180781749690705845214238400686281309956277733780976405728620123605743555
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216397370656463804304928162240248751141616515

total nodes
```

```
((220722 BV-ARRAY-WRITE '8 '8 '0 220705 220721)
 (220721 BV-ARRAY-WRITE '8 '8 '1 220704 220720)
 (220720 BV-ARRAY-WRITE '8 '8 '2 220702 220719)
 (220719 BV-ARRAY-WRITE '8 '8 '3 220700 220718)
 (220718 BV-ARRAY-WRITE '8 '8 '4 220717 220716)
 (220717 SLICE '31 '24 220698)
 (220716 BV-ARRAY-WRITE '8 '8 '5 220715 220712)
 (220715 SLICE '23 '16 220714)
 (220714 BVXOR '24 220666 220713)
 (220713 BVXOR '24 220696 2810))
 ...
 (10 . KEY2)
 (9 . KEY1)
 (8 . KEY0)
 (7 . IN7)
 (6 . IN6)
 (5 . IN5)
 (4 . IN4)
 (3 . IN3)
 (2 . IN2)
 (1 . IN1)
 (0 . IN0))
```

Scaling FM to more widespread use

A general approach: Inject formal into a standard process to make things a little bit better.

- Strive for complete automation.
- Make the "spec" easy to express, or spare the user from writing it.

Concretely (a new start at Kestrel):

- Programmers can write unit tests.
- A typical test covers a single input.
- What if we could replace a test with a little proof?
  - Just do slightly better: cover a set of inputs
  - Tool proves that all inputs in the set produce good behavior, or it finds a counterexample.
  - Tool achieves automation by using symbolic execution (seems okay to restrict to small inputs) and SMT solving.

- Don't compare this to a full proof and feel bad about it.
- Compare this to a unit test and feel good about it!