LoPSiL: A Location-based Policy-specification Language

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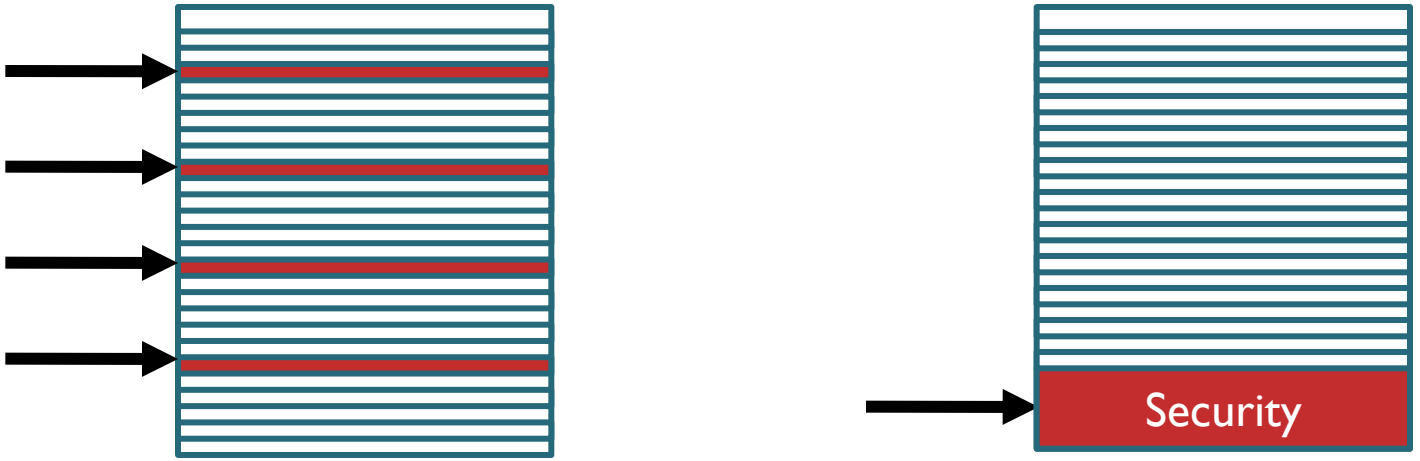
Introduction

- **Policy-specification languages** are domain-specific programming languages designed to make it easier to specify and enforce sound security policies

```
policy allowOnlyHTTP(Socket s)  {
  if (s.getPort() == 80 ||
        s.getPort() == 443)
  then ALLOW
  else DISALLOW
}
```

Motivations for Using Policy-specification Languages

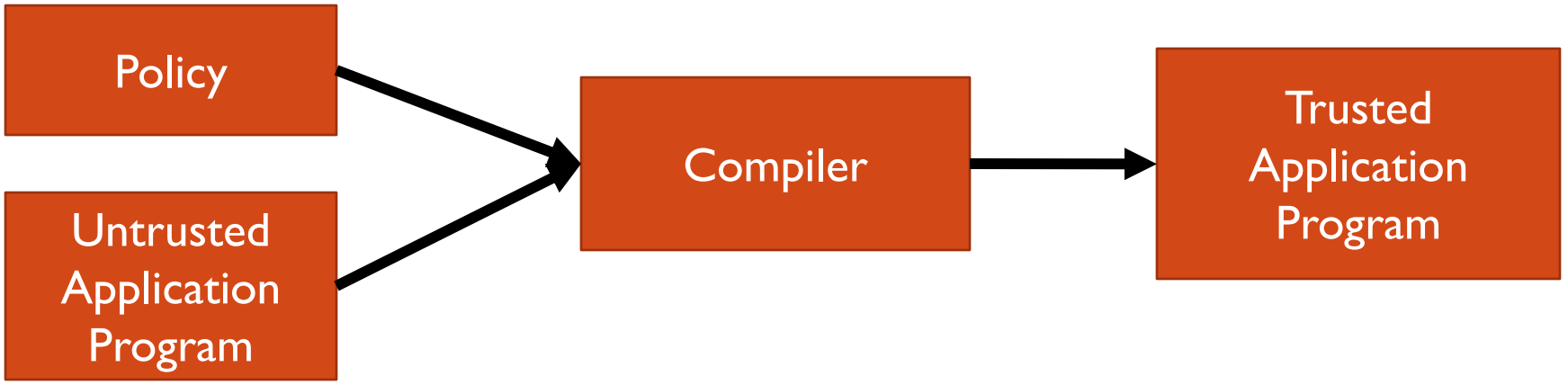
1. To specify and enforce custom constraints (i.e., a **policy**) on untrusted software
2. To enable programmers to organize their code with a centrally specified policy module



- No need to scatter security checks throughout code
- Provides standard policy-modularization benefits
  - Makes centralized policy easier to create, locate, analyze, and maintain

Related Work

- Many expressive policy-specification languages and systems have been implemented
- Implemented as compilers that convert untrusted into trusted applications



- The trusted application program is equivalent to the untrusted program except that it contains inlined code that enforces the policy at runtime

Related Work

- Several languages and systems employ this architecture
  - E.g., *Naccio, PoET/PSLang, Polymer*
  - But it can be inconvenient to specify mobile-device policies in these languages because they lack primitives for managing location information
- On the other hand, some policy-specification languages do provide primitives for managing location information
  - E.g., *Policy Mapper, OpenAmbient*
  - But these languages are Turing-incomplete and limited to access-control policies

LoPSiL (Location-based Policy-specification Language)

- This research designs and implements a language called **LoPSiL**
- As far as we are aware, LoPSiL is the first expressive (Turing-complete) policy-specification language that targets location-based policies
  - LoPSiL's novelty is that it provides abstractions for conveniently accessing and manipulating location information in policies
- We have posted the implementation of LoPSiL and several example policies online at www.cse.usf.edu/~ligatti/projects/runtime/

Outline

- Introduction
  - Motivation
  - Related work
- LoPSiL
  - Core linguistic constructs
  - Example policies
- A LoPSiL Compiler
  - Compiler architecture
  - Experiential observations
- Conclusions

Language Overview

- Due to the popularity of Java (particularly Java ME) as an application programming language for mobile devices, we'll talk about (and we've implemented) LoPSiL in the context of Java
- However, LoPSiL is based on six core abstractions (each implemented as a Java class) that we expect to be portable to other languages and platforms

Core Linguistic Construct 1

- **`Location`**
  - May refer to a room, chair, floor, building, campus, GPS coordinates, region of a network topology, etc.
    - Definition of locations is not "baked in"
    - Users can define their own (possibly abstract) locations by extending the **`Location`** class
- **`Locations`** have an identity (e.g., name or GPS coordinates)
- LoPSiL provides many built-in utility methods for manipulating GPS locations (e.g., calculate distance between two locations)
  - Users are free to define others

Core Linguistic Construct 2

- **`LocationDevice`**
  - Is LoPSiL's interface to real-time location information
- **`LocationDevices`** must implement two methods:
  1. To return the device's current location
  2. To return the device's **location granularity**: with what precision/accuracy the current location is known (e.g., within 0.5m, 2km, 1 room etc.)
- Policies can require devices to provide location information with particular granularity thresholds

Core Linguistic Construct 3

- **`PolicyAssumptions`**
  - Encapsulates two assumptions made by policies about a **`LocationDevice`**:
    - **`LocationGranularityAssumption`**: Policy may require location information with a particular accuracy
    - **`FrequencyOfUpdatesAssumption`**: Policy may require that location updates arrive with a particular frequency
- A LoPSiL policy gets notified automatically whenever a **`LocationDevice`** violates that policy's granularity or frequency-of-updates assumptions

Core Linguistic Construct 4

- **`Action`**
  - Encapsulates information (method signature, run-time arguments, calling object, return value, etc.) about a **security-relevant method**
- An **`Action`** object gets passed to a policy before and after every security-relevant method executes
- The policy can analyze an **`Action`** object passed to it to determine which security-relevant method is being invoked or has just been invoked
- Policies get to decide whether and how the **`Actions`** passed to it will execute

Core Linguistic Construct 5

- **`Reaction`**
  - Conveys a policy's decision about whether and how an action is allowed to execute
- Policies can react to a given **`Action`** ***a*** by returning one of four **`Reactions`**
  1. **`OK`**: ***a*** is safe to execute
  2. **`Exception`**: ***a*** is unsafe; exception should be raised
  3. **`Replace`**: ***a*** is unsafe; a precomputed return value should be returned instead of executing ***a***
  4. **`Halt`**: ***a*** is unsafe; program should be halted

Core Linguistic Construct 6

- **`Policy`**
  - Specifies constraints on untrusted software
- Five parts to a LoPSiL **`Policy`**
  1. **`PolicyAssumptions`**
  2. **`void handleGranularityViolation()`**
  3. **`void handleFrequencyViolation()`**
  4. **`void onLocationUpdate()`**
     - Invoked when any **`LocationDevice`** associated with the policy updates its **`Location`** information
  5. **`Reaction react(Action a)`**
     - Return a reaction to any security-relevant action

Example Policy: AllowAll

```
public class AllowAll extends Policy {
  public LocationDevice[] devices = {new
                                LopsilGPS(LopsilGPS.GARMIN)};
  public LocationGranularityAssumption lga =
         new LocationGranularityAssumption(15, Units.METERS);
  public FrequencyOfUpdatesAssumption foua =
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  public PolicyAssumptions pa =
         new PolicyAssumptions(this, devices, lga, foua);
  public void handleGranularityViolation() {System.exit(1);}
  public void handleFrequencyViolation() {System.exit(1);}
  public synchronized void onLocationUpdate() {
    System.out.println("new location = " +
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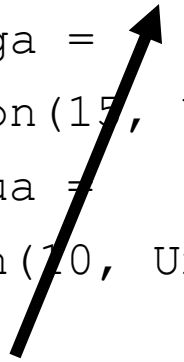

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Relationship with Existing Work

- Existing policy-specification languages such as Naccio, PSLang, and Polymer provide constructs similar to `Actions`, `Reactions`, and `Policy` with **`react`**-style methods
- LoPSiL's novelty is its addition of optional location-related policy components: `Locations`, `LocationDevices`, `PolicyAssumptions`, and `onLocationUpdate()`, `handleGranularityViolation()`, and `handleFrequencyViolation()` methods

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Access-control Policy

- Prevents an application from reading GPS data outside of work hours

```
public class NoGpsOutsideWorkTime extends Policy {
  public LocationDevice[] devices = {new
              LopsilGPS(LopsilGPS.GARMIN)};
  public PolicyAssumptions pa =  ...
  public synchronized Reaction react(Action a) {
    if(ActionPatterns.matchesLocationRead(a) &&
                  !TimeUtils.isWorkTime())
      //return a null location to the application
      return new Reaction("replace", null);
    else
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Deviation-from-path Policy

- Requires that navigational aid appear when the device's current location deviates from its expected path

```
public class ShowNavigation extends Policy {
  public LocationDevice[] devices = {new
              LopsilGPS(LopsilGPS.GARMIN)};
  public PolicyAssumptions pa =
  ...
  public synchronized void onLocationUpdate() {
    if(devices[0].getLocation().
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Other Policies

- Safe-region Policy:
  - Requires a robot to encrypt all outgoing communications when the robot's location is outside a secure-region perimeter
- Social-networking Policy:
  - If the policy infers that the device has completed a journey of at least 100km over the past 2 hours, then all friends in the user's address book who are located within 20km of the new location get invited to rendezvous

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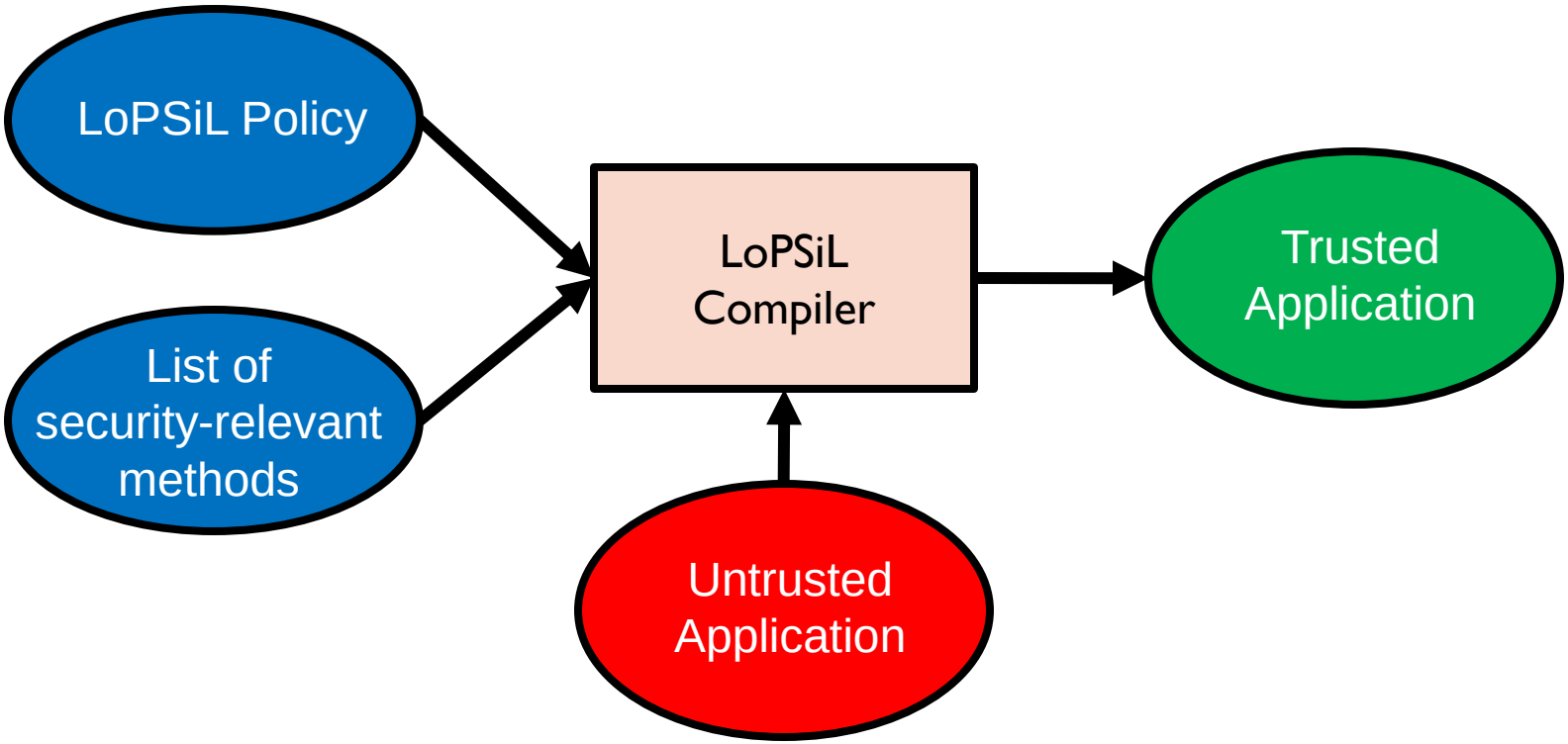
Compiler Architecture

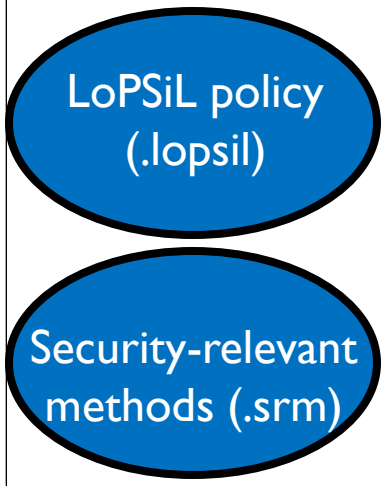
- A LoPSiL compiler needs to input a policy, a list of security-relevant methods, and an untrusted application
- A LoPSiL compiler needs to output a trusted application formed by inserting (inlining) policy code before and after every security-relevant method in the untrusted application



Compiler Architecture

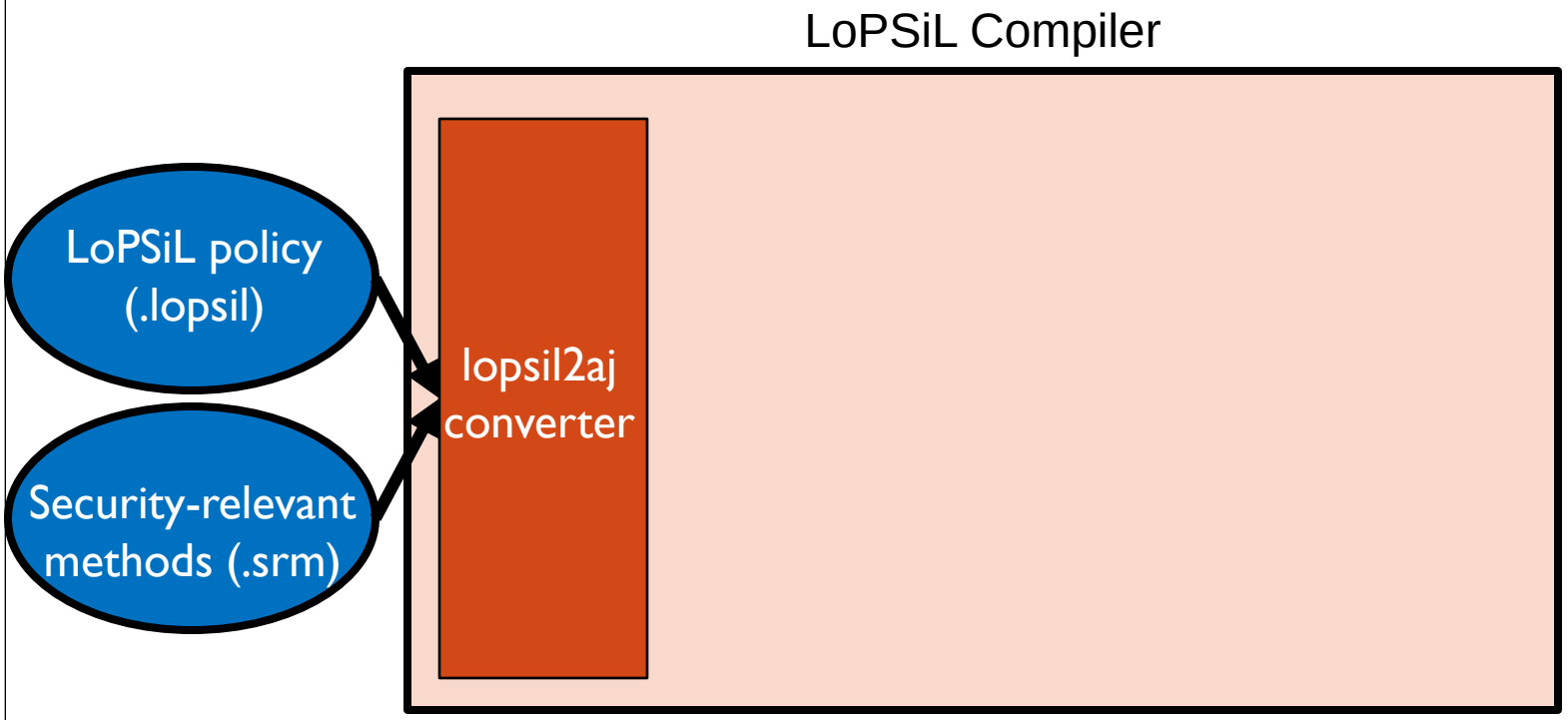
- We use AspectJ as a convenient tool for inlining policy code into the untrusted application
- LoPSiL inherits AspectJ's limitation that it can only inline code into application files (and not standard Java libraries)
  - So, LoPSiL monitors can't make decisions about the execution of security-relevant methods invoked by (non-application) library classes

Compiler Architecture



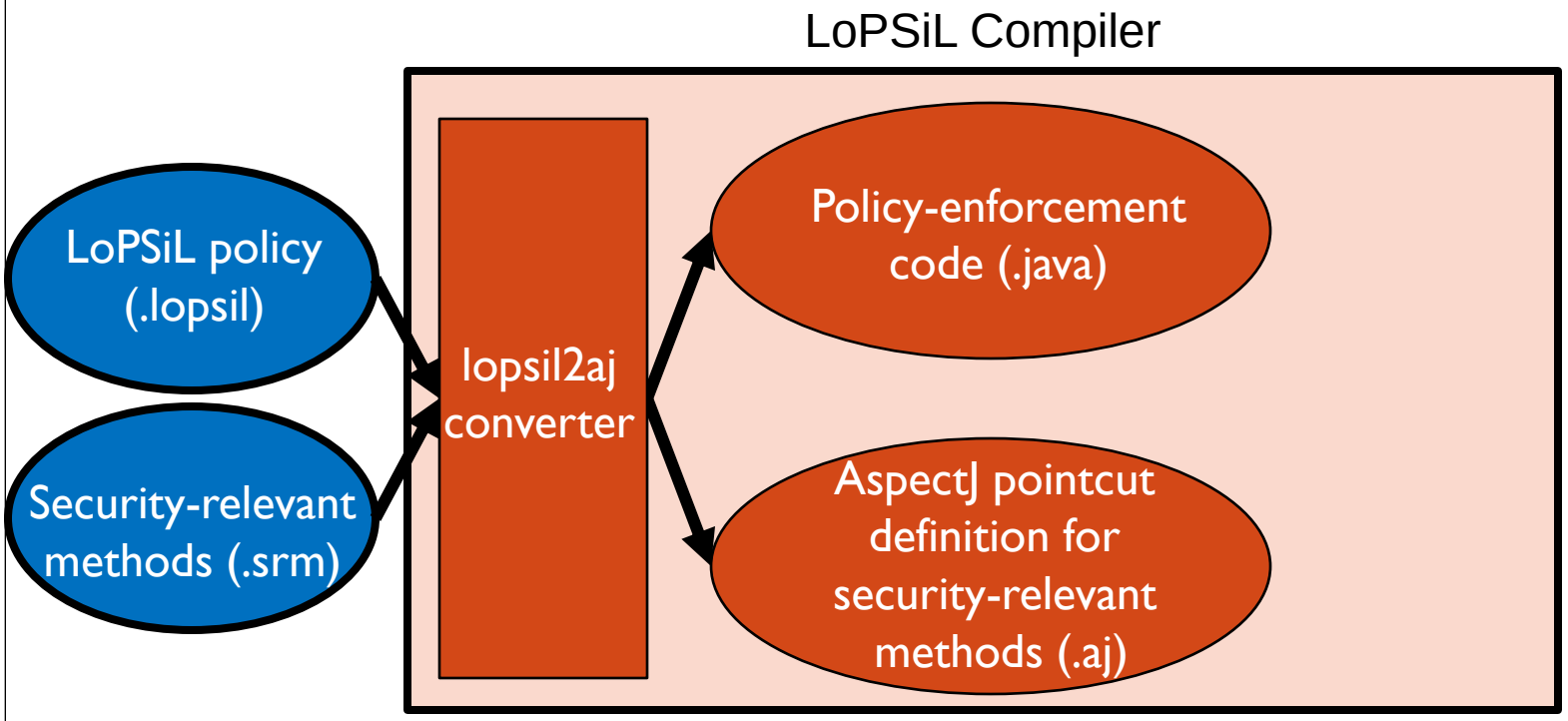
- User specifies desired policy in a `.lopsil` file
- User creates a listing of security-relevant methods in `.srm` file

Compiler Architecture



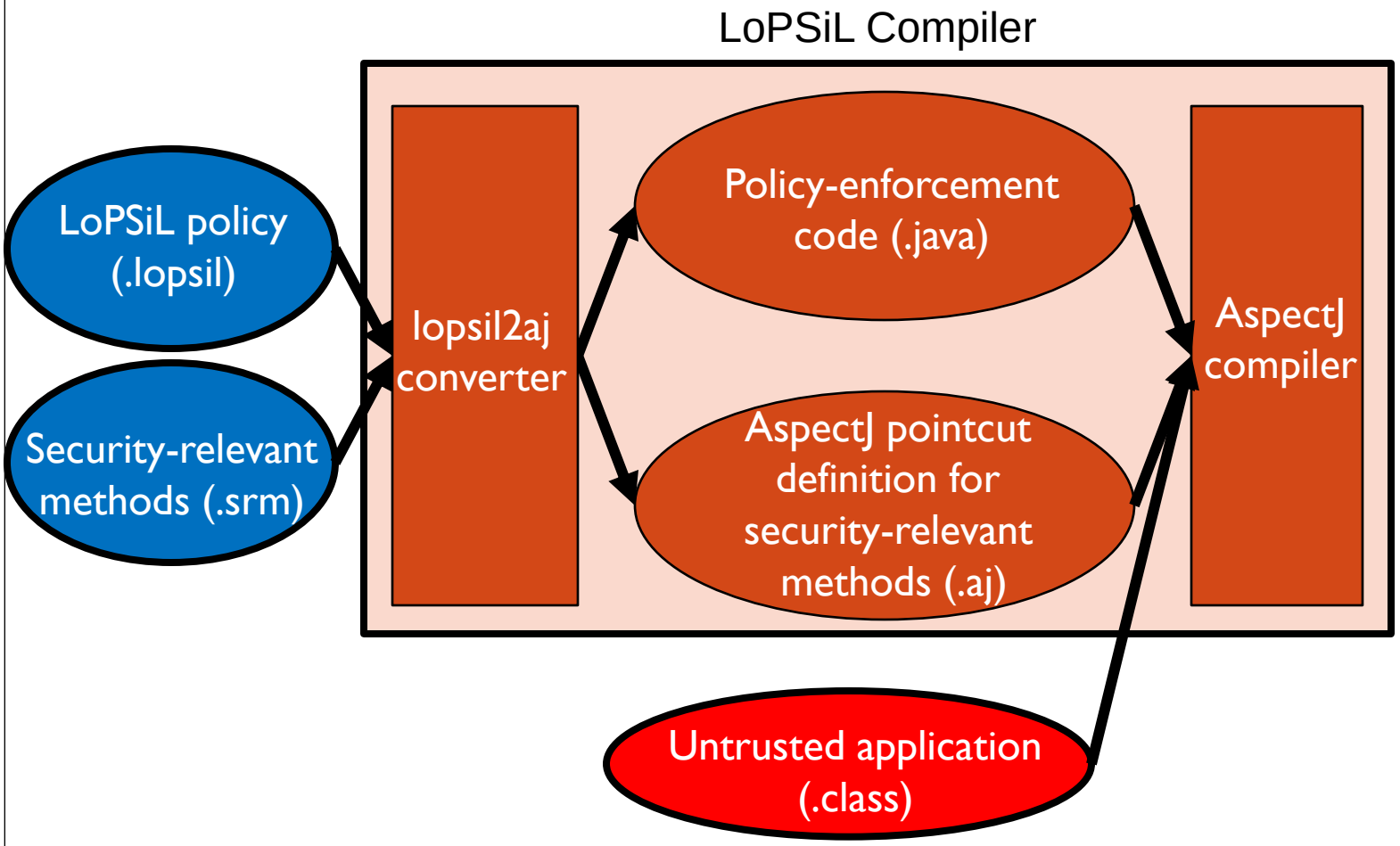
- User inputs the `.lopsil` and the `.srm` file into a `lopsil2aj` converter, because it converts LoPSiL files into files that can be input into an AspectJ compiler

Compiler Architecture



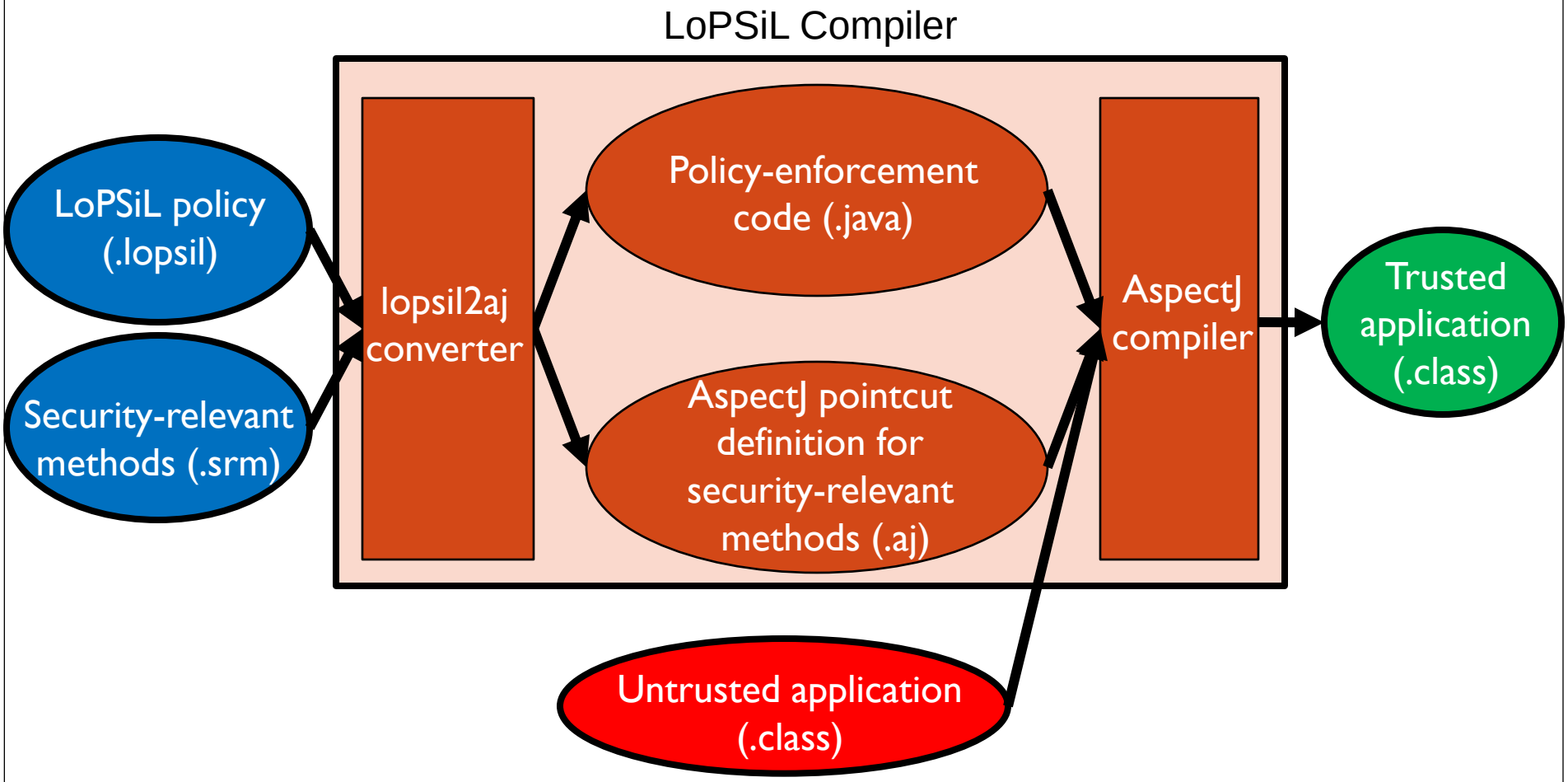
- The compiler converts the **`.lopsil`** file to Java version (**`.java`**) of the policy by inserting three lines of code to import LoPSiL-library classes
- The compiler converts the **`.srm`** file to an AspectJ-code file (**`.aj`**) that has definitions indicating
  1. which policy code is to be executed and
  2. when should that policy code be executed

Compiler Architecture



- The compiler inputs the `.java` file, the `.aj` file, and the untrusted application (`.class`) into a standard AspectJ compiler

Compiler Architecture



- AspectJ compiler inlines policy code before and after all security-relevant methods and produces an application that is secure w.r.t. the original LoPSiL policy

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Experiential Observations

- Our location-dependent policies consistently based policy decisions on:
  - Absolute location of the device
  - Geographic relationship of device's location with another location, or with a region of locations
  - Velocity or acceleration of the device
- Therefore, LoPSiL provides several utility methods for calculating distances, boundaries, velocities, and acceleration
- Users can access all these methods and can implement other custom operators when built-in methods are insufficient

Experiential Observations

- We found that LoPSiL was sufficiently expressive to specify all the location-dependent policies we considered enforcing
- None of the example policies mentioned earlier took much time (more than a few hours) to design, specify, and test
- Therefore, we believe that the six core constructs underlying LoPSiL serve as good abstractions for specifying location-dependent policies

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Conclusions

- LoPSiL is a language for specifying location-dependent runtime security policies
- LoPSiL's novelty lies in its expressive abstractions for accessing and manipulating location information in policies
- Given the increasing ubiquity of mobile devices, we believe the area of location-based policy-specification languages will be an important topic of research
  - Will need involvement/collaboration of researchers in the security, programming languages, and mobile-device-applications communities

Thanks/Questions?

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