ExCAPE

Expeditions in Computer Augmented Program Engineering

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Cornell, Maryland, Michigan, MIT, Penn, Rice, UC Berkeley, UCLA, UIUC

Reverse Site Visit, National Science Foundation, December 2011

Software: Enabling Technology with a Caveat

Software Inside!

Software → New features, Automation, Customization, Flexibility

Software → Bugs, Cost overruns, Cancelled projects

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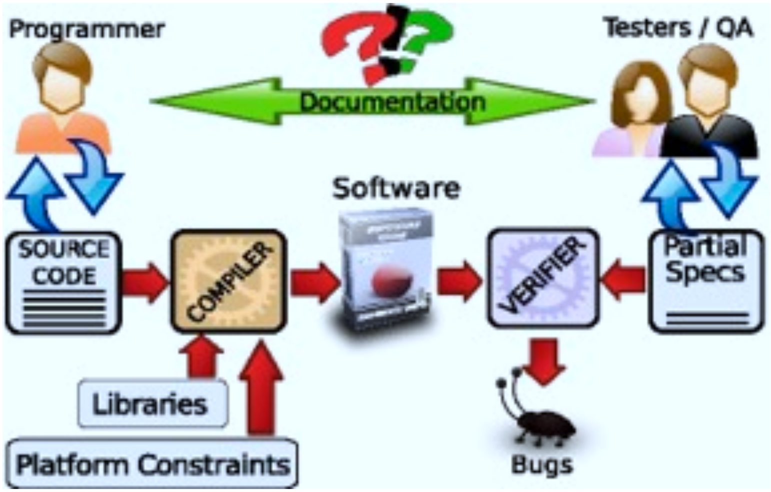
Grand challenge: Transform technology for software development

Software Design Methodology



- What has changed:
  - Programming languages
  - Libraries
  - Verification technology
- What has not changed:
  - Programming is done by experts
  - Fully specified by conventional programming
  - Verification phase is distinct from design

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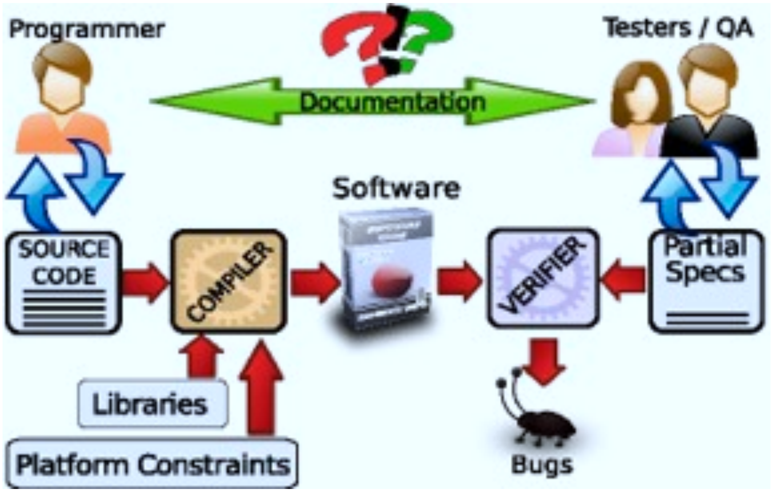

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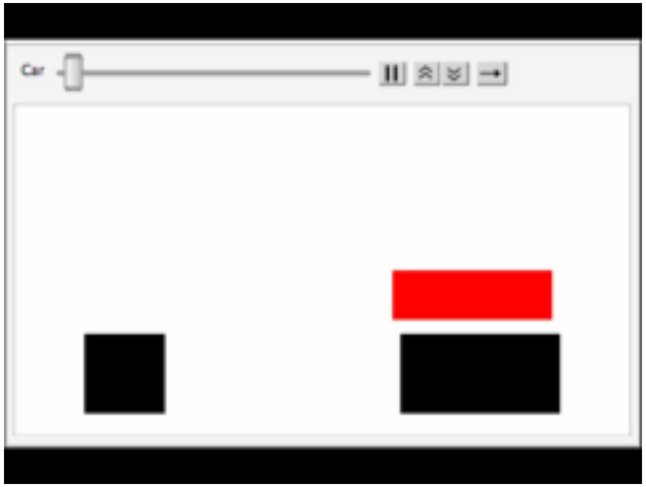
Can we leverage modern analysis tools and increased computing power to revolutionize the task of programming?

Inspiration: Recent innovations in synthesis illustrated by 3 projects

Sketch: Program completion

Ref: Solar-Lezama et al (PLDI 2010)

```
Err = 0.0;
for(t = 0; t<T; t+=dT){
  if(stage==STRAIGHT){
    if(t > ??) stage= INTURN;
  }
  if(stage==INTURN){
    car.ang = car.ang - ??;
    if(t > ??) stage= OUTTURN;
  }
  if(stage==OUTTURN){
    car.ang = car.ang + ??;
    if(t > ??) break;
  }
  simulate_car(car);
  Err += check_collision(car);
}
Err += check_destination(car);
```



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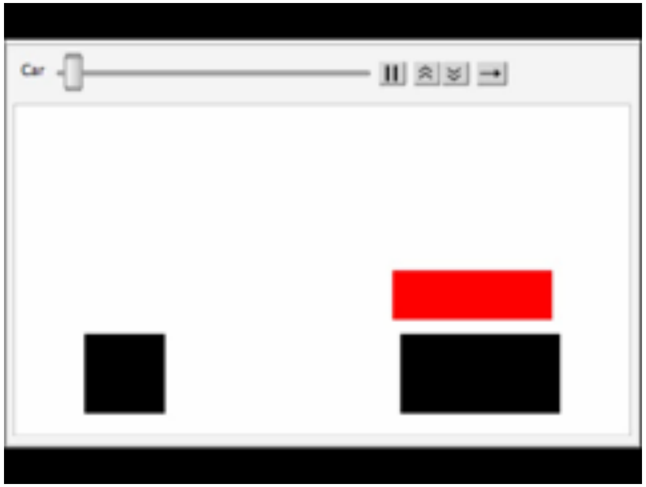
Backup straight

Turn

Straighten



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When to start turning?

Backup straight

How much to turn?

Turn

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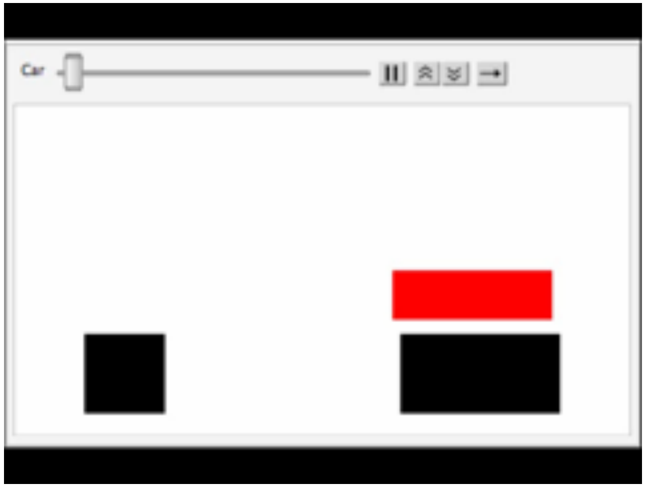

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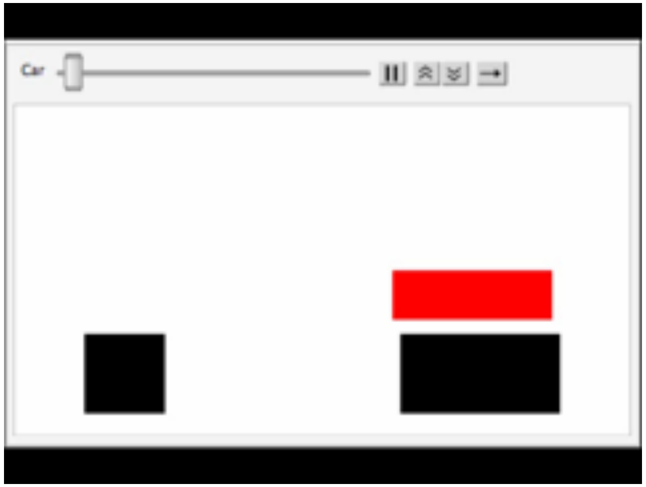

Enables programmers to focus on high-level solution strategy

QuickCode: Programming by Examples

Ref: Gulwani (POPL 2011)

Input	Output
(425)-706-7709	425-706-7709
510.220.5586	510-220-5586
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- Infers desired Excel macro program
- Iterative: user gives examples and corrections
- Being incorporated in next version of Microsoft Excel

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Enables non-programmers to program interactively

Paraglide: From Sequential to Parallel Code

Ref: Vechev et al (POPL 2010)

Sequential Program

```
bool add(int key){
 atomic
   Entry *pred,*curr,*entry
   locate(pred,curr,key);
   k = (curr->key == key)
   if (k) return false
   entry = new Entry()
   entry->next = curr
   pred->next = entry
   return true
}
```

Paraglide

Minimal Synchronization

```
bool add(int key) {
 Entry *pred,*curr,*entry
restart:
 locate(pred,curr,key)
 k = (curr->key == key)
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 entry = new Entry()
 entry->next = curr
 val= CAS(&pred->next,<curr,0>,<entry,0>) ✓
 if (!val) goto restart
 return true
}
```
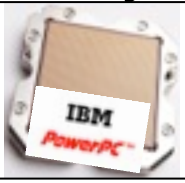

Architecture Description



- Target: Highly concurrent work queue in C/C++
- Infers minimal number of fences needed for synchronization
- Unexpected, correct, minimal solutions now deployed in IBM

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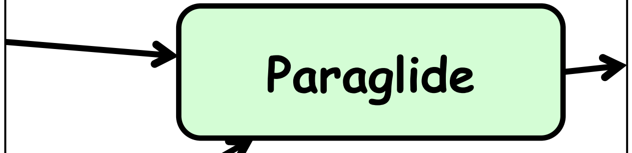

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Architecture Description

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- Infers minimal number of fences needed for synchronization
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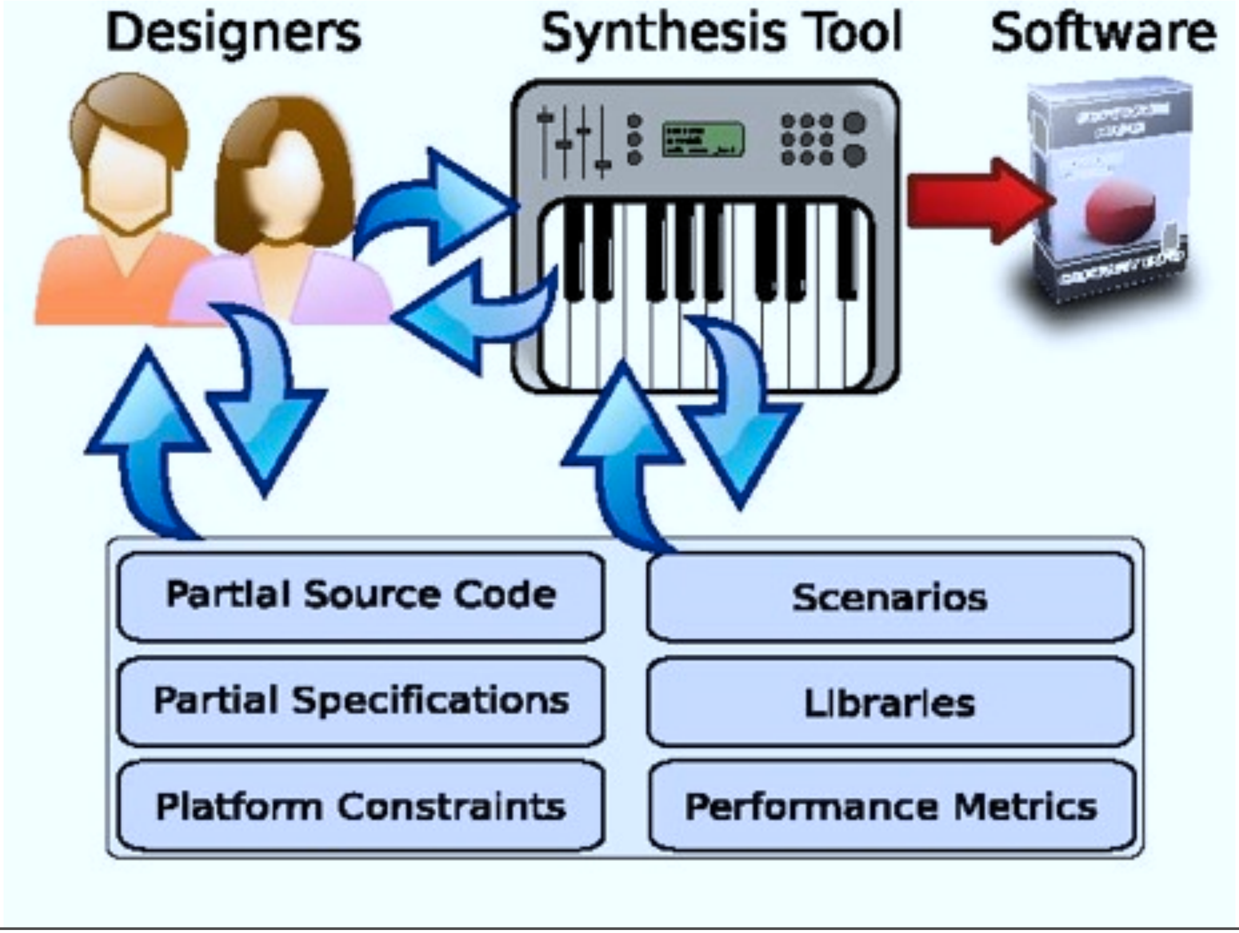
Enables programmers to meet new programming challenges

ExCAPE Vision

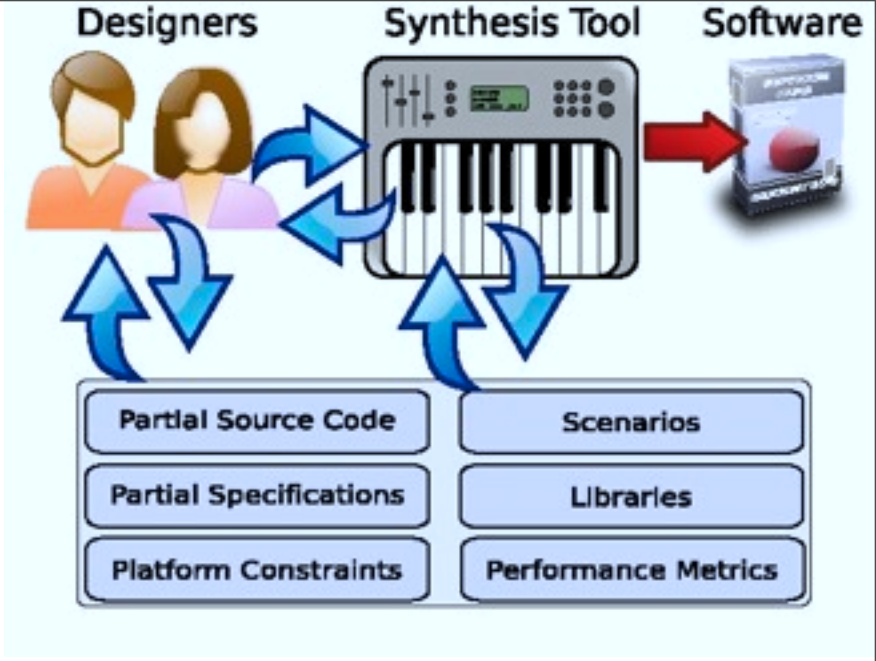
Harnessing computation to transform programming:

Programming made easier, faster, cheaper

Key enabler for next-generation software applications



ExCAPE Design Solution



- ❑ Designer expresses “what”, possibly using multiple input formats
- ❑ Synthesizer discovers new artifacts via integration and completion
- ❑ Synthesizer solves computationally demanding problems using advanced analysis tools
- ❑ Interactive iterative design
- ❑ Integrated formal verification

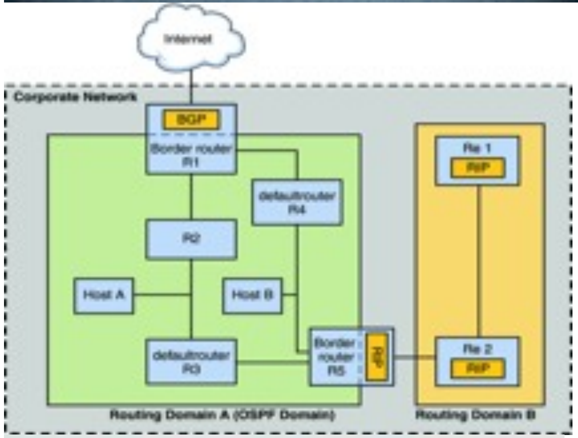
Challenge Problems

- ❑ Representative of complexity: cyber-physical systems on networked, multi-core platforms

- ❑ Concrete design problems to guide tools and methodology

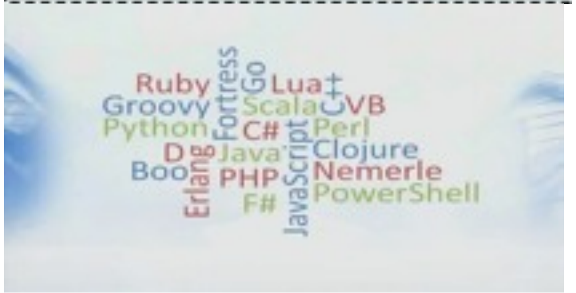
- ❑ Multiple challenge problems to avoid domain-specific solutions

Robotic Controllers



Networked Systems

Concurrent Programming



Multi-core Protocols

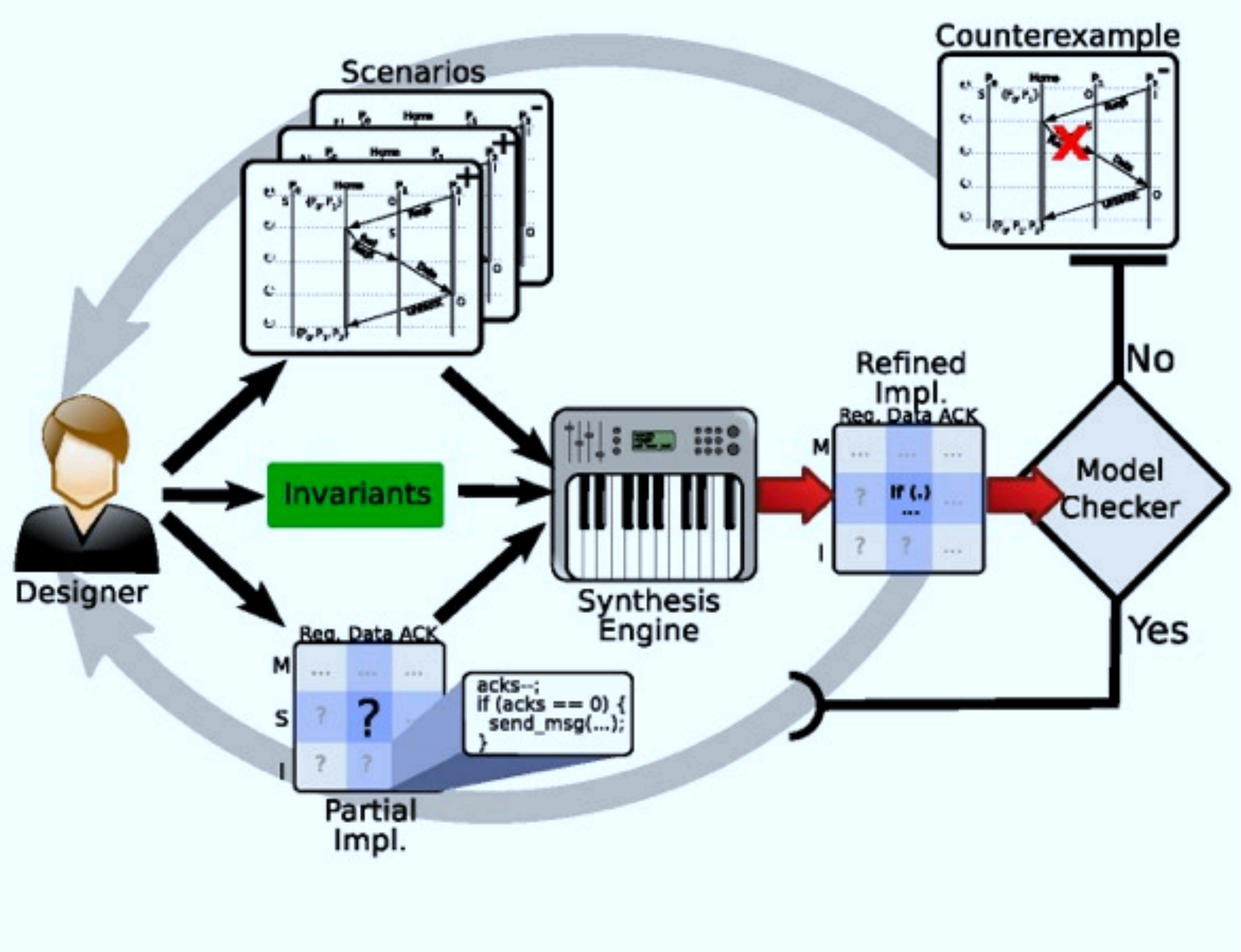
AMD FX 8-Core Architectural Diagram

Proposed Research

In each challenge area,

- Identify a concrete design problem for which new solutions can enable new applications
- Identify most promising synthesis-based solution strategies
- Develop theoretical foundations and algorithmic advances
- Build tools and prototypes
- Evaluate tools for scalability, user interaction, and programmer productivity
- Refine and advance computational/methodological solutions and tools

Multicore Protocols: ExCAPE Design Solution



```
acks--;
if (acks == 0) {
  send_msg(...);
}
```

Multicore Protocols: Research Questions

❑ How to consistently integrate (partial) state machines, example scenarios, and temporal-logic requirements ?

❑ How to suggest potential fixes ?

❑ What's a good programming notation for multi-modal specifications?

❑ How to program synthesis engine with completion strategies specific to a problem domain (e.g. cache coherence) ?

❑ How to address scalability ?

❑ How to evaluate and measure impact on programmer productivity ?

Foster

Hartmann

Lafortune

Kavraki

Kress-Gazit

Loo

Madhusudan

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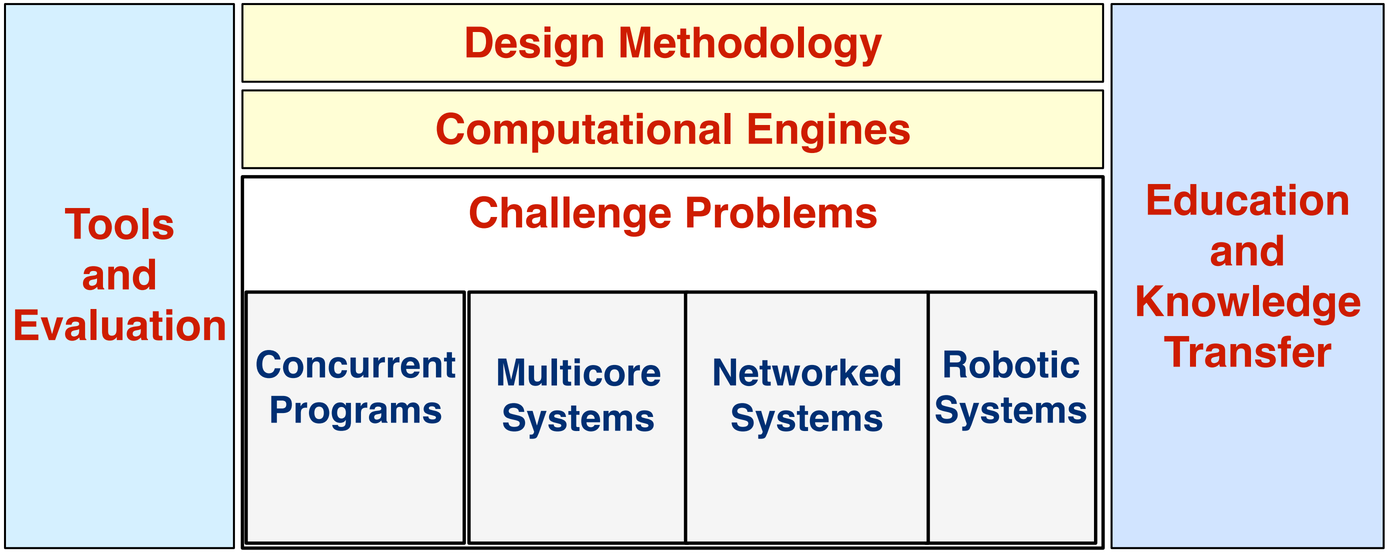
Zdancewic


Tools and Evaluation

Design Methodology

Computational Engines

Challenge Problems

Concurrent Programs

Multicore Systems

Networked Systems

Robotic Systems

Education and Knowledge Transfer

Martin

Pappas

Vardi

Tripakis

Tabuada

Solar-Lezama

Seshia

Sangiovanni

Impacting Industrial Practice

- ❑ Keys to transitioning academic research to industrial practice
  1. Market pull and industrial interest
  2. Algorithmic advances and computational tools
  3. Methodology for integration in design cycle

- ❑ Our plan: Advance computational tools and methodology, and demonstrate benefits on meaningful case studies

- ❑ Collaborators:

  Chitta (Willow Garage), Gulwani (Microsoft), Vechev (IBM)

- ❑ Advisory Board:

  Fix (Intel), Godbole (Honeywell), Kuehlmann (Coverity),
  Lee (Microsoft), Wegman (IBM), Zave (AT&T)

Education and Outreach

- Annual workshop
  - Academic and industrial participants
- Summer school
  - Integrative and multi-disciplinary training
- Synthesis competition
  - Benchmarks and tool evaluation
- Undergraduate education
  - Course modules for CS and CE courses
- Attracting high-school students to CS and Engineering
  - Programming is not equal to coding
  - Projects in robotics
  - Collaboration with existing high-school programs at PI institutions

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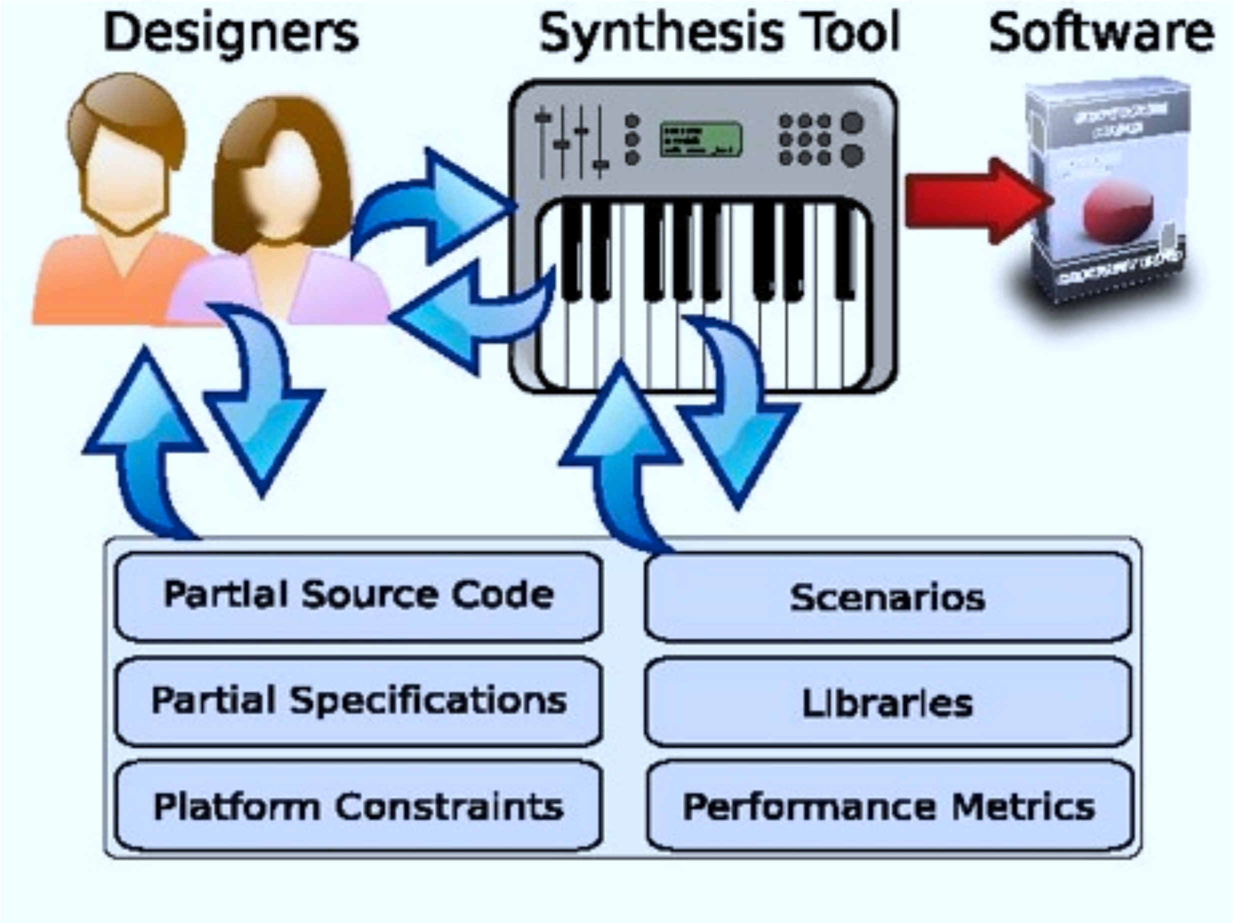

Designers

Synthesis Tool

Software

Partial Source Code

Partial Specifications

Platform Constraints

Scenarios

Libraries

Performance Metrics