The Power of Interoperability: Why Objects Are Inevitable

Onward! Essay, 2013

http://www.cs.cmu.edu/~aldrich/papers/objects-essay.pdf

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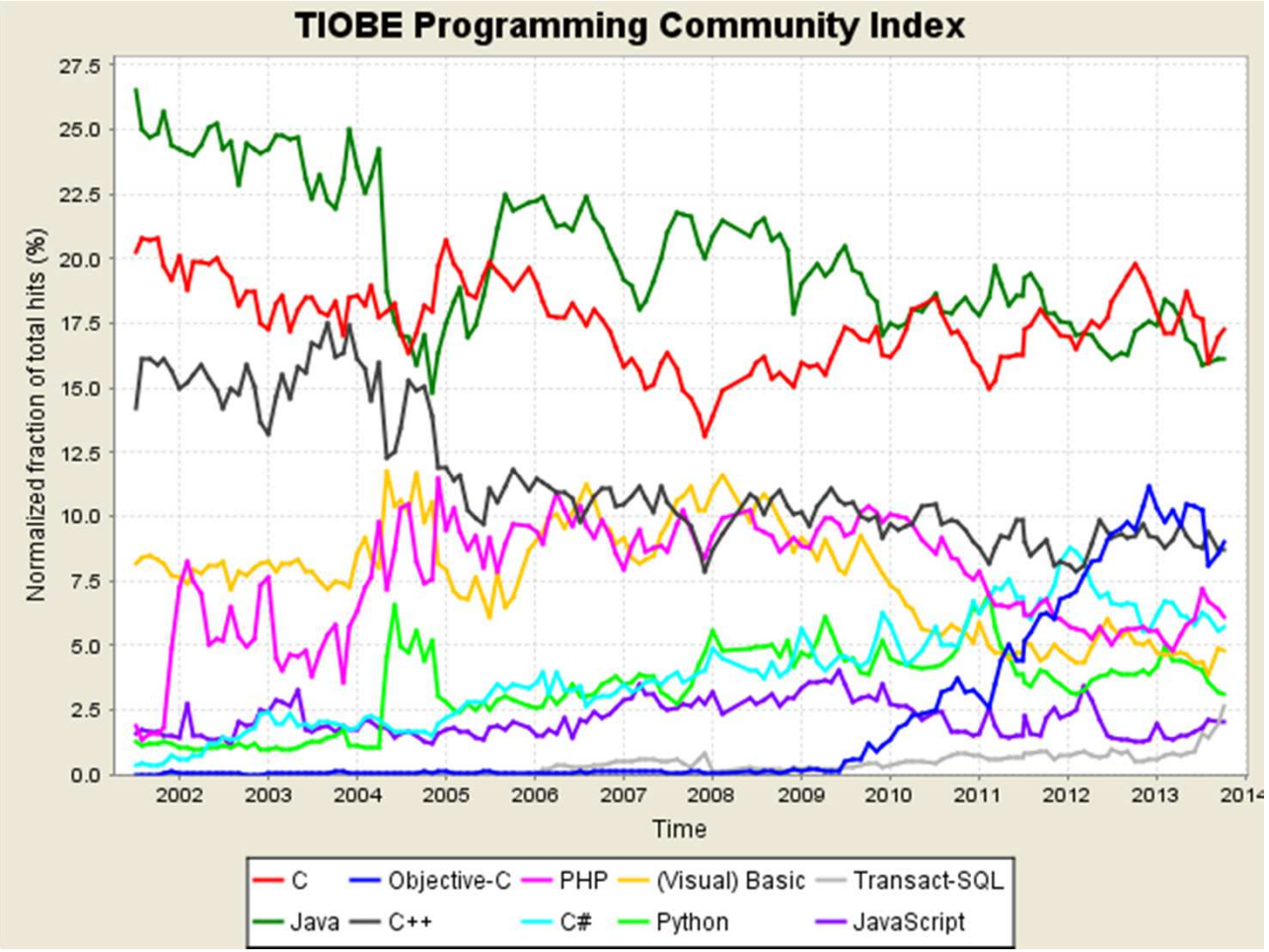
Object-Oriented Programming is Widespread



6-8 of top 10 PLs are OO – TIOBE

Object-Oriented Programming is Influential

- Major conferences: OOPSLA, ECOOP
- Turing awards for Dahl and Nygaard, and Kay
- Other measures of popularity
  - Langpop.com: 6-8 of most popular languages
  - SourceForge: Java, C++ most popular
  - GitHub: JavaScript, Ruby most popular
  - Significant use of OO design even in procedural languages
    - Examples: GTK+, Linux kernel, etc.

- Why this success?

OOP Has Been Criticized

"I find OOP **technically unsound… philosophically unsound… [and] methodologically wrong.**"

- Alexander Stepanov, developer of the C++ STL

Why has OOP been successful?

Why has OOP been successful?

"…it was hyped [and] it created a new software industry."

- Joe Armstrong, designer of Erlang

Marketing/adoption played a role in the ascent of OOP.

But were there also genuine advantages of OOP?

Why has OOP been successful?

"the object-oriented paradigm...is consistent with the natural way of human thinking"

- [Schwill, 1994]

OOP may have psychological benefits.

But is there a technical characteristic of OOP that is critical for modern software?

What kind of technical characteristic?

Talk Outline

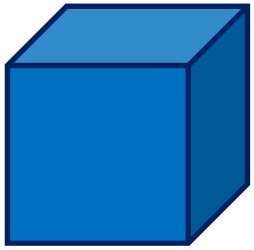
1. A technical characteristic **unique** to objects
   - Addressed in Cook's 2009 Onward! Essay

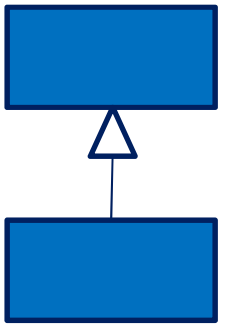
2. That has a **big impact**
   - Our focus: why that characteristic matters
   - I.e. how it affects **in-the-large software development**

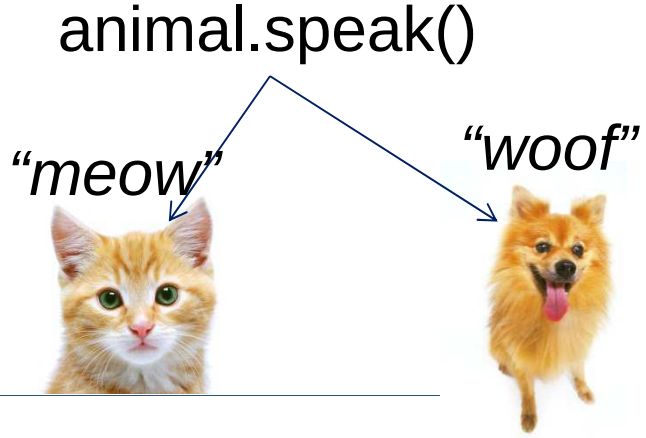
What Makes OOP Unique?

Candidates: key features of OOP

- Encapsulation?
  - Abstract data types (ADTs) also provide encapsulation
- Inheritance?
  - Neither universal nor unique in OOPLs
  - Worth studying, but not our focus
- Polymorphism/Dynamic dispatch?
  - Every OOPL has dynamic dispatch
  - Distinguishes objects from ADTs







Dynamic Dispatch as Central to OOP

Significant grounding in the OO literature

- Cook's 2009 Onward! essay
  - Object: "value exporting a procedural interface to data or behavior"
  - Objects are self-knowing (*autognostic*), carrying their own behavior
  - Equivalent to Reynolds' [1975] *procedural data structures*
- Historical language designs
  - "the big idea [of Smalltalk] is messaging" [Kay, 1998 email]
- Design guidance
  - "favor object composition over class inheritance" [Gamma *et al.* '94]
  - "black-box relationships *[based on dispatch, not inheritance]* are an ideal towards which a system should evolve" [Johnson & Foote, 1988]

Objects vs. ADTs

Two Object-Oriented Sets

```
interface IntSet {
    bool contains(int element)
    bool isSubsetOf(IntSet otherSet)
}
```

Interface is a set of **messages**

All communication is message-based; isSubsetOf() implemented by calling contains() on otherSet

```
class IntSet1 implements IntSet {…}
class IntSet2 implements IntSet {…}

// in main()
IntSet s1 = new IntSet1(...);
IntSet s2 = new IntSet2(...);
bool x = s1.isSubsetOf(s2);
```

{1} ⊆ {1,2} = true

{1} ⊆ {1,2} = true

{1} ⊆ {1,2} = true

Set Objects

Different implementations interoperate freely

Objects vs. **ADTs**

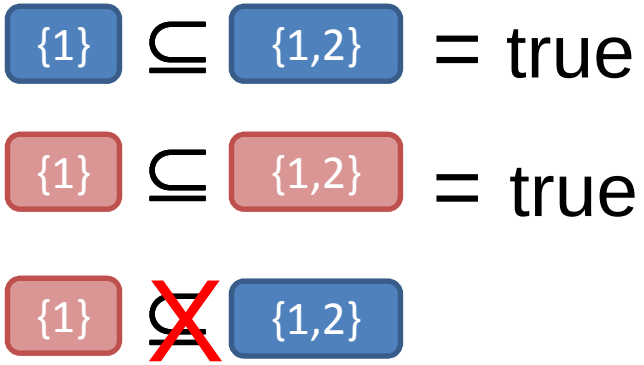
Two Set ADTs

```
final class IntSetA {
    bool contains(int element) { ... }
    bool isSubsetOf(IntSetA other) { ... }
}
final class IntSetB {
    bool contains(int element) { ... }
    bool isSubsetOf(IntSetB other) { ... }
}

// in main()
IntSet sA = new IntSetA(...);
IntSet sB = new IntSetB(...);
bool x = sA.isSubsetOf(sB); // ERROR!
```

Interface is a set of **operations** over a **fixed** but hidden type (IntSetA)

isSubsetOf() is a binary method that only works with other instances of IntSetA. Good for performance.



Set ADTs

Different ADT implementations cannot interoperate

Does Interoperability Matter?

- For data structures such as Set, maybe not
  - Maybe optimization benefits of ADTs dominate interoperability

  "Although a program development support system must store many implementations of a type..., allowing multiple implementations within a single program seems less important."

  - A History of CLU [Liskov, 1993]

- But are data structures what OOP is really about?

Are Objects "Procedural Data Structures?"

An object is "...a value exporting a procedural interface to data ***or behavior***." [Cook, 2009]

"a program execution is regarded as a physical model, ***simulating the behavior*** of either a real or imaginary part of the world"

[Madsen, Møller-Pedersen, Nygaard (and implicitly Dahl), 1993]

"The ***last thing*** you wanted any programmer to do is ***mess with internal state*** even if presented figuratively. Instead, the objects should be presented as sites of ***higher level behaviors*** more appropriate for use as dynamic components." [Kay, 1993]

Service Abstraction

- Objects can implement data structures
  - Useful, but not their **primary purpose**
  - Not a **unique** benefit of objects

- Kay [1993] writes of the "objects as server metaphor" in which every "object would be a server offering services" that are accessed via messages to the object.

- A better term is ***service abstraction***
  - Definition: a value exporting a procedural interface **to behavior**
  - Identical to procedural data abstraction, but focused on behavior
  - Captures the characteristic of objects in which we are interested

Service Abstraction provides Interoperability

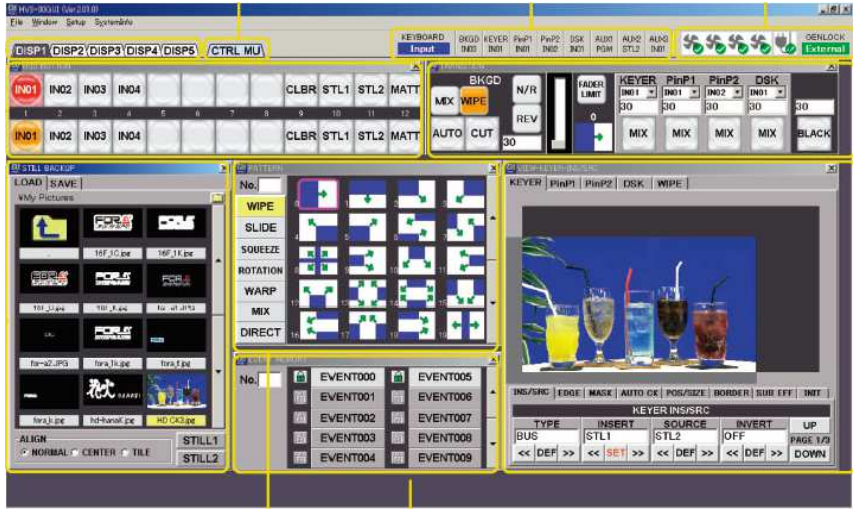
- Let's assume service abstraction is the core of OO

- What are the benefits of service abstraction?
  - Reynolds/Cook: procedural data abstraction provides ***interoperability***
  - But so do functions, type classes, generic programming, etc.

- **What makes service abstraction unique?**

Interoperability of Widgets

- Consider a Widget-based GUI
  - Concept notably developed in Smalltalk



Source: http://www.for-a.com/products/hvs300hs/hvs300hs.html

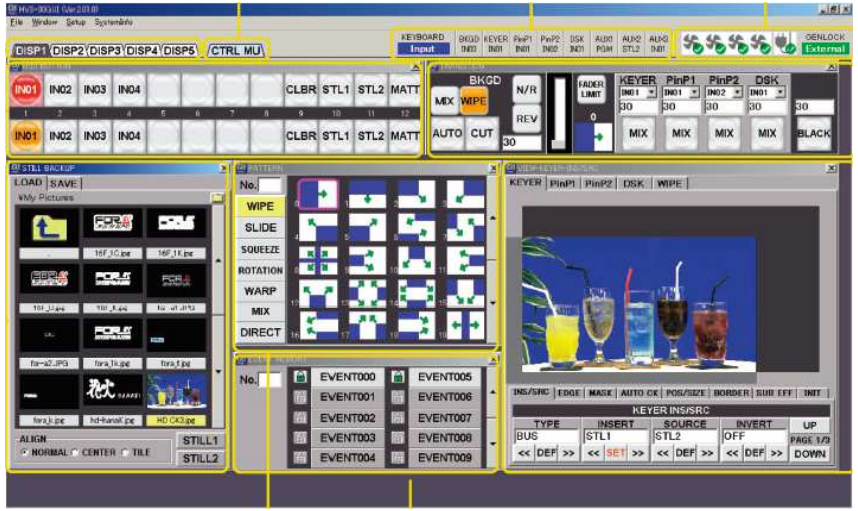
```
interface Widget {
    Dimension getSize();
    Dimension getPreferredSize();
    void setSize(Dimension size);
    void paint(Display display);

    … /* more here */ }          // based on ConstrainedVisual from Apache Pivot UI framework
```

- Nontrivial abstraction – not just paint()
  - A single first-class function is not enough

Interoperability of Composite Widgets

- Consider a **Composite GUI**
  - Concept notably developed in Smalltalk



Source: http://www.for-a.com/products/hvs300hs/hvs300hs.html

```
class CompositeWidget implements Widget {
    Dimension getSize();
    Dimension getPreferredSize();
    void setSize(Dimension size);
    void paint(Display display);
    void add(Widget widget)
    … /* more here */ }          // based on Container from Apache Pivot UI framework
```

- Nontrivial abstraction – not just paint()
  - A single first-class function is not enough
- Composite needs to store diverse subcomponents in a list
  - Can't do this with type classes, generic programming
- Composite needs to invoke paint() uniformly on all subcomponents
  - Also breaks type classes, generic programming

Design Leverage of Service Abstractions

*The ability to define **nontrivial abstractions** that are **modularly extensible**, where instances of those extensions can **interoperate in a first-class way**.*

- **Nontrivial abstractions**
  - An interface that provides at least two essential services
- **Modular extensibility**
  - New implementations not anticipated when the abstraction was designed can be provided without changing the original abstraction
- **First-class Interoperability**
  - Interoperability of **binary methods**
    - Such as adding a subcomponent to a composite

  - **First-class manipulation** of different implementations
    - Such as putting subcomponents in a list
  - **Uniform treatment** of different implementations
    - Such as invoking paint() on all subcomponents

Talk Outline

1. A technical characteristic **unique** to objects
   - Objects, for our purposes, are **service abstractions** that provide **dispatch**
   - Service abstractions uniquely provide **first-class interoperability**

2. That has a big **impact**
   - Well, first-class interoperability is nice for GUIs
   - Does this affect **in-the-large software development** more broadly?

Large-Scale Development Impact

- How might service abstractions impact in-the-large software development?

- Some hints
  - We are likely looking for an approach to **design**
  - We already know service abstractions are useful for **GUIs**
  - Anecdotally, one can argue that GUIs drove OO
    - Smalltalk, MacApp, Microsoft Foundation Classes, Java Applets, …
  - What are these GUI designs an instance of?

- A likely candidate: **software frameworks** [Johnson, 1997]

Software Frameworks

- A framework is "the skeleton of an application that can be customized by an application developer" [Johnson, 1997]

- Frameworks uniquely provide **architectural reuse**
  - Reuse of "the edifice that ties components together" [Johnson and Foote, 1988]
  - Johnson [1997] argues can reduce development effort by 10x

- As a result, frameworks are ubiquitous
  - GUIs: Swing, SWT, .NET, GTK+
  - Web: Rails, Django, .NET, Servlets, EJB
  - Mobile: Android, Cocoa
  - Big data: MapReduce, Hadoop

Frameworks need Service Abstraction

- Frameworks define **abstractions** that extensions implement
  - The developer "supplies [the framework] with a set of components that provide the application specific behavior" [Johnson and Foote, 1988]
  - Sometimes the application-specific behavior is just a function
  - More often, as we will see, these abstractions are **nontrivial**
- Frameworks require **modular extensibility**
  - Applications extend the framework without modifying its code
    - Frameworks are typically distributed as binaries or bytecode
    - *cf.* Meyer's [1988] open-closed principle
  - Framework developers cannot anticipate the details of extensions
    - Though they do plan for certain kinds of extensions
- Frameworks require **first-class interoperability**
  - Plugins often must **interoperate** with each other
  - Frameworks must **dynamically** and **uniformly** manage diverse plugins
  - We have already seen this for GUI widgets – let's look at other examples

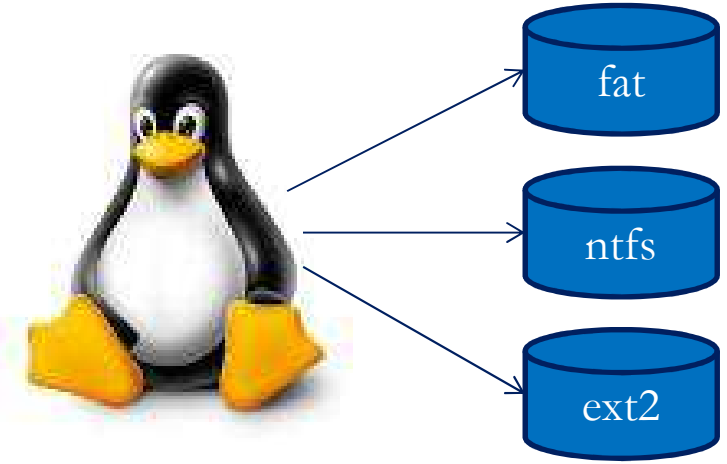
Web Frameworks: Java Servlets

```
interface Servlet {
  void service(Request req, Response res);
  void init(ServletConfig config);
  void destroy();
  String getServletInfo();
  ServletConfig getServletConfig();
}
```

- Nontrivial abstraction
  - Lifecycle methods for resource management
  - Configuration controls
- Modular extensibility
  - Intent is to add new Servlets
- First-class interoperability required
  - Web server has a list of diverse Servlet implementations
  - Dispatch is required to allow different Servlets to provide their own behavior

Operating Systems: Linux

- Linux is an OO framework!
  - In terms of design—not implemented in an OO language
- File systems as service abstractions
  - Interface is a struct of function pointers
  - Allows file systems to interoperate
    - E.g. symbolic links between file systems
- Not just file systems
  - Many core OS abstractions are extensible
  - ~100 Service abstractions in the kernel



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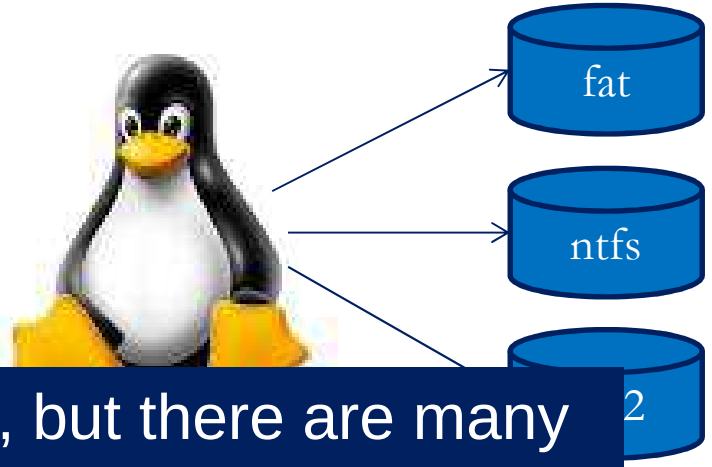


People often miss this, or even deny it, but there are many examples of object-oriented programming in the kernel. Although the kernel devel-opers may shun C++ and other explicitly object-oriented languages, thinking in terms of objects is often useful. The VFS [Virtual File System] is a good example of how to do clean and efficient OOP in C, which is a language that lacks any OOP constructs.

- Robert Love, *Linux Kernel Development (2nd Edition)*

Objection: If I want objects, I can build them!

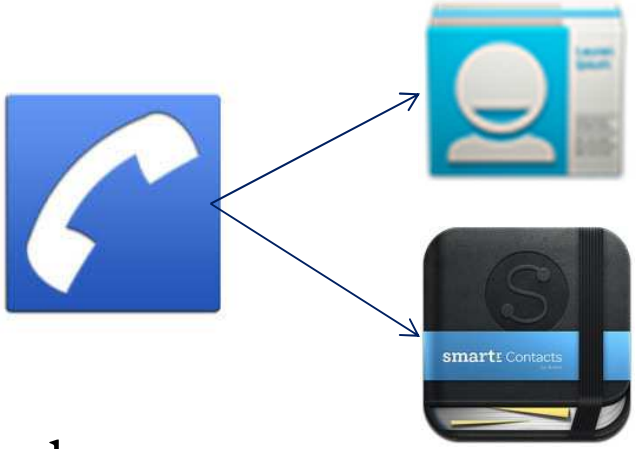
- Works nicely in a dynamically-typed setting with macros
  - Exhibit A: PLT Scheme / Racket
- Works poorly in a statically typed language
  - Certainly possible [Kiselyov and Lämmel, 2005]
  - Painful in C, Standard ML, Haskell, etc.
    - No built-in type gives you exactly what you want
    - Annoying object packing/unpacking is necessary
    - Feels like an encoding, rather than a natural expression of ideas
  - Typed Racket works because of special OO types
- Programmers do it when really necessary
  - *cf.* GTK+ GUI framework, Microsoft COM, Linux drivers, etc.
  - My take: people only do this if OO languages are excluded *a priori*

Software Ecosystems

- A ***software ecosystem*** is a "set of software solutions that enable, support, and automate the activities...[of] actors in the associated social or business ecosystem" [Bosch, 2009]
  - Examples: iOS, Android, Windows, Microsoft Office, Eclipse, Amazon Marketplace, …
- Ecosystems have enormous **economic impact**
  - Driven by network effects [Katz and Shapiro, 1985]
  - Top 5 tech firms control or dominate an ecosystem
    - Apple, Microsft, IBM, Samsung, Google
- Ecosystems require **first-class interoperability**
  - Critical to achieving benefit from network effects
  - "the architecture provides a formalization of the rules of interoperability and hence teams can, to a large extent, operate independently" [Bosch, 2009]

Mobile Devices: Android

```
class ContentProvider {
   abstract Cursor query(Uri uri, ...);
   abstract int insert(Uri uri, ContentValues vals);
   abstract Uri update(Uri uri, ContentValues vals, ...);
   abstract int delete(Uri uri, ...);
   ... // other methods not shown
}
```



- Network effects (apps) give Android value
- Apps build on each other
  - Example: contact managers
    - Smartr Contacts is a drop-in replacement for the default contact manager
    - Phone, email apps can use Smartr Contacts *without preplanning*
  - Enabled by service abstraction interfaces
    - Android keeps a list of heterogeneous ContentProvider implementations

Conclusions

- The essence of objects is **dispatch**, or **service abstraction**
- Dispatch uniquely provides **first-class interoperability**
- First-class interoperability is critical to **frameworks** and **ecosystems**
- Frameworks and ecosystems are **economically critical** to the software industry

Hypotheses

- Adding first-class modules to languages without objects will promote framework-like designs

- Fully parametric module systems will be more practical with OO types than with ADT types

Future Work

- Empirical validation for the benefits of interoperability
- Exploration of other possible benefits of OO
  - Psychology
  - Inheritance

Conclusions

- The essence of objects is **dispatch**, or **service abstraction**
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- Frameworks and ecosystems are economically critical to the software industry