

Typecasting Actors: from Akka to T Akka

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ABSTRACT

Scala supports actors and message passing with the Akka library. Though Scala is statically typed, messages in Akka are dynamically typed (that is, of type `Any`). The Akka designers argue that using static types is “impossible” because “actor behaviour is dynamic”, and, indeed, it is not clear that important actor support, such as supervision or name servers, can be implemented if messages are statically typed. Here we present T Akka, a variant of Akka where messages are statically typed, and show that it is possible to implement supervisors and name servers in such a framework. We show it is possible to smoothly migrate from Akka to T Akka, porting one module at a time. We show that T Akka can support behavioural upgrades where the new message type of an actor is a supertype of the old type. We demonstrate the expressiveness of T Akka by rewriting approximately 20 Akka applications; the percentage of lines that need to be changed varies from 44% (in a 25-line program) to 0.05% (in a 27,000-line program), with a geometric mean of 8.5%. We show that the execution speed, scalability, and throughput of T Akka programs are comparable to those of Akka programs.

Categories and Subject Descriptors

D.1.3 [PROGRAMMING TECHNIQUES]: Concurrent Programming; D.2.2 [Design Tools and Techniques]: Software libraries

General Terms

Languages Design Performance Reliability

Keywords

Actor Programming, Type Checking, Fault Tolerance

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1. INTRODUCTION

Can the benefits of static typing extend to message passing?

A distinguishing feature of Scala is its sophisticated static type system. A distinguishing feature of modern computing is its reliance on communication. Scala supports communication with the Akka library [21], partly inspired by Erlang [1], which in turn is inspired by actors and message passing [11]. However, these two features do not play well together—messages in Akka are dynamically typed (that is, of type `Any`).

There are sound reasons for this design. The Akka designers argue that using static types is “impossible” because “actor behaviour is dynamic” [13, 14]. The design of Akka is inspired by the Erlang OTP Design Principles, including supervision trees to ensure reliability, and Erlang is dynamically typed. Since supervision is generic—a supervision framework is instantiated to processes transmitting many types of messages—it is not immediately clear whether static typing is sensible. All supervised actors need to accept a fixed set of system messages, such as Poison Pill (to kill a supervised actor), and it is not clear how to incorporate these into statically typed messages. An important part of distributed infrastructure is a name server, which maps names to actors, and while it is easy to build a map from names to entities of dynamic type, it is again not clear how to build a map to entities with different static types.

This paper introduces T Akka, a variant of Akka with statically typed messages. It turns out that each of the issues above can be resolved straightforwardly. Each actor is parameterised by the type of messages it handles. In addition, each actor can also receive system messages, such as Poison Pill, which are handled by the supervision framework. The name server uses Scala “manifest” types to support a name server that maps names to actors with different static types.

It is essential that a large program can be upgraded incrementally, one module at a time, rather than requiring a monolithic change to all modules simultaneously—a principle we summarise by the motto “Evolution, not Revolution”. T Akka is designed to support incremental change, and, in particular, a service written in Akka can interact with a client written in T Akka, and vice versa. Backward compatibility is supported, because T Akka actors inherit from Akka actors.

In a system with multiple components, different components may require different interfaces; since all messages are received in the same mailbox, a naive approach would be to set the type to the union of all the interfaces, causing each component to see a type containing messages not intended for it to use—an issue we dub the Type Pollution Problem. Fortunately, the problem may be avoided by exploiting sub-

typing to publish a different interface to each layer.

To evaluate the expressiveness of our system, we rewrite approximately 20 Akka applications in TAKka. The percentage of lines that need to be changed varies from 44% (in a 25-line program) to 0.05% (in a 27,000-line program), with a geometric mean of 8.5%.

We confirm that Akka and TAKka have comparable performance in terms of throughput, runtime, and scalability. We compare the throughput of Play and Socko implementations written in both systems, and show the throughput of Akka and TAKka is on average within 8.75% of each other. We compare the runtime and scalability of six BenchErl benchmarks, and show that the runtimes of Akka and TAKka are on average within 8.89% of each other, and that they have similar scalability profiles.

The paper makes the following contributions.

- We contrast Akka and TAKka, illustrating the differences with a simple application, a supervised calculator (Section 2).
- We review the Akka API, and present the corresponding TAKka API (Section 3).
- We describe the construction of a name server that maps names to actors of different static types (Section 4).
- We demonstrate that TAKka supports the principle of “Evolution, not Revolution”, by showing how Akka and TAKka code for the supervised calculator can interact (Section 5).
- We illustrate the Type Pollution Problem and its solution on an instance of the Model-View-Controller pattern (Section 6).
- We rewrite a score of Akka programs in TAKka, and measure the differences in line count (Section 7).
- We compare the throughput of Play and Socko implementations written in both Akka and TAKka, and we compare the runtime and performance of a half-dozen BenchErl benchmarks written in both Akka and TAKka (Section 8).

Section 9 concludes.

2. ACTORS AND THEIR SUPERVISION

The Akka library [21] implements actor programming and makes supervision obligatory. As an introduction to Akka, Figure 1 defines a calculator. Each Actor defines a receive method that reacts to incoming messages. Each ActorRef references an actor, and may be sent messages with the `!` operator. Our example program defines `Multiplication` and `Division` messages (lines 5–6), a `Calculator` actor which receives them (lines 8–15), and instantiates a `SafeCalculator` actor reference which is sent such messages (lines 29–35). (The relation between `Calculator` and `SafeCalculator` is explained below.)

Akka makes supervision obligatory by restricting the manner of actor creation. Calling the `actorOf` method of an actor context creates a child actor supervised by that actor, forming a tree structure (lines 23–24). There is a system-provided guardian actor which serves as the root of the supervision tree (lines 29–31). (Strictly speaking, `actorOf` is invoked on an `ActorContext` or `ActorSystem`, and it is supplied with an instance of the `Props` class to specify properties of the actor

to be created; details are given in Section 3.3.) Obligatory supervision unifies the structure of actor deployment and simplifies the work of system maintenance.

The simple calculator does not consider the problematic case of dividing by 0, where an `ArithmeticException` will be raised. We define a `SafeCalculator` as the supervisor of `Calculator`. The `receive` method of the safe calculator delegates any messages received to the calculator (line 25), and defines a supervisor strategy that restarts the calculator when an `ArithmeticException` is raised (lines 17–22).

In Akka 2.0 and later versions, an undefined message (line 40) is discarded and an `UnhandledMessage` event is pushed to the event stream of the actor system. The event stream may be subscribed to by other actors who are interested in particular event messages. Our example program defines a handler (lines 44–49) and subscribes to the `UnhandledMessage` events (lines 37–39).

Figure 2 gives an equivalent TAKka implementation. Code that appears in the Akka version but not the TAKka version, or vice versa, is coloured blue. The TAKka Actor class takes a type parameter, `M`, which indicates the type of expected messages. Correspondingly, its message handler, `typedReceive`, has type `M => Unit`. Similarly, a type parameter is added to the `Props` class and the `ActorRef` class. An actor created from an instance of `Props[M]` has `Actor[M]`, whose corresponding actor reference has type `ActorRef[M]`. Messages sent to an actor reference of type `ActorRef[M]` must have type `M`.

Hence, developers only need to consider messages of the expected type. An attempt to send a message of a type not expected by the receiver is rejected at compile-time (line 36). TAKka uses a typed name server, as explained in Section 4. When looking up an actor by name, the expected type is provided, and if it does not match the type of the stored actor reference then an error is raised at run-time (lines 46–47). In the TAKka version, there is no need to define a handler for unexpected messages.

3. LIBRARY DESIGN

This section elaborates the design of the TAKka library, which provides type parameters for the Actor related classes found in Akka. Figure 3 gives the Akka API, and Figure 4 gives it TAKka counterpart. Implementation of the two APIs are omitted in this paper.

3.1 Actor

A TAKka actor has type `Actor[M]`. Unlike other actor libraries, every TAKka actor class takes a type parameter `M` which specifies the type of messages it expects to receive. The same type parameter is used as the input type of the receive function, the type parameter of the actor context and the type parameter of the actor reference pointing to itself. TAKka uses `Scala Manifest` to record type information required at runtime. In Figure 4, each of the three actor-related classes — `ActorRef`, `Actor`, and `ActorContext` — takes a manifest as its immutable field to record the value of its type parameter. The manifest is defined as an implicit parameter as Scala can infer its value. The `ActorRef` class defines manifest explicitly because its type parameter requires a contravariance annotation. The `Actor` class and the `ActorContext` class define manifest implicitly using `Scala context bounds`.

Notice that the `typedReceive` method in the TAKka Actor class has a function type rather than a partial function as in Akka. Using a function type has the advantage of exhaus-

```

1 package sample.akka.SafeCalculator
2 import akka.actor.{ActorRef, ActorSystem, Props, Actor}
3 import akka.actor.UnhandledMessage
4
5 case class Multiplication(m:Int, n:Int)
6 case class Division(m:Int, n:Int)
7
8 class Calculator extends Actor {
9   def receive = {
10     case Multiplication(m:Int, n:Int) =>
11       println(m + " * " + n + " = " + (m*n))
12     case Division(m:Int, n:Int) =>
13       println(m + " / " + n + " = " + (m/n))
14   }
15 }
16 class SafeCalculator extends Actor {
17   override val supervisorStrategy =
18     OneForOneStrategy() {
19       case _: ArithmeticException =>
20         println("ArithmeticException Raised to: "+self)
21         Restart
22     }
23   val child:ActorRef = context.actorOf(
24     Props[Calculator], "child")
25   def receive = { case m => child ! m }
26 }
27 object SafeCalculatorTest extends App {
28   val system = ActorSystem("MySystem")
29   val calculator:ActorRef =
30     system.actorOf(Props[SafeCalculator],
31       "calculator")
32
33   calculator ! Multiplication(3, 1)
34   calculator ! Division(10, 0)
35   calculator ! Division(10, 5)
36
37   val handler = system.actorOf(Props[MessageHandler])
38   system.eventStream.subscribe(handler,
39     classOf[UnhandledMessage]);
40   calculator ! "Hello"
41 }
42
43 class MessageHandler extends Actor{
44   def receive = {
45     case UnhandledMessage(message, sender, recipient) =>
46       println("unhandled message: "+message);
47   }
48 }
49
50 /* Terminal Output:
51 3 * 1 = 3
52 java.lang.ArithmeticException: / by zero
53 ArithmeticException Raised to:
54   Actor[akka://MySystem/user/calculator]
55 10 / 5 = 2
56 unhandled message: Hello
57 */

```

Figure 1: Akka Example: Supervised Calculator

```

1 package sample.takka.SafeCalculator
2 import takka.actor.{ActorRef, ActorSystem, Props, Actor}
3
4 sealed trait Operation
5 case class Multiplication(m:Int, n:Int) extends Operation
6 case class Division(m:Int, n:Int) extends Operation
7
8 class Calculator extends Actor[Operation]{
9   def typedReceive = {
10     case Multiplication(m:Int, n:Int) =>
11       println(m + " * " + n + " = " + (m*n))
12     case Division(m, n) =>
13       println(m + " / " + n + " = " + (m/n))
14   }
15 }
16 class SafeCalculator extends Actor[Operation] {
17   override val supervisorStrategy =
18     OneForOneStrategy() {
19       case _: ArithmeticException =>
20         println("ArithmeticException Raised to: "+typedSelf)
21         Restart
22     }
23   val child:ActorRef[Operation] = typedContext.actorOf(
24     Props[Operation, Calculator], "child")
25   def typedReceive = { case m => child ! m }
26 }
27 object SafeCalculatorTest extends App{
28   val system = ActorSystem("MySystem")
29   val calculator:ActorRef[Operation] =
30     system.actorOf(Props[Operation, SafeCalculator],
31       "calculator")
32
33   calculator ! Multiplication(3, 1)
34   calculator ! Division(10, 0)
35   calculator ! Division(10, 5)
36   // calculator ! "Hello"
37   // compile error: type mismatch; found :
38   //   String("Hello") required:
39   //   sample.takka.SupervisedCalculator.Operation
40
41   System.out.println("Name server test")
42   val calMul = system.actorFor[Multiplication]
43     ("akka://MySystem/user/calculator")
44   calMul ! Multiplication(3, 2)
45   Thread.sleep(1000)
46   val calStr = system.actorFor[String]
47     ("akka://MySystem/user/calculator")
48   // Exception raised before this line is reached
49   calStr ! "Hello"
50 }
51 /* Terminal Output:
52 3 * 1 = 3
53 java.lang.ArithmeticException: / by zero
54 ArithmeticException Raised to:
55   Actor[akka://MySystem/user/calculator]
56 10 / 5 = 2
57 Name server test
58 3 * 2 = 6
59 Exception in thread "main" java.lang.Exception:
60   ActorRef[akka://MySystem/user/calculator] does not
61   exist or does not have type ActorRef[String]
62 */

```

Figure 2: TAkka Example: Supervised Calculator

```

1 package akka.actor

2 abstract class ActorRef
3   def !(message: Any): Unit

4 trait Actor
5   def receive: PartialFunction[Any, Unit]
6   val self: ActorRef
7   private val context: ActorContext
8   var supervisorStrategy: SupervisorStrategy

9 trait ActorContext
10  def actorOf(props: Props): ActorRef
11  def actorOf(props: Props, name: String): ActorRef
12  def actorFor(path: String): ActorRef
13  def setReceiveTimeout(timeout: Duration): Unit
14  def become(behavior: PartialFunction[Any, Unit],
15             discardOld: Boolean = true): Unit
16  def unbecome(): Unit

17 final case class Props(deploy: Deploy,
18                       clazz: Class[_],
19                       args: immutable.Seq[Any])

20 object Props extends Serializable
21   def apply(creator: => Actor): Props
22   def apply(actorClass: Class[_ <: Actor]): Props
23   def apply[T <: Actor]()
24     (implicit arg0: Manifest[T]): Props

25 abstract class SupervisorStrategy
26 case class OneForOneStrategy(restart: Int = -1,
27                             time: Duration = Duration.Inf)
28   (decider: Throwable => Directive)
29   extends SupervisorStrategy
30 case class OneForAllStrategy(restart: Int = -1,
31                             time: Duration = Duration.Inf)
32   (decider: Throwable => Directive)
33   extends SupervisorStrategy

```

Figure 3: Akka API

tiveness checks on its input if its input type is a sealed-trait ADT. Section 7 will report examples we ported from Akka for expressiveness checks. For all examples considered, there is no problem when replacing a partial function with a total function. We believe that exhaustiveness checks are helpful in practice.

The TAKka Actor class inherits the Akka Actor trait to minimize implementation effort. Users of the TAKka library, however, do not need to use any Akka Actor API. Instead, we encourage programmers to use the typed interface given in Figure 4. The limitation of using inheritance to implement TAKka actors is that Akka features are still available to library users. Unfortunately, this limitation cannot be overcome by using delegation because, as we have seen in the SupervisedCalculator example, a child actor is created by calling the actorOf method from its supervisor’s actor

```

1 package takka.actor

2 abstract class ActorRef[-M](implicit mt: Manifest[M])
3   def !(message: M): Unit
4   def publishAs[SubM <: M]
5     (implicit smt: Manifest[SubM]): ActorRef[SubM]

6 abstract class Actor[M: Manifest] extends akka.actor.Actor
7   def typedReceive: M => Unit
8   val typedSelf: ActorRef[M]
9   private val typedContext: ActorContext[M]
10  var supervisorStrategy: SupervisorStrategy

11 abstract class ActorContext[M: Manifest]
12  def actorOf [Msg] (props: Props[Msg])
13    (implicit mt: Manifest[Msg]): ActorRef[Msg]
14  def actorOf [Msg] (props: Props[Msg], name: String)
15    (implicit mt: Manifest[Msg]): ActorRef[Msg]
16  def actorFor [Msg] (path: String)
17    (implicit mt: Manifest[Msg]): ActorRef[Msg]
18  def setReceiveTimeout(timeout: Duration): Unit
19  def become[SupM >: M] (behavior: SupM => Unit)
20    (implicit smt: Manifest[SupM]): ActorRef[SupM]

21 case class BehaviorUpdateException(smt: Manifest[_],
22                                   mt: Manifest[_]) extends Exception(smt + "must be a
23                                   supertype of "+mt+".")

24 final case class Props[-T] (props: akka.actor.Props)

25 object Props extends Serializable
26   def apply[T](creator: => Actor[T]): Props[T]
27   def apply[T](actorClass: Class[_ <: Actor[T]]): Props[T]
28   def apply[T, A <: Actor[T]]
29     (implicit arg0: Manifest[A]): Props[T]

26 abstract class SupervisorStrategy
27 case class OneForOneStrategy(restart: Int = -1,
28                             time: Duration = Duration.Inf)
29   (decider: Throwable => Directive)
30   extends SupervisorStrategy
31 case class OneForAllStrategy(restart: Int = -1,
32                             time: Duration = Duration.Inf)
33   (decider: Throwable => Directive)
34   extends SupervisorStrategy

```

Figure 4: TAKka API

context, which is a private field of the supervisor. Actor is the only TAKka class that is implemented using inheritance. Other TAKka classes are either implemented by delegating tasks to Akka counterparts or rewritten in TAKka. Re-implementing the TAKka Actor library would require a similar amount of work as implementing the Akka Actor library.

3.2 Actor Reference

A reference to an actor of type Actor[M] has type ActorRef[M]. An actor reference provides a ! method, through which users can send a message to the referenced actor. Sending an actor a message of unexpected type will raise an error at compile time. By using type-parameterized actor references, the receiver does not need to worry about unexpected messages, while senders can be sure that messages will be understood

```

1 package sample.akka
2 import akka.actor.{ActorRef, ActorSystem, Props, Actor}
3
4
5
6 case class Multiplication(m:Int, n:Int)
7
8 case class Upgrade(advancedCalculator:
9     PartialFunction[Any,Unit])
10
11 class CalculatorServer extends Actor {
12     def receive = {
13         case Multiplication(m:Int, n:Int) =>
14             println(m + " * " + n + " = " + (m*n))
15         case Upgrade(advancedCalculator) =>
16             println("Upgrading ...")
17             context.become(advancedCalculator)
18     }
19 }
20
21 object CalculatorUpgrade extends App {
22     val system = ActorSystem("CalculatorSystem")
23     val simpleCal:ActorRef =
24         system.actorOf(Props[CalculatorServer],
25             "calculator")
26
27     simpleCal ! Multiplication(5, 1)
28
29     case class Division(m:Int, n:Int)
30
31     def advancedCalculator:PartialFunction[Any,Unit] = {
32         case Multiplication(m:Int, n:Int) =>
33             println(m + " * " + n + " = " + (m*n))
34         case Division(m:Int, n:Int) =>
35             println(m + " / " + n + " = " + (m/n))
36         case Upgrade(_) =>
37             println("Upgraded.")
38     }
39
40     simpleCal ! Upgrade(advancedCalculator)
41     simpleCal ! Divison(10, 2)
42     val advancedCal = system.actorFor
43         ("akka://CalculatorSystem/user/calculator")
44     advancedCal ! Multiplication(5, 3)
45     advancedCal ! Divison(10, 3)
46     advancedCal ! Upgrade(advancedCalculator)
47 }
48 /* Terminal Output:
49 5 * 1 = 5
50 Upgrading ...
51 10 / 2 = 5
52 5 * 3 = 15
53 10 / 3 = 3
54 Upgraded.
55 */

```

Figure 5: Akka Example: Behaviour Upgrade

and processed, as long as the message is delivered.

An actor typically responds to a finite set of different messages whereas our notion of actor reference only takes one type parameter. In a type system that supports untagged union types, no special extension is required. In a type system which supports subtyping, ActorRef should be contravariant on its type argument M , denoted as $\text{ActorRef}[-M]$ in Scala. Consider the simple calculator defined in Figure 2, it is clear that ActorRef is contravariant because ActorRef[Operation] is a subtype of ActorRef[Division] though Division is a subtype of Operation. Contravariance is crucial to avoid the type pollution problem described in Section 6.

```

1 package sample.takka
2 import takka.actor.{ActorRef, ActorSystem, Props, Actor}
3
4 trait Operation
5 trait BasicOperation extends Operation
6 case class Multiplication(m:Int, n:Int)
7     extends BasicOperation
8 case class Upgrade[Op >: BasicOperation]
9     (advancedCalculator:Op=>Unit) extends
10     BasicOperation
11 class CalculatorServer extends Actor[BasicOperation] {
12     def typedReceive = {
13         case Multiplication(m:Int, n:Int) =>
14             println(m + " * " + n + " = " + (m*n))
15         case Upgrade(advancedCalculator) =>
16             println("Upgrading ...")
17             typedContext.become(advancedCalculator)
18     }
19 }
20
21 object CalculatorUpgrade extends App {
22     val system = ActorSystem("CalculatorSystem")
23     val simpleCal:ActorRef[BasicOperation] =
24         system.actorOf( Props[BasicOperation,
25             CalculatorServer], "calculator")
26
27     simpleCal ! Multiplication(5, 1)
28
29     case class Division(m:Int, n:Int) extends Operation
30
31     def advancedCalculator:Operation=>Unit = {
32         case Multiplication(m:Int, n:Int) =>
33             println(m + " * " + n + " = " + (m*n))
34         case Division(m:Int, n:Int) =>
35             println(m + " / " + n + " = " + (m/n))
36         case Upgrade(_) =>
37             println("Upgraded.")
38     }
39
40     simpleCal ! Upgrade(advancedCalculator)
41     // simpleCal ! Divison(10, 2) // compile error
42     val advancedCal = system.actorFor[Operation]
43         ("akka://CalculatorSystem/user/calculator")
44     advancedCal ! Multiplication(5, 3)
45     advancedCal ! Division(10, 3)
46     advancedCal ! Upgrade(advancedCalculator)
47 }
48 /* Terminal Output:
49 5 * 1 = 5
50 Upgrading ...
51
52 5 * 3 = 15
53 10 / 3 = 3
54 Upgraded.
55 */

```

Figure 6: TAKka Example: Behaviour Upgrade

For ease of use, ActorRef provides a publishAs method that casts an actor reference to a version that only accepts a subset of supported messages. The publishAs method encapsulates the process of type casting ActorRef, a contravariant type. We believe that using the notation of the publishAs method can be more intuitive than thinking about contravariance and subtyping relationship when publishing an actor reference as different types in a complex application. In addition, type conversion using publishAs is statically type checked. More importantly, with the publishAs method, users can give a supertype of an actor reference on demand, without defining new types and recompiling af-

fectured classes in the type hierarchy. The last advantage is important in Scala because a library developer may not have access to code written by others.

3.3 Props and Actor Context

The type `Props` denotes the properties of an actor. An instance of type `Props[M]` is used when creating an actor of type `Actor[M]`. Line 24 in Figures 1 and 2 initialises an instance of `Props` using the last `apply` method in Figures 3 and 4 respectively. The code uses Scala syntactical sugar that omits the method name `apply` and lets Scala provide the value of `manifest`, which is an implicit parameter.

Unlike an actor reference, which is the interface for receiving messages, an actor context describes the actor's view of the outside world. Because each actor defines an independent computation, an actor context is private to the corresponding actor. From its actor context, an actor can (i) retrieve an actor reference corresponding to a given actor path using the `actorFor` method, (ii) create a child actor with a system-generated or user-specified name using one of the `actorOf` methods, (iii) set a timeout denoting the time within which a new message must be received using the `setReceiveTimeout` method, and (iv) update its behaviours using the `become` method.

3.4 Reusing Akka Supervisor Strategies in Takka

None of the supervisor strategies in Figure 4 require a type-parameterized class during construction. Therefore, from the perspective of API design, it is easy to reuse Akka supervisor strategies in Takka. As actors communicate with each other by sending messages, system messages for supervision purposes should be handled by all actors. To keep the API simple, we separate the handler for system messages from the handler for other messages. In retrospect, the type parameter of the `Actor` class is not a supertype of system messages, whose types are private API in Takka. Crucially, our design avoids the requirement for a union type, which is not provided by Scala.

3.5 Behaviour Upgrades

Behaviour upgrades in Akka and Takka can be done using one of two complementary techniques: using the `become` method or defining an actor as a Finite State Machine (FSM).

The `become` method upgrades the behaviour of an actor. After the upgrade, the actor might be able to process messages of more types. Figures 5 and 6 compare using `become` in Akka and Takka. As new subtypes can be introduced later (line 39 in Figure 6), an actor can be upgraded to a version that is able to receive more types of messages. However, unlike the Akka version, behaviour upgrade in Takka *must* be backward compatible and *cannot* be rolled back. In other words, an actor must evolve into a version that is at least able to handle the original message patterns. The above decision is made so that a service published to users will not be unavailable later. Supporting behaviour upgrades in Takka also requires that there is a suitable supertype defined in advance. This requirement is a weakness compared to Akka, which permits upgrading the behaviour to any syntactically correct implementation.

An actor that implements the FSM trait switches between predefined states. In each state, that actor may only react to messages of a particular type, i.e. events associated with

that state, and discard messages of other types. Because the internal state of an FSM is invisible to others, it accepts all messages that may trigger an action. In other words, the type of its actor reference does not change. The ATM simulator example in Table 1 is implemented using the FSM trait. We show that rewriting an FSM-based Akka application using Takka is straightforward.

3.6 Related Work

Akka attempts to merge supervision and typed actors via a `TypedActor` class whose instance is initialised in a special way. A service of `TypedActor` object is invoked by method invocation instead of message passing. The Akka `TypedActor` class prevents some type errors but has two limitations. Firstly, `TypedActor` does not permit behaviour upgrade. Secondly, avoiding the type pollution problem (Section 6) by using Akka typed actors is as same cumbersome as using a simple object-oriented model, where supertypes need to be defined in advance. In Scala, introducing a supertype in a type hierarchy requires modification to all affected classes, whose source code may not be accessible by application developers.

Alternative to the actor model, different concurrent programming paradigms have been proposed. An important category of concurrent programming model is channel based communications, originated from CCS [16] and π -calculus [19]. Models that support typed channels include the join-calculus [7] and the typed π -calculus [19]. Another group of concurrent programming model, which focuses on communication coordination, is the event loops model. Examples of this model are the E programming language [15] and the AsyncScala framework [18]. The E programming language is dynamically typed. The `Vat` class in AsyncScala encapsulates a process and takes a continuation as its input. Neither the E language or the AsyncScala framework employs typed messages.

4. TYPED NAME SERVER

An important part of distributed infrastructure is a name server, which maps names to a dynamically typed value. A name can be encoded as a `Symbol` in Scala so that names which represent the same string have the same value. As a value retrieved from a name server is *dynamically typed*, it needs to be checked and cast to the expected type at the client side before using it.

To overcome the limitations of the untyped name server, we design a typed name server. A typed name server maps each registered typed name to a value of the corresponding

```

1 case class TSymbol[T:Manifest](val s:Symbol) {
2   private [takka] val t:Manifest[_] = manifest[T]
3   override def hashCode():Int = s.hashCode()
4   override def equals(that: Any) :Boolean = {
5     case ts: TSymbol[_] => ts.t.equals(this.t) &&
6       ts.s.equals(this.s)
7     case _ => false
8   }
9 }
10 case class TValue[T:Manifest](val value:T){
11   private [takka] val t:Manifest[_] = manifest[T]
12 }
```

Figure 7: TSymbol and TValue


```

1 package untype.nameserver
2 object NameServer
3   @throws(classOf[NamesExistException])
4   def set(name:Symbol, value:Any):Boolean
5   def unset(name:Symbol):Boolean
6   def get(name:Symbol):Option[Any]
7 case class NamesExistException(name:Symbol)
8   extends Exception("Name "+name+" has been registered.")

```

Figure 8: Dynamic Typed Name Server

type, and allows look-up of a value by giving a typed name. A typed name, `TSymbol`, is a name shipped with a type descriptor. A typed value, `TValue`, is a value shipped with a type descriptor, which describes a super type of the most precise type of that value. `TSymbol` and `TValue` can be defined as in Figure 7. The APIs of a dynamic typed name server and a typed name server are given in Figure 8 and 9 respectively.

Each TAKka actor system contains a typed name server. The typed name server is used when the actor is created and when an actor reference is requested. When an actor is created, the actor records a map from a typed actor path and the typed actor reference for the created actor. Upon retrieving a typed actor reference, line 47 in Figure 2 for example, the typed name server checks if the typed actor path matches any record.

5. EVOLUTION, NOT REVOLUTION

Akka systems can be smoothly migrated to TAKka systems. In other words, existing systems can evolve to introduce more types, rather than requiring a revolution where all actors and interactions must be typed. The above property is analogous to adding generics to Java programs. Java generics are carefully designed so that programs without generic types can be partially replaced by an equivalent generic version (evolution), rather than requiring generic types everywhere (revolution) [17].

Section 2 presents how to define and use a safe calculator in the Akka and TAKka systems respectively. Think of a `SafeCalculator` actor as a service and its reference as a client interface. This section shows how to upgrade the Akka version to the TAKka version gradually, either upgrading the service implementation first or the client interface.

5.1 TAKka Service with Akka Client

It is often the case that an actor-based service is implemented by one organization but used in a client application implemented by another. Let us assume that a developer decides to upgrade the service using TAKka actors, for example, by upgrading the Socko Web Server [12], the Gatling stress testing tool [6], or the core library of Play [22], as we do in Section 7. Will the upgrade affect legacy client applications built using the Akka library? Fortunately, no changes are required at all.

As the TAKka Actor class inherits the Akka Actor class, it can be used to create an Akka actor. For example, the object `akkaCal`, created at line 5 in Figure 10, is created from a TAKka actor and used as an Akka actor reference. After the service developer has upgraded all actors to equivalent TAKka versions, the developer may want to start a TAKka actor system. Until that time, the developer can create TAKka actor references but publish their untyped version to users

```

1 package takka.nameserver
2 object NameServer
3   @throws(classOf[NamesExistException])
4   def set[T:Manifest](name:TSymbol[T], value:T):Boolean
5   def unset[T:Manifest](name:TSymbol[T]):Boolean
6   def get[T:Manifest](name:TSymbol[T]):Option[T]
7 case class NamesExistException(name:TSymbol[_])
8   extends Exception("Name "+name+" has been registered.")

```

Figure 9: Static Typed Name Server

who are working in the Akka environment (line 19). As a result, no changes are required for a client application that uses Akka actor references. Because an Akka actor reference accepts messages of any type, messages of unexpected type may be sent to TAKka actors. As a result, handlers for the `UnhandledMessage` event is required in a careful design (line 10 and 20).

5.2 Akka Service with TAKka Client

Sometimes developers want to update the client code or API before upgrading the service implementation. For example, a developer may not have access to the service implementation; or the service implementation may be large, so the developer may want to upgrade the library gradually.

Users can initialize a TAKka actor reference by providing an Akka actor reference and a type parameter. In Figure 11, we re-use the Akka calculator, initialise it in an Akka actor system, and obtain an Akka actor reference. Then, we wrap the Akka actor reference as a TAKka actor reference, `takkaCal`, which only accepts messages of type `Operation`.

6. THE TYPE POLLUTION PROBLEM

In a system with multiple components, different components may require different interfaces; since all messages are received in the same mailbox, a naive approach would be to set the type to the union of all the interfaces, causing each component to see a type containing messages not intended for it to use—an issue we dub the Type Pollution Problem.

We illustrate the Type Pollution Problem and its solution on an instance of the Model-View-Controller pattern [4]. The Model and View have separate interfaces to the Controller, and neither should see the interface used by the other. However, the naive approach would have the Controller message type contain all the messages the Controller receives, from both the Model and the View. A similar problem can occur in a multi-tier architecture [8], where an intermediary layer interfaces with both the layer above and the layer below.

One solution to the type pollution problem is using separate channels for distinct parties. For instance, in Model-View-Controller, one channel would communicate between Model and Controller, and a distinct channel communicate between Model and View. Programming models that support this solution includes the join-calculus [7] and the typed π -calculus [19]. Can we gain similar advantages for a system based on actors rather than channels?

TAKka solves the type pollution problem with subtyping. The code outline in Figure 12 summarises a Tic-Tac-Toe example in the TAKka code repository [9], which uses the Model-View-Controller pattern. Traits `V2CMessage` and `M2CMessage` represent the types of messages expected by the View and the Model respectively. Both are subtypes of `ControllerMsg`, which represents the type of all mes-

```

1 import sample.takka.SafeCalculator.SafeCalculator
2
3 object TSAC extends App {
4   val akkasystem = akka.actor.ActorSystem("AkkaSystem")
5   val akkaCal = akkasystem.actorOf(
6     akka.actor.Props[SafeCalculator], "acal")
7   val handler = akkasystem.actorOf(
8     akka.actor.Props(new MessageHandler(akkasystem)))
9
10  akkasystem.eventStream.subscribe(handler,
11    classOf[UnhandledMessage]);
12  akkaCal ! Multiplication(3, 1)
13  akkaCal ! "Hello Akka"
14
15  val takkasystem =
16    akka.actor.ActorSystem("TakkaSystem")
17  val takkaCal = takkasystem.actorOf(
18    akka.actor.Props[String, TakkaStringActor], "tcal")
19
20  val untypedCal= takkaCal.untypedRef
21  takkasystem.system.eventStream.subscribe(
22    handler, classOf[UnhandledMessage]);
23  untypedCal ! Multiplication(3, 2)
24  untypedCal ! "Hello Takka"
25 }
26 /* Terminal output:
27 3 * 1 = 3
28 unhandled message:Hello Akka
29 3 * 2 = 6
30 unhandled message:Hello Takka
31 */

```

Figure 10: TAKka Service with Akka Client

sages expected by the controller. In the code, the Controller actor publishes itself at different types to the View actor and the Model actor (lines 26–29), by sending appropriate initialisation messages. In line 27, typedSelf is of type ActorRef[ControllerMsg] while ModelSetController expects a parameter of type ActorRef[M2CMessage]. Since ActorRef is contravariant in its type parameter, the call is correct even if the call to publishAs is omitted; the call is to make the programmer’s intent explicit and allows the compiler to catch more errors.

7. EXPRESSIVENESS

This section investigates whether the type discipline enforced by TAKka restricts the expressibility of Akka. Table 1 lists the examples used for expressiveness checks. Examples are selected from QuviQ [2] and open source Akka projects to ensure that the main requirements for actor programming are not unintentionally neglected. Examples from QuviQ are re-implemented using both Akka and TAKka. Examples from Akka projects are re-implemented using TAKka. Following standard practice, we assess the overall code modification and code size by calculating the geometric mean of all examples [10]. The evaluation results in Table 1 show that when porting an Akka program to TAKka, about 8.5% lines of code need to be modified including additional type declarations. Sometimes, the code size can be smaller because TAKka code does not need to handle unexpected messages. On average, the total program size of Akka and TAKka applications are almost the same. Figure 13 reports the same result in a Scatter chart.

A type error is reported by the compiler when porting the Socko example [12] from its Akka implementation to

```

1 import sample.akka.SafeCalculator.SafeCalculator
2
3 object ASTC extends App {
4   val system = akka.actor.ActorSystem("AkkaSystem")
5   val akkaCal = system.actorOf(
6     akka.actor.Props[SafeCalculator], "calculator")
7   val takkaCal = new takka.actor.ActorRef[Operation]{
8     val untypedRef = akkaCal
9   }
10  takkaCal ! Multiplication(3, 1)
11  // takkaCal ! "Hello"
12  // compile error: type mismatch;
13  // found : String("Hello") required:
14  // sample.takka.SupervisedCalculator.Operation
15 }
16 /* Terminal output:
17 3 * 1 = 3
18 */

```

Figure 11: Akka Service with Takka Client

```

1 trait ControllerMessage
2 trait V2CMessage extends ControllerMessage
3 // sub-classes of V2CMessage messages go here
4 trait M2CMessage extends ControllerMessage
5 // sub-classes of M2CMessage messages go here
6 trait C2VMessage
7 case class ViewSetController
8   (controller:ActorRef[V2CMessage]) extends C2VMessage
9 trait C2MMessage
10 case class ModelSetController
11   (controller:ActorRef[M2CMessage]) extends C2MMessage
12
13 class View extends Actor[C2VMessage] {
14   private var controller:ActorRef[V2CMessage]
15   // rest of implementation
16 }
17 class Model extends Actor[C2MMessage] {
18   private var controller:ActorRef[M2CMessage]
19   // rest of implementation
20 }
21
22 class Controller(model:ActorRef[C2MMessage],
23   view:ActorRef[C2VMessage])
24   extends Actor[ControllerMessage] {
25   override def preStart() = {
26     model ! ModelSetController
27     (typedSelf.publishAs[M2CMessage])
28     view ! ViewSetController
29     (typedSelf.publishAs[V2CMessage])
30   }
31   // rest of implementation
32 }

```

Figure 12: Outline for Model-View-Controller

its equivalent TAKka implementation. Socko is a library for building event-driven web services. The Socko designer defines a SockoEvent class to be the supertype of all events. One subtype of SockoEvent is HttpRequestEvent, representing events generated when an HTTP request is received. The designer further implements subclasses of the Method class, whose unapply method is intended to have an output of type Option[HttpRequestEvent]. The Socko designer made a type error in the method declaration so that the unapply has output type Option[SockoEvent]. The type error is not exposed in test examples because those examples only test HTTP events. The design flaw is exposed when rewriting Socko using TAKka.

Source	Example	Akka Code Lines	Modified Takka Lines	% of Modified Code	TAkka Code Lines	% of Code Size
Small Examples	String Processor	25	11	44	22	88
	Supervised Calculator	38	11	29	41	108
	Behaviour Upgrade	38	10	26	39	102
	NQueens	235	6	3	236	100
BenchErl Examples	bang	93	8	8.6	94	101
	big	93	10	11	100	108
	ehb	201	23	11	216	107
	mbrot	125	8	6	130	104
	ran	98	8	2.6	101	103
	serialmsg	146	20	14	146	100
QuviQ [2]	ATM simulator	1148	199	17.3	1160	101
	Elevator Controller	2850	172	9.3	2878	101
Akka Documentation [21]	Ping Pong	67	13	19.4	67	100
	Dining Philosophers	189	23	12.1	189	100
	Distributed Calculator	250	43	17.2	250	100
	Fault Tolerance	274	69	25.2	274	100
Other Open Source Akka Applications	Barber Shop [24]	754	104	13.7	751	99
	EnMAS [5]	1916	213	11.1	1909	100
	Socko Web Server [12]	5024	227	4.5	5017	100
	Gatling [6]	1635	111	6.8	1623	99
	Play Core [22]	27095	15	0.05	27095	100
geometric mean		354.1	30.2	8.5	360.1	101.7

Table 1: Results of Expressiveness Evaluation

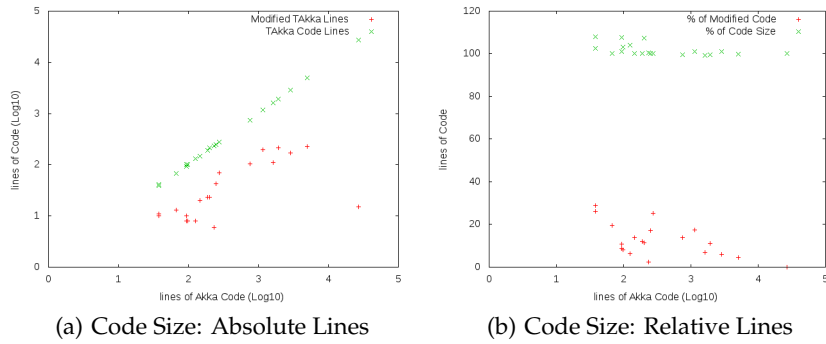


Figure 13: Code Size Evaluation

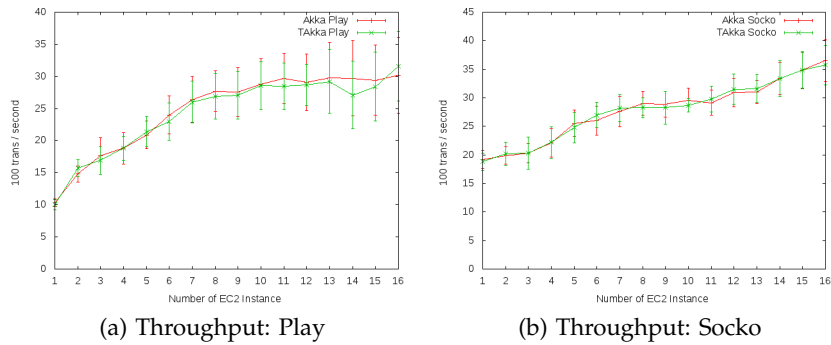


Figure 14: Throughput Benchmarks

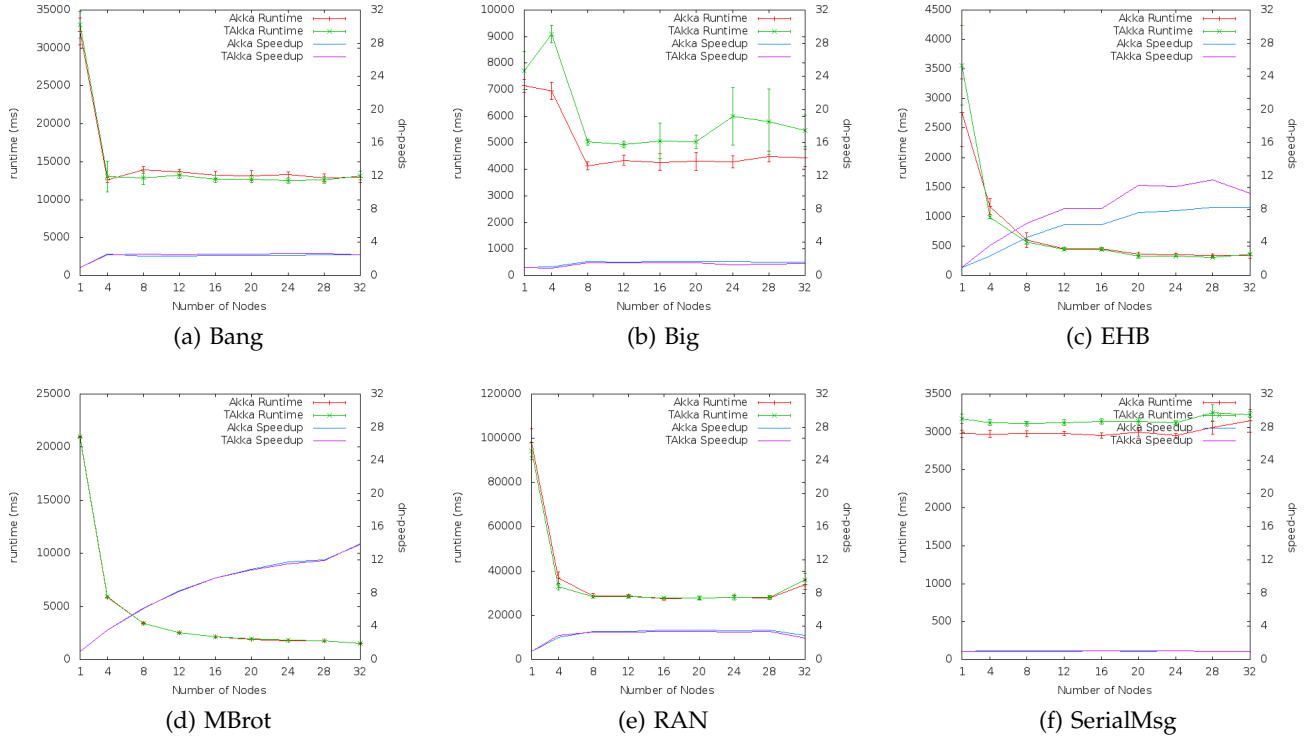


Figure 15: Runtime & Scalability Benchmarks

8. THROUGHPUT AND SCALABILITY

This section investigates whether managing type information in TAKka reduces performance. The TAKka library is built on Akka so that code for shared features can be re-used. The three main sources of overheads in the TAKka implementation are: (i) the cost of adding an additional operational layer on top of Akka code, (ii) the cost of constructing type descriptors, and (iii) the cost of transmitting type descriptors in distributed settings. We assess the effects of the above overheads in terms of throughput and scalability.

The example used in the throughput benchmark is the JSON serialization example [20]. The example was implemented using Akka Play, TAKka Play, Akka Socko, and TAKka Socko. All four versions of the web service are deployed to Amazon EC2 Micro instances (t1.micro), each of which has 0.615GB memory. The throughput is tested with up to 16 EC2 Micro instances. For each number of EC2 instances, 10 rounds of throughput measurement are executed to gather the average and standard deviation of the throughput. The results reported in Figure 14 show that web servers built using the Akka-based library and the TAKka-based library have very similar throughput.

We further investigate the speed-up of multi-node TAKka applications by porting 6 BenchErl benchmarks [3] which do not involve Erlang/OTP specific features. Each BenchErl benchmark spawns one master process and many child processes for a given task. Each child process performs a certain amount of computation and reports the result to the master process. The benchmarks are run on a 32 node Beowulf cluster at Heriot-Watt University. Each Beowulf node comprises eight Intel 5506 cores running at 2.13GHz. All machines run

under Linux CentOS 5.5. The Beowulf nodes are connected with a Baystack 5510-48T switch.

Figure 15 reports the results of the BenchErl benchmarks. We report the average and the standard deviation of the runtime of each example. Depending on the ratio of the computation time and the I/O time, benchmark examples scale at different levels. In all examples, TAKka and Akka implementations have almost identical run-time and scalability. It appears that the Akka and TAKka implementations of the Big benchmark have different runtimes and overlapped poor scalability. We do not understand why it is the only benchmark that seems to reveal a significant difference in terms of runtime.

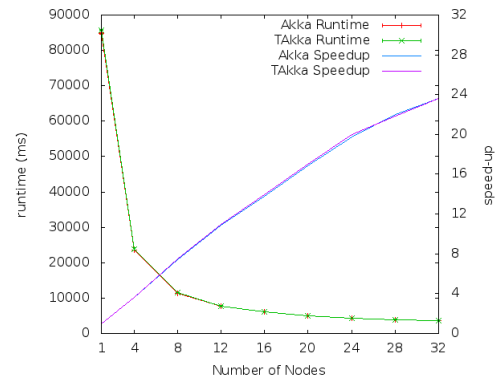


Figure 16: Benchmark: N-Queens Puzzle

In the BenchErl examples, child processes are asked to execute the same computation a number of times. In contrast, distributed and cluster computing techniques are often used to solve a computationally expensive task by distributing sub-tasks to independent nodes. To simulate such a scenario, another benchmark, N-Queens Puzzle [23], is added. Finding all solutions of an N-Queen Puzzle is an NP-hard problem. Therefore, a suitable n makes the problem a good benchmark to demonstrate the advantage of cluster and distributed programming. Figure 16 reports the result when n is set to 14. The result shows that both the Akka and TAKka implementation have good scalability and similar efficiency.

9. CONCLUSION

The Akka library accepts dynamically typed messages. The TAKka library introduces a type-parameter for actor-related classes. The additional type-parameter specifies the communication interface of that actor. With the help of type-parameterized actors, unexpected messages to actors are rejected at compile time. We have shown that type-parameterized actors can form supervision trees in the same way as untyped actors (Section 3). We have shown that adding type parameter does not restrict expressiveness, and requires only small amounts of refactoring (Section 7). We have shown that TAKka does not introduced performance penalties (Section 8), with respect to throughput, efficiency, and scalability. The above results are encouraging for the use of types and supervision trees to implement reliable applications and improve the reliability of legacy applications with little effort.

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