Secure, High-Assurance Development Environment (SHADE) Program

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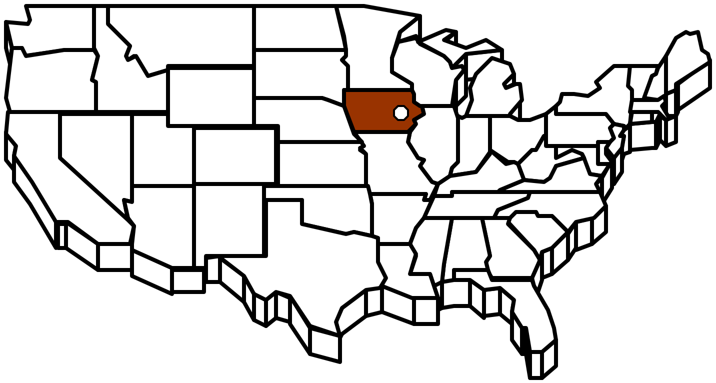
Rockwell Collins

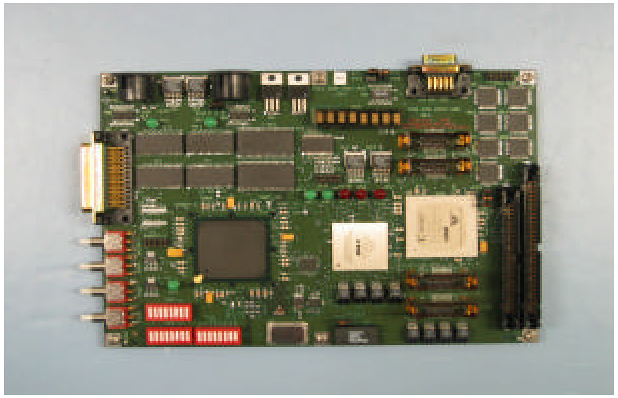
- **Provider of Advanced Communication and Aviation Equipment to Air Transport, Business and Regional, and Military Markets**
  - **$2.8 Billion in Sales**
  - **Headquartered in Cedar Rapids, IA**
  - **14,500 Employees Worldwide**

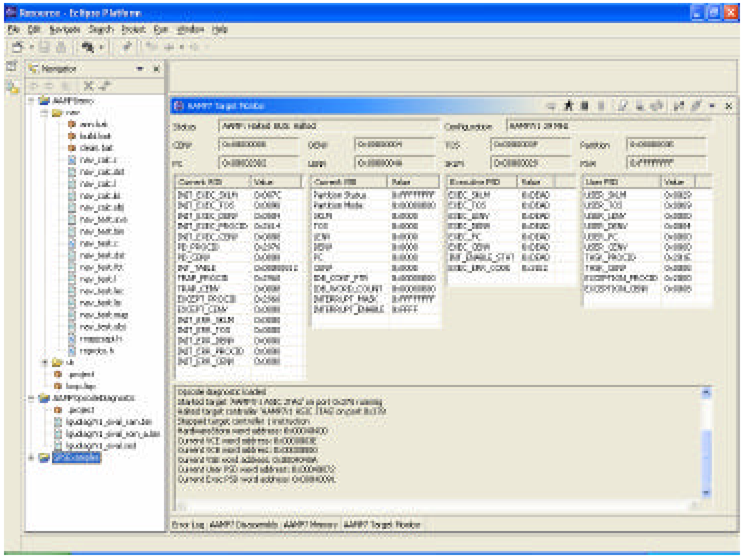


- **The** *Automated Analysis section* **of the RCI Advanced Technology Center applies advanced mathematical tools to the problem of producing high assurance systems**
  - Perform applied research in model-checking and theorem proving for safety-critical and secure systems
  - 6 full-time formal methods researchers
  - Particular expertise in processor modeling, separation kernels, avionics system requirements
  - **We're hiring!**

Secure High-Assurance Development Environment (SHADE)

- A “nuts-and-bolts” partitioned development environment that automates important aspects of secure system development
- A highly-assured, evaluatable method for implementing cryptographic algorithms written in the Cryptol language, including a verifying Cryptol-to-AAMP7 compiler
- Support for automatic machine-code proofs of AAMP7 code
- Tool support for the creation and analysis of secure multipartition cryptographic applications that exploit the AAMP7’s intrinsic partitioning capability
- Funded by NSA R2/I2 and Rockwell Collins

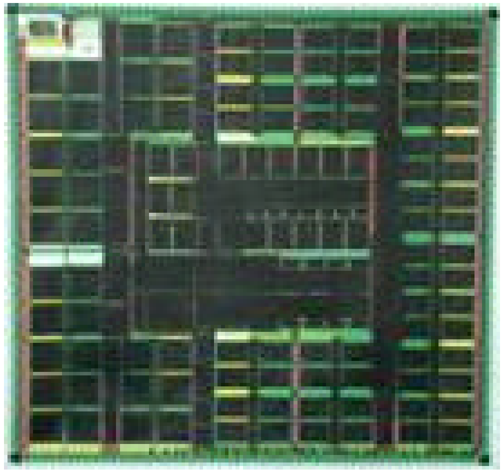




Why a verifying compiler for Cryptol?

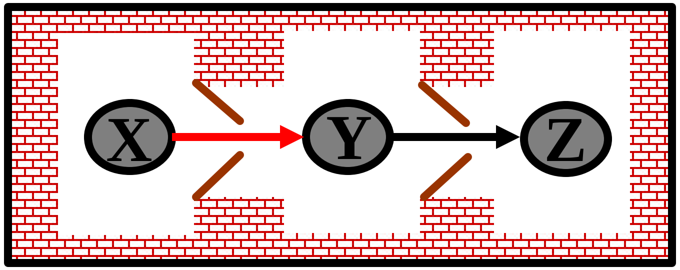
- Cryptographic systems need to be correct
  - NSA is a demanding customer
  - NSA suppliers realize that typical “commercial grade” engineering just won’t cut it
- Cryptographic systems are difficult, expensive to certify
  - A verifying compiler could markedly reduce code-to-spec review costs and reduce time-to-market for cryptographic devices
- Reference Cryptol specifications for common crypto algorithms are available
- A domain-specific language, such as Cryptol, seems to present lower risk than attempting a verifying compiler for a general-purpose programming language
- The AAMP7 is an “easy” code generation target (think JVM)
- Theorem prover technology has matured sufficiently to make this program feasible

Rockwell Collins AAMP7 CPU



Features
- Used in RCI GPS and Infosec products
- High Code Density
- Low Power Consumption (250 mW)
- 100 MHz operation
- Screened for full military temp range
- Implements *intrinsic partitioning*

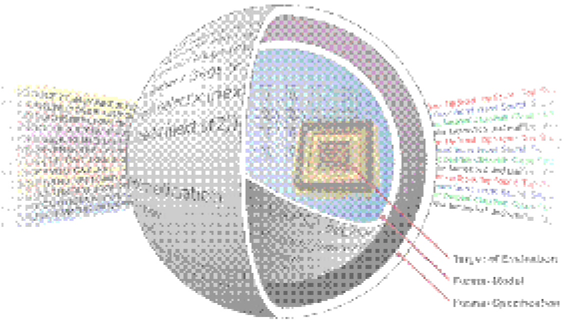
Intrinsic partitioning
- Computing Platform Enforces Data Isolation
- “Separation Kernel in Hardware”



AAMP7r1 Intrinsic Partitioning Formal Verification

- **Formal description of separation for uniprocessor, multipartition system**
  - **“GWV” separation theorem**

- **Detailed formal models of Trusted AAMP7r1 microcode operation, subjected to intensive NSA code-to-spec review against microcode listings.**



- **Machine-checked proof that separation holds of AAMP7r1 model -- “EAL7+”**

- **Artifacts accepted by NSA evaluators in March 2004. Official NSA MILS certification expected soon.**

A COMPUTATIONAL LOGIC

ACL2

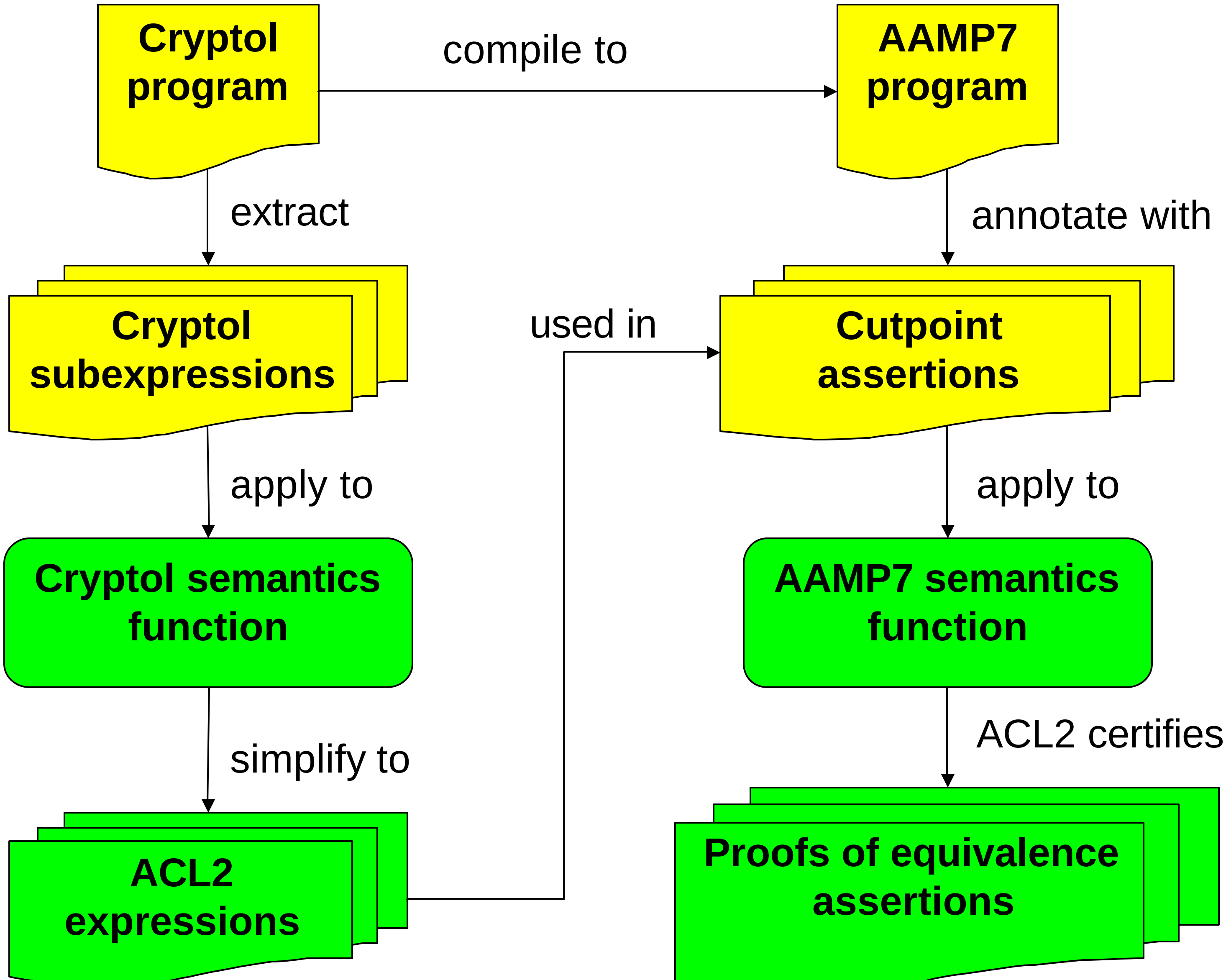
APPLICATIVE COMMON LISP

Cryptol

- Cryptol is a domain-specific language for cryptography, developed by Galois Connections, Inc.
- Cryptol specifications are compact and expressive – DES core is at right
- Cryptol specifications can be compiled to C, or to machine code

```
des : {a b} (a >= 7) => ([2**(a-1)],[b][48]) -> [64];
des (pt, keys) = permute (FP, swap (split last))
  where { pt’ = permute (IP, pt);
          iv = [| round (k, split lr)
               || k <- keys
               || lr <- [pt’] # iv
               |];
          last = iv @ (width keys - 1);
         };

round (k, [l r]) = r # (l ^ f (r, k));

f (r, k) = permute (PP, SBox (k ^ permute (EP, r)));

swap [a b] = b # a;

permute : {a b} (b >= 1) =>
                    ([a][b], [2**(b - 1)]) -> [a];
permute (p, m) = [| m @ (i - 1) || i <- p |];
```

Verifying Compiler Dataflow

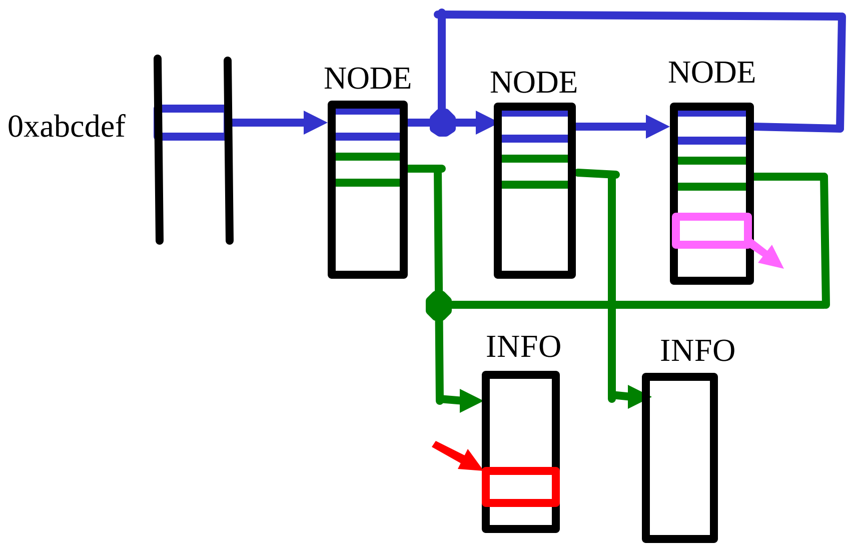


AAMP7 Semantics Function

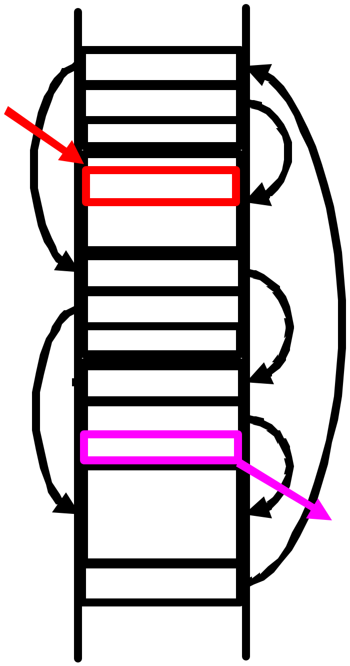
- Provides instruction-level simulator for the AAMP7
- Written in ACL2 (~50 KSLOC with all RCI support books)
- Can be used as a processor simulator, as well as a vehicle for proof
- GACC (Generalized Accessor) library now used to model memory, same as used in AAMP7 separation proofs
  - Underlying bags (multiset) library optimized to support large models

Data Structure Representation

Programmer's view --
"boxes and arrows"



Reality –
mapped into a single linear address space



We must "face reality" in order to verify a compilation

AAMP7 Model State

- **Processor state is modelled using an ACL2 Single-Threaded Object (stobj)**
  - **Stobj mechanism in ACL2 allows functional program objects to be updated in place, rather than updating copies**
- **AAMP7 state is composed of nearly 60 elements, including Program Counter, Top-of-Stack pointer, Partition Management Unit, RAM, etc., many of which are updated every instruction**
  - **Stobj’s are a huge win for the AAMP7 model!**

Status and Summary

- We are a work in progress -- SHADE program is scheduled to run through FY06
- SHADE is a significant engineering effort, encompassing contributions from 10 different developers in three locations
- The SHADE compiler can now generate AAMP7 binary code for canonical examples that execute on the AAMP7 ACL2 model, as well as on the real machine
- Currently investigating whether some of the “middle-end” passes of the compiler can actually be implemented as rewrite rules within the theorem prover