

Type-parameterized Actors and Their Supervision (v6.5)

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Abstract

The robustness of distributed message passing applications can be improved by (i) employing failure recovery mechanisms such as the supervision principle, or (ii) using typed messages to prevent ill-typed communication. The former approach has been implemented in the OTP (Open Telecom Platform) library for Erlang and the Akka library for Scala. The later approach has been well explored in systems including the join-calculus and the typed π -calculus. An important open question is how easily the two approaches can be combined.

Combining the supervision principle with typed messages raises three challenges. Firstly, a novel name server is required to retrieve typed actor references for typed actor paths. Secondly, supervisor actors must interact with a wide variety of child actors and it is not obvious whether or not it would be easy to type supervisors. Thirdly, an actor which receives messages from distinct parties may suffer from the type pollution problem, in which case a party imports too much type information and can send the actor a message not expected from it.

This paper introduces the typed Akka library, TAKka, which resolves above problems. Although TAKka actors inherit from Akka actors and Scala TypeTag is used as serializable type information, we believe that similar improvements can be made to actor libraries in other languages.

We evaluate the TAKka library by re-implementing 19 examples built from Erlang or Akka libraries. Results show that TAKka adds little runtime and code size overheads to Akka. TAKka programs have similar scalability to their Akka equivalents. Finally, we port the Chaos Monkey library for testing the reliability and

design a Supervision View library for dynamically capturing the structure of supervision trees.

Categories and Subject Descriptors D.1.3 [Programming Techniques]: Concurrent Programming

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1. Introduction

The Erlang/OTP (Open Telecom Platform) library [Ericsson AB. 2012a] was released in 1996 for writing Erlang code using the Actor model [Hewitt et al. 1973] together with five OTP design principles derived from ten years' experience. The OTP Design principles, especially the supervision tree principle, made it easier to build reliable distributed applications [Armstrong 2007].

The notions of actor and supervision tree have been ported to statically typed languages including Scala and Haskell. Scala actor libraries including Scala Actors [Haller and Odersky 2006, 2007] and Akka [Typesafe Inc. (a) 2012; Typesafe Inc. (b) 2012] use dynamically-typed messages even though Scala is a statically typed language. Cloud Haskell [Epstein et al. 2011], a recent actor library, supports both dynamically and statically typed messages, but does not support supervision.

The key claim in this paper is that actors in supervision trees can be typed by parameterizing the actor class with the type of messages it expects to receive. Type-parameterized actors benefit both users and developers of actor-based services. For users, sending ill-typed messages is prevented at compile time. Because messages are usually transmitted asynchronously, it may be difficult to trace the source of errors at runtime, especially in distributed environments. For service developers, since unexpected messages are eliminated from the system, they can focus on the logic of the services rather than worrying about incoming messages of unexpected types. Implementing type-parameterized actors in a statically-typed language; however, requires solving following three problems.

1. A novel name server is required to retrieve actor references of a given types. A distributed system

usually requires a name server that maps names of services to processes that implement that service. If processes are dynamically typed, this is always to implement as a map from names to processes. Can this be adapted to the cases where processes are statically typed?

2. Supervisors must interact with a wide variety of processes. Actors are structured in supervision trees to improve system reliability. Each actor in a supervision tree needs to handle messages of its interest and a special category of messages for supervision purposes. Is it practical to define an actor that supervises children parameterized by a variety of types?
3. Actors which receive messages from distinct parties may suffer from the type pollution problem, in which case a party imports too much type information about an actor and can send the actor messages not expected from it. Systems built on layered architecture or the MVC model are often victims of the type pollution problem. As an actor-based component receives messages from distinct parties using its sole channel, when the actor-based component is naively parameterized with the union type of all expected message types, or receives dynamically typed messages like in Erlang and Akka designs, every party can send the actor messages not expected from it. Can a type-parameterised actor have different types when used by distinct parties.

Continuing a line of work on merging types with actor programming by Haller and Odersky [Haller and Odersky 2006, 2007] and Akka developers [Typesafe Inc. (b) 2012], along with the work on system reliability test by Netflix, Inc. [Netflix, Inc. 2013] and Luna [Luna 2013], this paper makes following four contributions.

- It presents the design and implementation of a novel typed name server that maps typed names to values, for example actor references, of the corresponding type. The typed name server (section 3.2) mixes static and dynamic type checking so that type errors are detected at the earliest opportunity. The implementation requires runtime support for type reflection and a notion of first class type descriptors. In Scala, the `Manifest` class meets the requirement.
- It describes the design of the TAKka library. Section 4.1 to 4.3 illustrate how type parameters are added to actor related classes to improve type safety. By separating the handler for system messages from the handler for user defined messages, section 4.5 and 4.6 shows that type-parameterized actors can form supervision trees in the same manner as untyped actors. Section 4.7 compares the design of TAKka with alternatives adopted by other actor libraries.
- It shows that Akka programs can be gradually migrate to their TAKka equivalents. Section 5 explains strategies of gradually upgrading Akka programs to their TAKka equivalents.
- It gives a straightforward solution to the type pollution problem (section 6.1). We present a simple API to cast the type of an actor reference to its super type. The semantics of the API is easy to understand and does not require deep understanding of underlying concepts such as inheritance, polymorphism, and contravariant types.
- It gives a critical evaluation of the TAKka library. Results in section 6.2 confirm that using type parameterized actors sacrifice neither expressiveness nor correctness. Efficiency and scalability test in section 6.3 shows that TAKka applications have little overhead at the initialisation stage but have almost identical run-time performance and scalability comparing to their Akka equivalents. The TAKka library also ships with a Chaos Monkey library and a Supervision View library for revealing breakpoint of supervision trees.

2. Actor Programming

2.1 Actor Model and OTP Design Principles

The Actor model defined by Hewitt et al. [Hewitt et al. 1973] treats actors as primitive computational components. Actors collaborate by sending asynchronous messages to each other. An actor independently determines its reaction to messages it receives.

The Actor model is adopted by the Erlang programming language, whose developers later summarized 5 OTP design principles to improve the reliability of Erlang applications [Ericsson AB. 2012b]. We notice that the Behaviour principle, the Application principle, and the Release principle coincide with good programming practices in Object-Oriented Programming (OOP). The Release Handling principle requires runtime support on hot swapping. In a platform, for example the Java Virtual Machine (JVM), where hot swapping is not supported in general, hot swapping a particular component can be simulated by updating the reference to that component. For example, Section 4.4 explains how hot swapping the behaviour of an actor is supported in TAKka, which runs on the JVM. Table 1 lists the observed correspondence between OTP design principles and programming practices in JAVA and Scala. The Supervision Tree principle, which is the central topic of this paper, has no direct correspondence in native JVM based systems.

OTP Design Principle	JAVA/Scala Programming
Supervision Tree	no direct correspondence
Behaviour	defining an abstract class
Application	defining an abstract class that has two abstract methods: start and stop
Release	packaging related application classes
Release Handling	hot swapping support on key modules is required

Table 1. Using OTP Design Principles in JAVA/Scala Programming

2.2 Akka Actor

An Akka Actor has four important fields given in Figure 1: (i) a receive function that defines its reaction to incoming messages, (ii) an actor reference pointing to itself, (iii) the actor context representing the outside world of the actor, and (iv) the supervisor strategy for its children.

```

1 package akka.actor
2 trait Actor {
3   def receive: Any => Unit
4   val self: ActorRef
5   val context: ActorContext
6   var supervisorStrategy: SupervisorStrategy
7 }

```

Figure 1. Akka Actor API

Figure 2 shows an example actor in Akka. The receive function of the Akka actor has type `Any=>Unit` but the defined actor, `ServerActor`, is only intended to process strings. Line 16 creates and passes a `Props`, an abstraction of actor creation, to an actor system, creates an actor with name `server`, and returns a reference pointing to that actor. Another way to obtain an actor is using the `actorFor` method as shown in line 24. We then use actor references to send the actor string messages integer messages. String messages are processed in the way defined by the receive function.

Undefined messages are treated differently in different actor libraries. In Erlang, an actor keeps undefined messages in its mailbox, attempts to process the message again when a new message handler is in use. In versions prior to 2.0, an Akka actor raises an exception when it processes an undefined message. In recent Akka versions, an undefined message is discarded by the actor and an `UnhandledMessage` event is pushed to the event stream of the actor system. The event stream may be subscribed by other actors who are interested in particular event messages. To handle the unexpected

```

1 class ServerActor extends Actor {
2   def receive = {
3     case m:String => println("received message: "+m)
4   }
5 }
6
7 class MessageHandler(system: ActorSystem) extends
  Actor {
8   def receive = {
9     case akka.actor.UnhandledMessage(message,
10      sender, recipient) =>
11       println("unhandled message:"+message);
12   }
13 }
14 object ServerTest extends App {
15   val system = ActorSystem("ServerTest")
16   val server = system.actorOf(Props[ServerActor],
17     "server")
18   val handler = system.actorOf(Props(new
19     MessageHandler(system)))
20   system.eventStream.subscribe(handler,
21     classOf[akka.actor.UnhandledMessage]);
22   server ! "Hello World"
23   server ! 3
24   val serverRef =
25     system.actorFor("akka://ServerTest/user/server")
26   serverRef ! "Hello World"
27   serverRef ! 3
28 }
29
30 /*
31 Terminal output:
32 received message: Hello World
33 unhandled message:3
34 received message: Hello World
35 unhandled message:3
36 */

```

Figure 2. A String Processor in Akka

integer message in the above short example, an event handler are defined and created with 8 lines of code.

2.3 Supervision

Reliable Erlang applications typically adopt the Supervision Tree Principle [Ericsson AB. 2012b], which suggests that actors should be organised in a tree structure so that any failed actor can be properly restarted by its supervisor. Nevertheless, adopting the Supervision Tree principle is optional in Erlang.

The Akka library makes supervision obligatory by restricting the way of creating actors. Actors can only

be initialised by using the `actorOf` method provided by `ActorSystem` or `ActorContext`. Each actor system provides a guardian actor for all user-created actors. Calling the `actorOf` method of an actor system creates an actor supervised by the guardian actor. Calling the `actorOf` method of an actor context creates a child actor supervised by that actor. Therefore, all user-created actors in an actor system, together with the guardian actor of that actor system, form a tree structure. Obligatory supervision unifies the the structure of actor deployment and simplifies the work of system maintenance.

Each actor in Akka is associated with an actor path. The string representation of the actor path of a guardian actor has format `akka://mysystem@IP:port/user`, where *mysystem* is the name of the actor system, *IP* and *port* are the IP address and the port number which the actor system listens to, and *user* is the name of the guardian actor. The actor path of a child actor is actor path of its supervisor appended by the name of the child actor, either a user specified name or a system generated name.

Figure 3 defines a simple calculator which supports multiplication and division. The simple calculator does not consider the problematic case of dividing a number by 0, where an `ArithmeticException` will be raised. We then define a safe calculator as the supervisor of the simple calculator. The safe calculator delegates calculation tasks to the simple calculator and restart the simple calculator when an `ArithmeticException` is raised. The supervisor strategy of the safe calculator also specifies the maximum failures its child may have within a time range. If the child fails more frequently than the allowed frequency, the safe calculator will be stopped, and its failure will be reported to its supervisor, the system guardian actor in this example. The terminal output shows that the simple calculator is restarted before the third and fifth message are delivered. The last message is not processed because the both calculators a terminated because the simple calculator fails more frequently than allowed.

3. Mixing Static and Dynamic Type Checking

A key advantages of static typing is that it detects some type errors at an early stage, i.e. at compile time. The T Akka library is designed to detect type errors as early as possible. However, not all type errors can be statically detected, and some dynamic type checks are required. To address this issue, a notion of run-time type descriptor is required.

This section summarises the type reflection mechanism in Scala and explains how it benefits the implementation of our typed name server. Our typed name

```

1 case class Multiplication(m:Int, n:Int)
2 case class Division(m:Int, n:Int)
3
4 class Calculator extends Actor {
5   def receive = {
6     case Multiplication(m:Int, n:Int) =>
7       println(m + " * " + n + " = " + (m*n))
8     case Division(m:Int, n:Int) =>
9       println(m + " / " + n + " = " + (m/n))
10  }
11 }
12
13 class SafeCalculator extends Actor {
14   override val supervisorStrategy =
15     OneForOneStrategy(maxNrOfRetries = 2,
16       withinTimeRange = 1 minute) {
17     case _: ArithmeticException =>
18       println("ArithmeticException Raised to:
19         "+self)
20       Restart
21   }
22   val child:ActorRef =
23     context.actorOf(Props[Calculator], "child")
24   def receive = {
25     case m => child ! m
26   }
27 }
28
29 val system = ActorSystem("MySystem")
30 val actorRef:ActorRef =
31   system.actorOf(Props[SafeCalculator],
32     "safecalculator")
33
34 calculator ! Multiplication(3, 1)
35 calculator ! Division(10, 0)
36 calculator ! Division(10, 5)
37 calculator ! Division(10, 0)
38 calculator ! Multiplication(3, 2)
39 calculator ! Division(10, 0)
40 calculator ! Multiplication(3, 3)
41
42 /*
43 Terminal Output:
44 3 * 1 = 3
45 java.lang.ArithmeticException: / by zero
46 ArithmeticException Raised to:
47   Actor[akka://MySystem/user/safecalculator]
48
49 10 / 5 = 2
50 java.lang.ArithmeticException: / by zero
51 ArithmeticException Raised to:
52   Actor[akka://MySystem/user/safecalculator]
53 java.lang.ArithmeticException: / by zero
54
55 3 * 2 = 6
56 ArithmeticException Raised to:
57   Actor[akka://MySystem/user/safecalculator]
58 java.lang.ArithmeticException: / by zero
59 */

```

Figure 3. Supervised Calculator

server can be straightforwardly ported to other platforms that support type reflection.

3.1 Scala Type Descriptors

Scala 2.8 introduces a `Manifest` class¹ whose instance is a first class type descriptor used at runtime. With the help of the `Manifest` class, users can record the type information, including generic types, which may be erased by the JAVA compiler.

In the Scala interactive session below, we obtain a `Manifest` value at Line 5 and test a subtype relationship at Line 8. To define a method that obtains type information of a generic type, Scala requires a type tag as an implicit argument to the method. To simplify the API, Scala further provides a form of syntactic sugar called context bounds. We define a method using context bounds at Line 11, which is compiled to the version using implicit arguments as shown at Line 12.

```
1 scala> class Sup; class Sub extends Sup
2 defined class Sup
3 defined class Sub
4
5 scala> manifest[Sub]
6 res0: Manifest[Sub] = Sub
7
8 scala> manifest[Sub] <:< manifest[Sup]
9 res1: Boolean = true
10
11 scala> def getType[T:Manifest] = {manifest[T]}
12 getType: [T](implicit evidence$1:
    Manifest[T])Manifest[T]
13
14 scala> getType[Sub => Sup => Int]
15 res2: Manifest[Sub => (Sup => Int)] =
    scala.Function1[Sub, scala.Function1[Sup,
    Int]]
```

3.2 Typed Name Server

In distributed systems, a name server maps each registered name, usually a unique string, to a value, and provides a function to look up a value for a given name. A name can be encoded as a `Symbol` in Scala so that names which represent the same string have the same value. As values retrieved from the name server is dynamically typed, values needs to be checked against and be cast to expected type by the client before use.

To overcome the limitations of the untyped name server, we design and implement a typed name server which maps each registered typed name to a value of the corresponding type, and allows to look up a value by giving a typed name.

¹ Scala 2.10 introduces the `Type` class and the `TypeTag` class to replace `Manifest`. At the time of this writing, `TypeTag` is not serializable as it should be due to bug SI-5919.

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. In Scala, `TSymbol` and `TValue` can be simply defined as in figure 4:

```
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 }
5
6 case class TValue[T:Manifest](val value:T){
7   private [takka] val t:Manifest[_] = manifest[T]
8 }
```

Figure 4. `TSymbol` and `TValue`

`TSymbol` is declared as a *case class* in Scala so that the name `TSymbol` can be used as a data constructor and for pattern matching. In addition, the type descriptor, `t`, is constructed automatically and is private to the `takka` package so that only the library developer can access it as a field of `TSymbol`. `TValue` is declared as a *case class* for the same reason.

With the help of `TSymbol`, `TValue`, and a hashmap, we can implement a typed name server that provides following three operations:

- `set[T:Manifest](name:TSymbol[T], value:T):Boolean`

The operation registers a typed name with a value of corresponding type and returns true if the symbol representation of *name* has not been registered; otherwise the typed name server discards the request and returns false.

- `unset[T](name:TSymbol[T]):Boolean`

The operation cancels the entry *name* and returns true if (i) its symbol representation is registered and (ii) the type `T` is a supertype of the registered type; otherwise the operation returns false.

- `get[T](name:TSymbol[T]):Option[T]`

The operation returns `Some(v:T)`, where `v` is the value associated with *name*, if (i) *name* is associated with a value and (ii) `T` is a supertype of the registered type; otherwise the operation returns `None`.

Notice that `unset` and `get` operations succeed as long as the associated type of the input name conforms the associated of the registered name. To permit polymorphism, the `hashCode` method of `TSymbol` defined in Figure 4 does not take type value into account. Equivalence comparison on `TSymbol` instances; however, should consider the type. Although the notion of `TValue` does not appear in the API, it is required for efficient library implementation because the type

information in `TSymbol` is neglected in the hashmap. Overriding the hash function of `TSymbol` also prevents the case where users accidentally register two typed names with the same symbol but different types, in which case if one type is a supertype of the other, the return value of `get` can be non-deterministic. Last but not least, when an operation fails, the name server returns `false` or `None` rather than raising an exception so that it is always available.

In general, dynamic type checking can be carried out in two ways. The first method is to check whether the most precise type of a value conforms the structure of a data type. Examples of this method include dynamically typed languages and the `instanceof` method in JAVA and other languages. The second method is to compare two type descriptors at run time. The implementation of our typed name server employs the second method because it detects type error which may otherwise be left out. Our implementation requires the runtime type reification feature provided by Scala. In a system that does not have such feature, implementing typed name server is more difficult.

4. TAKka Library Design

This section presents the design of the TAKka library. We outline how we add types to actors and how to construct supervision trees of typed actors in TAKka. This section concludes with a brief discussion about design alternatives used by other actor libraries.

4.1 Type-parameterized Actor

A TAKka actor has type `TypedActor[M]`. It inherits from the Akka Actor trait to minimise implementation effort. Users of the TAKka library, however, do not need to use any Akka Actor APIs. Instead, we encourage programmers to use Akka equivalent fields given in Figure 5. 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 actor context and the type parameter of the actor reference pointing to itself.

```
1 package takka.actor
2 abstract class TypedActor[M:Manifest] extends
  akka.actor.Actor {
3   def typedReceive:M=>Unit
4   val typedSelf:ActorRef[M]
5   val typedContext:ActorContext[M]
6   var supervisorStrategy: SupervisorStrategy
7 }
```

Figure 5. TAKka Actor API

The two immutable fields of `TypedActor`: `typedContext` and `typedSelf`, will be initialized automatically when the actor is created. Library users may override the default supervisor strategy in the way explained in Section 4.5. The implementation of the `typedReceive` method, on the other hand, is always provided by users.

The limitation of using inheritance to implement TAKka Actor 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 Figure 2, a child actor is created by calling the `actorOf` method from its supervisor's actor context, which is a private API of the supervisor. `TypedActor` is the only TAKka class that is implemented using inheritance. Other TAKka classes are either implemented by delegating tasks to Akka counterpart or rewritten in TAKka. We believe that re-implementing the TAKka Actor library requires similar amount of work of implementing the Akka Actor library.

4.2 Actor Reference

A reference to an actor of type `TypedActor[M]` has type `ActorRef[M]`. An actor reference provides a `!` method, through which users could send a message to the referenced actor. Sending an actor a message whose type is not the expected 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 and processed, as long as the message is delivered.

An actor usually can react to a finite set of different message patterns 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 polymorphism, `ActorRef` should be contravariant on its type argument `M`, denoted as `ActorRef[-M]`. Consider rewriting the simple calculator defined in Section 2.3 using TAKka, 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 at Section 6.1.

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

Figure 6. Actor Reference

For ease of use, TAKka provides a `publishAs` method that casts an actor reference to a version that only accepts a subset of supported messages. The `publishAs` method has three advantages. Firstly, explicit type conversion using `publishAs` is always type safe because the type of the result is the supertype of the original actor reference. Secondly, the semantic of `publishAs` does not require a deep understanding of underlying concepts like contravariance and inheritance. Thirdly, with the `publishAs` method, users can give a supertype of an actor reference on demand, without defining new types and recompiling affected classes in the type hierarchy.

Figure 2 defines the same string processing actor given in Section 2.2. The `typedReceive` method now has type `String⇒Unit`, which is the same as our intention. In this example, types of `typedReceive` and `m` may be omitted because they could be inferred by the compiler. Unlike the Akka example, sending an integer to `server` is rejected by the compiler. Although the type error introduced at line 19 cannot be statically detected, it is captured by the run-time as soon as the `actorFor` method is called. In the TAKka version, there is no need to define a handler for unexpected messages.

4.3 Props and Actor Context

The type `Props` denotes the properties of an actor. A `Props` of type `Props[M]` is used when creating an actor of type `TypedActor[M]`. Say `myActor` is of type `MyActor`, which is a subtype of `TypedActor[M]`, a `Prop` of type `Prop[M]` could be created by one of the APIs in figure 8:

Contrary to actor reference, an actor context describes the actor's view of the outside world. Because each actor is an independent computational primitive, an actor context is private to the corresponding actor. By using APIs in Figure 9, an actor can (i) retrieve an actor reference corresponding to a given actor path using the `actorFor` method, (ii) create a child actor with 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. Comparing corresponding Akka APIs, our methods take an additional type parameter whose meaning will be explained below.

The two `actorOf` methods are used to create a type-parameterized actor supervised by the current actor. Each created actor is assigned with a typed actor path, an Akka actor path together with a Manifest of the message type. We set up a typed name server in each actor system. When an actor is created, we register the mapping from the assigned typed actor path to typed actor reference in the typed name server inside the actor

```
1 class ServerActor extends TypedActor[String] {
2   def typedReceive = {
3     case m:String => println("received message:
4                               "+m)
5   }
6 }
7 object ServerTest extends App {
8   val system = ActorSystem("ServerTest")
9   val server = system.actorOf(Props[String,
10                                ServerActor], "server")
11
12   server ! "Hello World"
13   // server ! 3
14   // compile error: type mismatch; found : Int(3)
15   // required: String
16
17   val serverString = system.actorFor[String]
18   ("akka://ServerTest/user/server")
19   serverString ! "Hello World"
20   val serverInt = system.actorFor[Int]
21   ("akka://ServerTest/user/server")
22   serverInt ! 3
23 }
24 /*
25 Terminal output:
26 received message: Hello World
27 received message: Hello World
28 Exception in thread "main" java.lang.Exception:
29 ActorRef[akka://ServerTest/user/server] does not
30 exist or does not have type ActorRef[Int] at
31 takka.actor.ActorSystem.actorFor(ActorSystem.scala:223)
32 ...
33 */
```

Figure 7. A String Processor in TAKka

```
1 val props:Props[M] = Props[M, MyActor]
2 val props:Props[M] = Props[M](new MyActor)
3 val props:Props[M] = Props[M](myActor.getClass)
```

Figure 8. Actor Props

system where the created actor resides. By doing this, the `actorFor` method in the `ActorContext` classes can return an actor reference of the desired type, if the actor located at the specified actor path has a compatible type.

4.4 Backward Compatible Hot Swapping

Hot swapping is a desired feature of distributed systems, whose components are typically developed separately. Unfortunately, hot swapping is not supported by the JVM, the platform on which the TAKka library runs.

```

1 abstract class ActorContext[M:Manifest] {
2   def actorOf [Msg] (props: Props[Msg])(implicit
     mt: Manifest[Msg]): ActorRef[Msg]
3   def actorOf [Msg] (props: Props[Msg], name:
     String)(implicit mt: Manifest[Msg]):
     ActorRef[Msg]
4   def actorFor [Msg] (actorPath: String)
     (implicit mt: Manifest[Msg]): ActorRef[Msg]
5   def setReceiveTimeout(timeout: Duration): Unit
6
7   def become[SupM >: M](
8     newTypedReceive: SupM => Unit,
9     newSystemMessageHandler:
10      SystemMessage => Unit,
11     newSupervisorStrategy: SupervisorStrategy
12   )(implicit smt: Manifest[SupM]): ActorRef[SupM]
13 }
14

```

Figure 9. Actor Context

To support hot swapping on an actor’s receive function, system message handler, and supervisor strategy, those three behaviour methods are maintained as object references.

The become method enables hot swapping on the behaviour of an actor. The become method in TAKka is different from behaviour upgrades in Akka in two aspects. Firstly, the supervisor strategy can be updated as well. In the Akka supervisor strategy is an immutable value of an actor. We believe the supervisor strategy is an important behaviour of an actor and it should be as swappable as message handlers. Secondly, hot swapping in TAKka must be backward compatible. In other words, an actor must evolve to a version that is able to handle the same amount of or more message patterns. The above decision is made so that a service published to users will not be unavailable later.

The become method is implemented as in Figure 10. The static type *M* should be interpreted as the least general type of messages addressed by the actor initialized from `TypedActor[M]`. The type value of *SupM* will only be known when the become method is invoked. When a series of become invocations are made at run time, the order of those invocations may be non-deterministic. Therefore, performing dynamic type checking is required to guarantee backward compatibility. Nevertheless, static type checking prevents some invalid become invocations at compile time.

4.5 Supervisor Strategies

The Akka library implements two of the three supervisor strategies in OTP: `OneForOne` and `AllForOne`. If a supervisor adopts the `OneForOne` strategy, a child will be restarted when it fails. If a supervisor adopts the `AllForOne` supervisor strategy, all children will be

```

1 trait ActorContext[M] {
2   implicit private var mt: Manifest[M] = manifest[M]
3
4   def become[SupM >: M](
5     newTypedReceive: SupM => Unit,
6     newSystemMessageHandler:
7      SystemMessage => Unit
8     newSupervisorStrategy: SupervisorStrategy
9   )(implicit smtTag: Manifest[SupM]): ActorRef[SupM]
10   = {
11     val smt = manifest[SupM]
12     if (! (mt <:= smt))
13       throw BehaviorUpdateException(smt, mt)
14     this.mt = smt
15     this.systemMessageHandler =
16       newSystemMessageHandler
17     this.supervisorStrategy = newSupervisorStrategy
18   }
19 }

```

Figure 10. Hot Swapping in TAKka

restarted when any of them fails. The third OTP supervisor strategy, `RestForOne`, restarts children in a user-specified order, and hence is not supported by Akka as it does not specify an order of initialization for children. Simulating the `RestForOne` supervisor strategy in Akka requires ad-hoc implementation that groups related children and defines special messages to trigger actor termination. None of the Erlang examples in section 5 require the `RestForOne` strategy. It is not clear whether the lack of the `RestForOne` strategy will result in difficulties when rewriting Erlang applications in Akka and TAKka.

Figure 11 gives APIs of supervisor strategies in Akka. As in OTP, for each supervisor strategy, users can specify the maximum number of restarts of any child within a period. The default supervisor strategy in Akka is `OneForOne` that permits unlimited restarts. `Directive` is an enumerated type with the following values: The `Escalate` action throws the exception to the supervisor of the supervisor. The `Restart` action replaces the failed child with a new one. The `Resume` action asks the child to process the message again. The `Stop` action terminates the failed actor permanently.

None of the supervisor strategy in Figure 11 requires type-parameterized class to construct. Therefore, from the perspective of API design, both supervisor strategies are constructed in TAKka in the same way as in Akka.

4.6 Handling System Messages

Actors communicate with each other by sending messages. To maintain a supervision tree, a special category


```

1 abstract class SupervisorStrategy
2 case class OneForOne(restart:Int,
   time:Duration)(decider: Throwable =>
   Directive) extends SupervisorStrategy
3 case class OneForAll(restart:Int,
   time:Duration)(decider: Throwable =>
   Directive) extends SupervisorStrategy

```

Figure 11. Supervisor Strategies

of messages should be handled by all actors. We define a trait ² `SystemMessage` to be the supertype of all messages for system maintenance purposes. The five Akka system messages retained in `Takka` are given as follows:

- `ChildTerminated(child: ActorRef[M])`
A message sent from a child actor to its supervisor before it terminates.
- `Kill`
An actor that receives this message will send a `ActorKilledException` to its supervisor.
- `PoisonPill`
An actor that receives this message will be permanently terminated. The supervisor cannot restart the killed actor.
- `Restart`
A message sent from a supervisor to its terminated child asking the child to restart.
- `ReceiveTimeout`
A message sent from an actor to itself when it has not received a message after a timeout.

The next question is whether a system message should be handled by the system or by users. In Erlang and early Akka versions, all system messages could be explicitly handled by users in the receive block. In recent Akka versions, some system messages are handled in the library implementation and are not accessible by library users.

As there are only two kinds of supervisor strategies to consider, both of which have clearly defined operational behaviours, all messages related to the liveness of actors are handled in the `Takka` library. Library users may indirectly affect the system message handler via specifying the supervisor strategies. In contrast, messages related to the behaviour of an actor, e.g. `ReceiveTimeout`, are better to be handled by application developers. In `Takka`, `ReceiveTimeout` is the only system message that can be explicitly handled by users.

² A trait in Scala is similar to a JAVA abstract class, but trait permits multiple inheritance.

Nevertheless, we keep the `SystemMessage` trait in the library so that new system messages can be included in the future if needed.

A key design decision in `Takka` is to separate the system message and user-defined message handlers. The above decision has two benefits. Firstly, the type parameter of actor-related classes only denotes the type of user defined messages rather than the untagged union of user defined and system messages. Therefore, the `Takka` API applies to systems that do not support an untagged union type. Secondly, since system messages can be handled by the default handler, which applies to most applications, users can focus on the logic of handling user defined messages.

4.7 Design Alternatives

Akka Typed Actor In the Akka library, there is a special class called `TypedActor`, which contains an internal actor and could be supervised. Users of Akka typed actors invoke a service by calling a method instead of sending messages. Code in Figure 12 demonstrates how to define a simple string processor using Akka typed actor. Akka typed actors prevent some type errors but have two limitations. Firstly, Akka typed actors do not permit hot swapping on its behaviours. Secondly, avoiding type pollution by using Akka typed actors is as awkward as by using a plain object-oriented model, where supertypes need to be introduced. In Scala and Java, introduce a super type in a type hierarchy requires modification to all affected subtypes.

```

1 trait MyTypedActor{
2   def processString(m:String)
3 }
4 class MyTypedActorImpl(val name:String) extends
   MyTypedActor{
5   def this() = this("default")
6
7   def processString(m:String) {
8     println("received message: "+m)
9   }
10 }
11 object FirstTypedActorTest extends App {
12   val system = ActorSystem("MySystem")
13   val myTypedActor:MyTypedActor =
14     TypedActor(system).typedActorOf(
15       TypedProps[MyTypedActorImpl]())
16   myTypedActor.processString("Hello World")
17 }
18
19 /*
20 Terminal output:
21 received message: Hello World
22 */

```

Figure 12. Akka TypedActor Example

Actors with or without Mutable States The actor model formalised by Hewitt et al. [Hewitt et al. 1973] does not specify its implementation strategy. In Erlang, a functional programming language, actors do not have mutable states ♠**Erlang actors may evolve to new actors with a different state value** ♠. In Scala, an object-oriented programming language, actors may have mutable states. The TAKka library is built on top of Akka and implemented in Scala. As a result, TAKka does not prevent users from defining actors with mutable states. Nevertheless, the authors of this paper encourage the use of actors in a functional style, for example encoding the sender of a synchronous message as part of the incoming message rather than a state of an actor, because it is difficult to synchronize mutable states of replicated actors in a cluster environment.

In a cluster, resources are replicated at different locations to provide efficient fault-tolerant services. The CAP theorem [Gilbert and Lynch 2002] states it is impossible to achieve consistency, availability, and partition tolerance in a distributed system simultaneously. For actors that contain mutable states, system providers have to either sacrifice availability or partition tolerance, or modify the consistency model. For example, Akka actors have mutable state and Akka cluster developers spend a great effort to implement an eventual consistency model [Kuhn et al. 2012]. If an actor can define its behaviour without using mutable states, as evidenced by the success of RESTful web services, the actor is more likely to have a good scalability and availability.

Bi-linked Actors In addition to one-way linking in the supervision tree, Erlang and Akka provide mechanism to define two-way linkage between actors. Bi-linked actors are aware of the liveness of each other. We consider bi-linked actors is a redundant design in a system where supervision is obligatory. Notice that, if the computation of an actor relies on the liveness of another actor, those two actors should be organised in the same supervision tree.

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 equivalent generic version (evolution), rather than requiring use generic types everywhere (revolution) [Naftalin and Wadler 2006].

In previous sections, we have seen how to use Akka actors in an Akka system (Figure 2) and how to use

TAKka actors in a TAKka system (Figure 7). In the following, we will explain how to use TAKka actors in an Akka system and use an Akka actor in a TAKka system.

5.1 TAKka actor in Akka system

It is often the the case that an actor-based library is implemented by one organisation but used in a client application implemented by another organisation. If a developer decided to upgrade the library implementation using TAKka actors, for example, upgrading the Socko Web Server [Imtarnasan and Bolton 2012], the Gatling [Excilys Group 2012] stress testing tool, or the core library of the Play framework [Typesafe Inc. (c) 2013] as we have done in Section 6.2, how would the upgrade affects client code, especially legacy applications built using the Akka library? TAKka actor and actor reference are implemented using inheritance and delegation respectively so that no changes are required for legacy applications.

TAKka actors inherits Akka actors. In Figure 13, the actor implementation is upgraded to the TAKka version as in Figure 7. The client code, line 15 through line 25, is the same as the old Akka version as given in Figure 2. That is, no changes are required for the client application.

TAKka actor reference delegates the task of message sending to an Akka actor reference, its `untypedRef` field. In line 31 below, we get an untyped actor reference from `typedserver` and use the untyped actor reference in code where an Akka actor reference is expected. Because untyped actor reference accepts messages of any type, messages of unexpected may be sent to TAKka actors if Akka actor reference is used. As a result, users who are interested in the `UnhandledMessage` event need to subscribe the event stream as in line 33.

5.2 Akka Actor in TAKka system

Sometimes, developers want to update client code before actor is upgraded. For example, a developer may not have the access to the actor code; or the library may be large, so the developer may want to upgrade the library gradually.

Users can initialise a TAKka actor reference by providing an Akka actor reference and a type parameter. In Figure 14, we re-use the Akka actor, initialise the actor in an Akka actor system, and obtained an Akka actor reference as in Figure 2. Then, we initialise an TAKka actor reference, `takkaServer`, which only accepts String messages.

6. Library Evaluation

This section presents preliminary evaluation results of the TAKka library. We show that the Wadler's type pollution problem can be avoided in a straightforward way

```

1 class TakkaServerActor extends
  takka.actor.TypedActor[String] {
2   def typedReceive = {
3     case m:String => println("received message:
      "+m)
4   }
5 }
6
7 class MessageHandler(system:
  akka.actor.ActorSystem) extends
  akka.actor.Actor {
8   def receive = {
9     case akka.actor.UnhandledMessage(message,
      sender, recipient) =>
10      println("unhandled message:"+message);
11   }
12 }
13
14 object TakkaInAkka extends App {
15   val akkasystem =
    akka.actor.ActorSystem("AkkaSystem")
16   val akkaserver = akkasystem.actorOf(
    akka.actor.Props[TakkaServerActor], "server")
17
18   val handler = akkasystem.actorOf(
    akka.actor.Props(new
      MessageHandler(akkasystem)))
19
20   akkasystem.eventStream.subscribe(handler,
    classOf[akka.actor.UnhandledMessage]);
21   akkaserver ! "Hello Akka"
22   akkaserver ! 3
23
24   val takkasystem =
    takka.actor.ActorSystem("TakkaSystem")
25   val typedserver = takkasystem.actorOf(
    takka.actor.Props[String, ServerActor],
      "server")
26
27   val untypedserver = takkaserver.untypedRef
28
29   takkasystem.system.eventStream.subscribe(
    handler, classOf[akka.actor.UnhandledMessage]);
30
31   untypedserver ! "Hello Takka"
32   untypedserver ! 4
33 }
34
35 /*
36 Terminal output:
37 received message: Hello Akka
38 unhandled message:3
39 received message: Hello Takka
40 unhandled message:4
41 */

```

Figure 13. Takka actor in Akka application

```

1 class AkkaServerActor extends akka.actor.Actor {
2   def receive = {
3     case m:String => println("received message:
      "+m)
4   }
5 }
6
7 object AkkaInTakka extends App {
8   val system = akka.actor.ActorSystem("AkkaSystem")
9   val akkaserver = system.actorOf(
    akka.actor.Props[AkkaServerActor], "server")
10
11   val takkaServer = new
    takka.actor.ActorRef[String]{
12     val untypedRef = akkaserver
13   }
14
15   takkaServer ! "Hello World"
16   // takkaServer ! 3
17 }
18
19 /*
20 Terminal output:
21 received message: Hello World
22 */

```

Figure 14. Akka actor in TAKka application

by using TAKka. We further assess the TAKka library by porting examples written in Erlang and Akka. Results show that TAKka detects type errors without bringing obvious runtime and code-size overheads.

6.1 Wadler's Type Pollution Problem

Wadler's type pollution problem refers to the situation where a communication interface of a component publishes too much type information to another party and consequently that party can send the component a message not expected from it. Without due care, actor-based systems constructed using the layered architecture or the MVC model

One solution to the type pollution problem is using separate channels for distinct parties. Programming models that support this solution includes the join-calculus [Fournet and Gonthier 2000] and the typed π -calculus [Sangiorgi and Walker 2001].

Another solution to the type pollution problem is to use polymorphism. Take the code template in Figure 15 for example. Let V2CMessage and M2CMessage be the type of messages expected from the View and the Model respectively. Both V2CMessage and M2CMessage are subtypes of ControllerMsg, which is the least general type of messages expected by the controller. In the template code, the controller publishes itself as different types to the view actor and model actor.

Therefore, both the view and the model only know the communication interface between the controller and itself. The `ControllerMsg` is a sealed trait so that users cannot define a subtype of `ControllerMsg` outside the file and send the controller a message of unexpected type. Although type convention in line 21 and line 22 could be omitted, we explicitly use the `publishAs` to express our intentions and let the compiler check the type safety. The Tik-Tak-Tok example in the TAKka code repository is developed from the given code template.

```

1 sealed trait ControllerMsg
2 class V2CMessage extends ControllerMsg
3 class M2CMessage extends ControllerMsg
4
5 trait C2VMessage
6 fcase class
7   ViewSetController(controller:ActorRef[V2CMessage])
8   extends
9     C2VMessage
10  trait C2MMessage
11  case class
12    ModelSetController(controller:ActorRef[M2CMessage])
13    extends
14      C2MMessage
15
16 class View extends TypedActor[C2VMessage] {
17   private var controller:ActorRef[V2CMessage] =
18     // rest of implementation
19 }
20
21 class Model extends TypedActor[C2MMessage] {
22   private var controller:ActorRef[M2CMessage] =
23     // rest of implementation
24 }
25
26 class Controller(model:ActorRef[C2MMessage],
27   view:ActorRef[C2VMessage]) extends
28   TypedActor[ControllerMessage] {
29   override def preStart() = {
30     model ! ModelSetController(
31       typedSelf.publishAs[M2CMessage])
32     view ! ViewSetController(
33       typedSelf.publishAs[V2CMessage])
34   }
35   // rest of implementation
36 }

```

Figure 15. Template for Model-View-Controller

6.2 Expressiveness and Correctness

Table 2 lists examples used for expressiveness and correctness. We selected examples from Erlang Quiviq [Arts et al. 2006] and open source Akka projects to ensure that the main requirements for actor programming are not unintentionally neglected. Examples from Erlang Quiviq are re-implemented using both

Akka and TAKka. Examples from Akka projects are re-implemented in TAKka. We assess the overhead of code modification and code size by calculating the geometric mean of all examples, according to the methodology suggested by Hennessy and Patterson [Hennessy and Patterson 2006]. We give the evaluation results in Table 3. Results show that when porting an Akka program to TAKka, about 7.4% 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.

A type error is reported by the compiler when porting the Socko example [Imtarnasan and Bolton 2012] from its Akka implementation to 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 `Method`, whose `unapply` method intends to pattern match `SockoEvent` to `HttpRequestEvent`. The SOCKO designer made a type error in the method declaration so that the `unapply` method pattern matches `SockoEvent` to `SockoEvent`. The type error is not exposed in test examples because the designer always passes instances of `HttpRequestEvent` to the `unapply` method and send the returned values to an actor that accepts messages of `HttpRequestEvent` type. Fortunately, the design flaw is exposed by the compiler when upgrading the SOCKO implementation using TAKka.

6.3 Performance, Throughput, and Scalability

The TAKka library is built on top of Akka so that code for shared features can be re-used. The three main source of overheads in the TAKka implementation are: (i) the cost of adding an additional operation layer on top of Akka code, (ii) the cost of constructing type descriptor, and (iii) the cost of transmitting type descriptor in distributed settings. We assess the upper bound of the cost of the first two factors by a micro benchmark which assesses the time of initializing n instances of `MyActor` defined in Figure 2 and Figure 7. When n ranges from 10^4 to 10^5 , the TAKka implementation is about 2 times slower as the Akka implementation. The cost of the last factor is close to the cost of transmitting the string representation of fully qualified type names.

We use the JSON serialization example [TechEmpower, Inc. 2013] to compared the throughput of 4 web services built using Akka Play, TAKka Play, Akka Socko, and TAKka Scoko. For each HTTP request, the example gives an HTTP response with pre-defined content. Web services are deployed to Amazon EC2 instances

Source	Example	Description	number of actor classes
Quviq [Arts et al. 2006]	ATM simulator	A bank ATM simulator with backend database and frontend GUI.	5
	Elevator Controller	A system that monitors and schedules a number of elevators.	6
Akka Documentation [Typesafe Inc. (b) 2012]	Ping Pong	A simple message passing application.	2
	Dining Philosophers	A application that simulates the dining philosophers problem using Finite State Machine (FSM) model.	2
	Distributed Calculator	An application that examines distributed computation and hot code swap.	4
	Fault Tolerance	An application that demonstrates how system responses to component failures.	5
Other Open Source Akka Applications	Barber Shop [Zachrisson 2012]	A application that simulates the Barber Shop problem.	6
	EnMAS [Doyle and Allen 2012]	An environment and simulation framework for multi-agent and team-based artificial intelligence research.	5
	Socko Web Server [Imtarnasan and Bolton 2012]	lightweight Scala web server that can serve static files and support RESTful APIs	4
	Gatling [Excilys Group 2012]	A stress testing tool.	4
	Play Core [Typesafe Inc. (c) 2013]	A Java and Scala web application framework for modern web application development.	1

Table 2. Examples for Correctness and Expressiveness Evaluation

Source	Example	Akka Code Lines	Modified Takka Lines	% of Modified Code	TAkka Code Lines	% of Code Size
Quviq	ATM simulator	1148	199	17.3	1160	101
	Elevator Controller	2850	172	9.3	2878	101
Akka Documentation	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	754	104	13.7	751	99
	EnMAS	1916	213	11.1	1909	100
	Socko Web Server	5024	227	4.5	5017	100
	Gatling	1635	111	6.8	1623	99
	Play Core	27095	15	0.05	27095	100
geometric mean		991.7	71.6	7.4	992.1	100.0

Table 3. Results of Correctness and Expressiveness Evaluation

with a Load Balancer. All EC2 instances are Micro instances (t1.micro) with 0.615GB Memory. We use shell script to spawn 1200 siege tests [Jeff Fulmer 2013] in parallel. Each siege test sends 500 requests in its benchmark mode. The result summarised in Figure 20 shows the throughput is approximately linear to the number

of EC2 instances, before we reaching the limit of the bandwidth.

We further investigated the efficiency and scalability of TAKka by porting 6 micro benchmark examples, listed in Table 4, from the BenchErl benchmarks in the RELEASE project [Boudeville et al. 2012]. Each BenchErl benchmark spawns one master process and

Example	Description
bang	This benchmark tests many-to-one message passing. The benchmark spawns a specified number sender and one receiver. Each sender sends a specified number of messages to the receiver.
big	This benchmark tests many-to-many message passing. The benchmark creates a number of actors that exchange ping and pong messages.
ehb	This is a benchmark and stress test. The benchmark is parameterized by the number of groups and the number of messages sent from each sender to each receiver in the same group.
mbrot	This benchmark models pixels in a 2-D image. For each pixel, the benchmark calculates whether the point belongs to the Mandelbrot set.
ran	This benchmark spawns a number of processes. Each process generates a list of ten thousand random integers, sorts the list and sends the first half of the result list to the parent process.
serialmsg	This benchmark tests message forwarding through a dispatcher.

Table 4. Examples for Efficiency and Scalability Evaluation

many child processes for a tested task. Each child process is asked to perform a certain amount of calculation and report the result to the master process. The benchmarks are run on a Beowulf cluster at the Heriot-Watt University. The 32 Beowulf cluster nodes each comprise 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 with 48 10/100/1000 ports.

Figure 16 and 17 reports the results the BenchErl benchmarks. We report the average and the standard deviation of the run-time of each example. Depending on the ratio of the calculation time and the I/O time, benchmark examples scales at different levels. In all examples, Takka and Akka implementations have almost identical run-time and scalability.

6.4 Assessing System Reliability

The supervision tree principle is adopted by Erlang and Akka users with the hope of improving the reliability of software applications. Apart from the reported nine "9"s reliability of Ericsson AXD 301 switch [Armstrong, Joe 2002] and the wide range of Akka use cases, how could software developers assure the reliability of their newly implemented applications?

Takka is shipped with a Chaos Monkey library and a Supervision View library for assessing the reliability of Takka applications. A Chaos Monkey test randomly kills actors in a supervision tree and a Supervision View test dynamically captures the structure of supervision trees. With the help of Chaos Monkey and Supervision View, users can visualize how their Takka applications react to adverse conditions. Missing nodes in the supervision tree (Section 6.4.2) show that failures occur during the test. On the other hand, any failed actors are restored, and hence appropriately supervised applications (Section 6.4.3) pass Chaos Monkey tests.

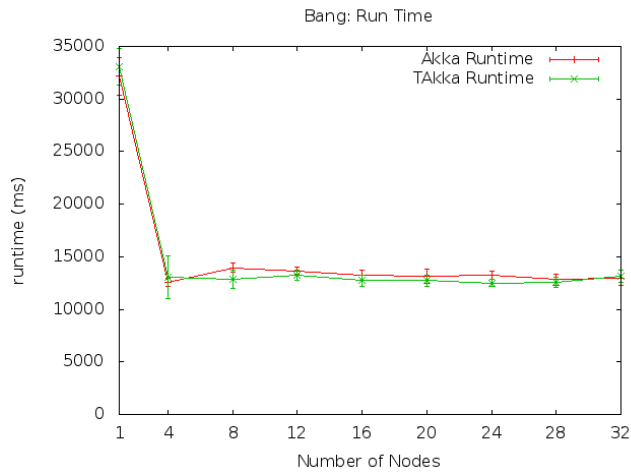
6.4.1 Chaos Monkey and Supervision View

Chaos Monkey [Netflix, Inc. 2013] randomly kills Amazon Elastic Compute Cloud (Amazon EC2) instances in an Auto Scaling Group. In a Chaos Monkey test, the reliability of an application is tested against an intensive adverse conditions. The same idea is ported into Erlang to detect potential flaws of supervision trees [Luna 2013]. We port the Erlang version of Chaos Monkey into the Takka library. In addition to randomly killing actors, users can simulate other common failures by using other modes in Table 5.

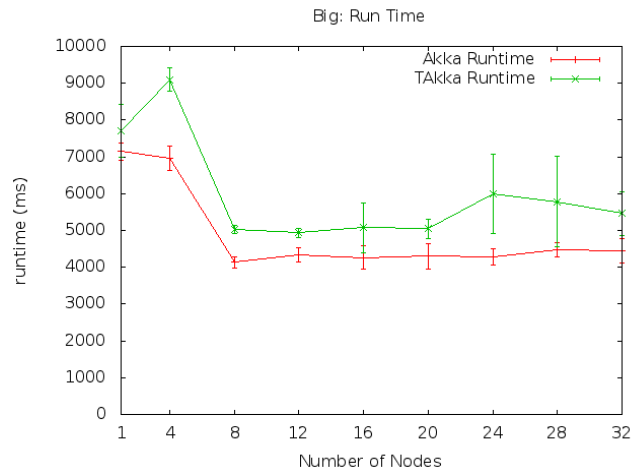
To dynamically monitor changes of supervision trees, we design and implement a Supervision View library. In a supervision view test, an instance of ViewMaster periodically sends request messages to interested actors of a target Takka application. On the time when the request message is received, an active Takka actor replies its status to the view master and pass the request message to its children. The status message includes its actor path, paths of its children, and the time when the reply is sent. The view master records received status messages and passes them to a visualiser, which analyzes and interprets changes of the tree structure during the testing period, at the end of the test.

6.4.2 A Partly Failed Safe Calculator

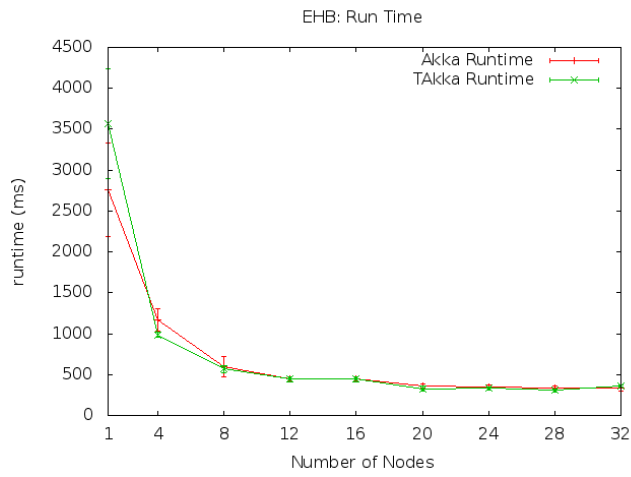
In the hope that Chaos Monkey and Supervision View tests can reveal breaking points of a supervision tree, we modify the Safe Calculator example and run a test as follows. Firstly, we run three safe calculators on three Beowulf nodes, under the supervision of a root actor using the OneForOne strategy with Restart action. Secondly, we set different supervisor strategies for each safe calculator. The first safe calculator, S1, restart its failed child immediately. The second safe calculator, S2, computes a Fibonacci number in a naive way for about 10 seconds before restarting failed child.



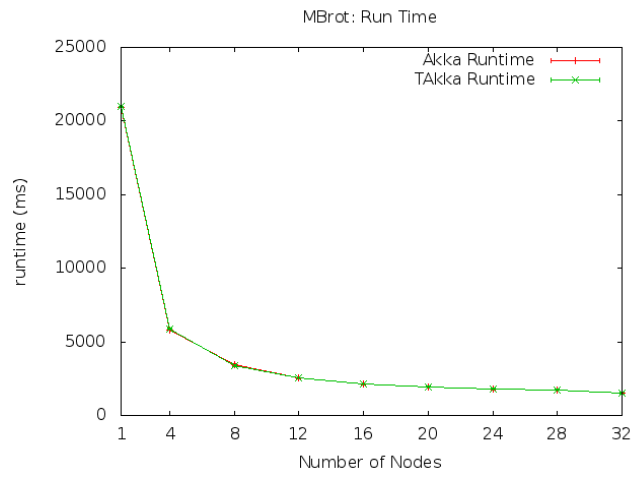
(a)



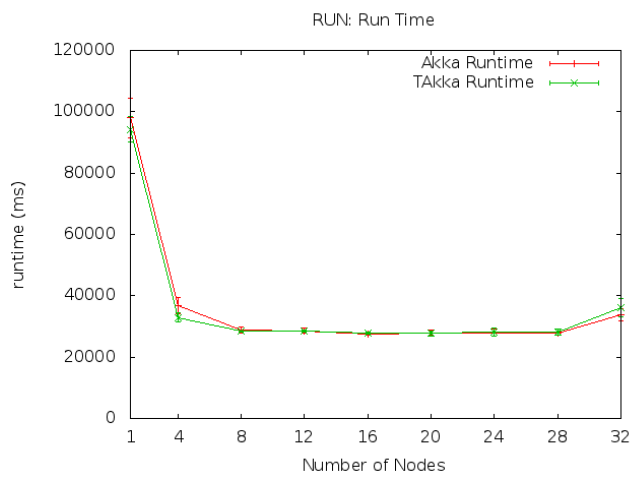
(b)



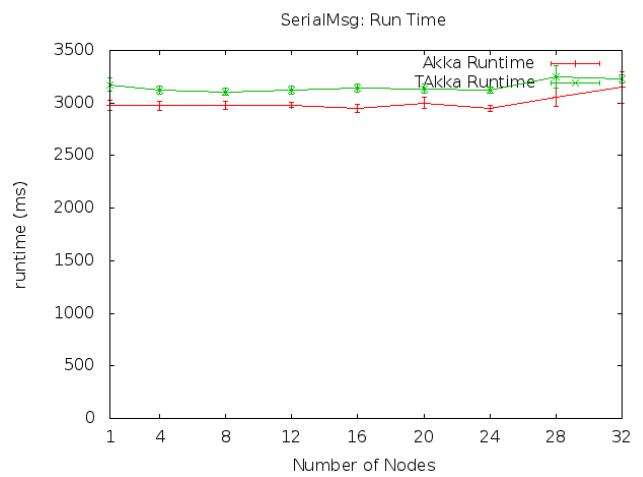
(c)



(d)

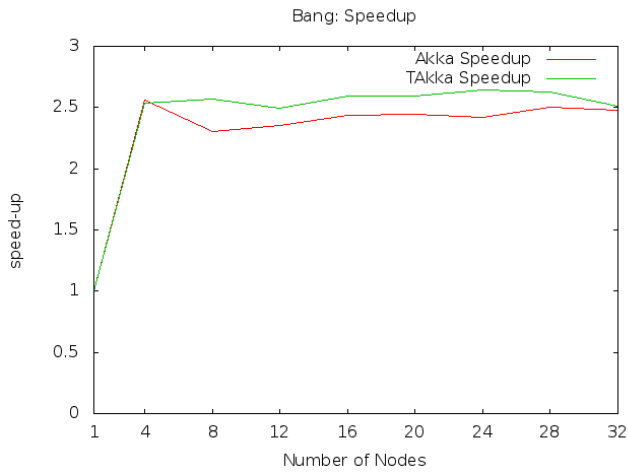


(e)



(f)

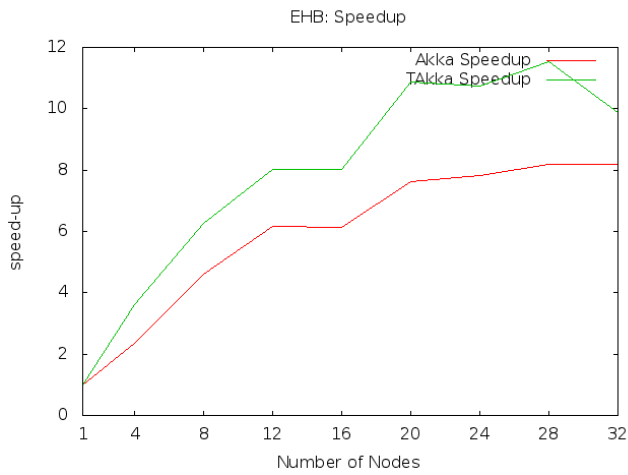
Figure 16. Runtime Benchmarks



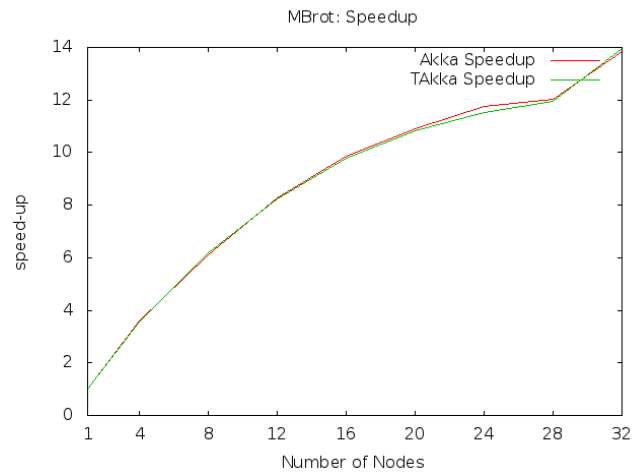
(a)



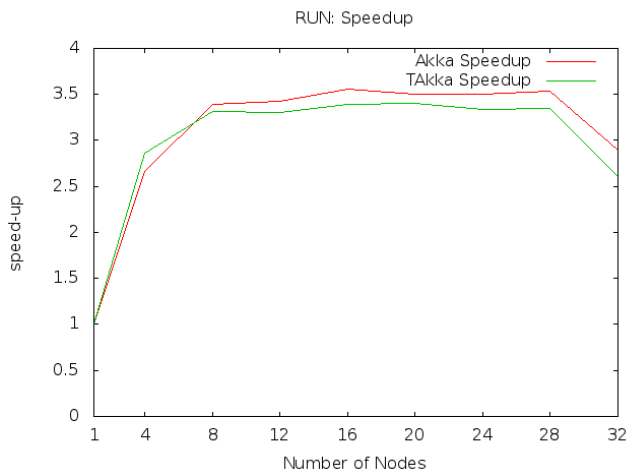
(b)



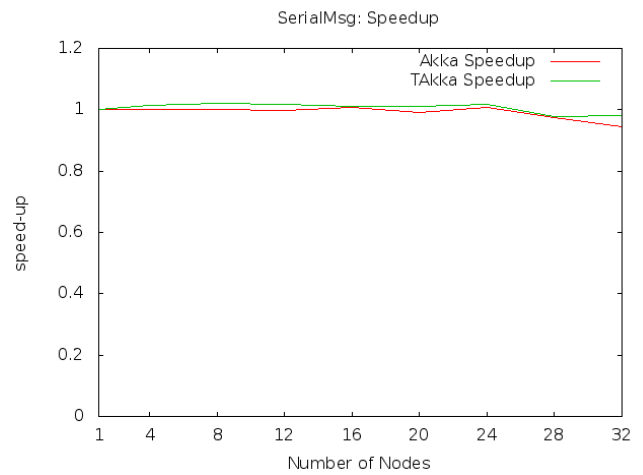
(c)



(d)



(e)



(f)

Figure 17. Scalability Benchmarks

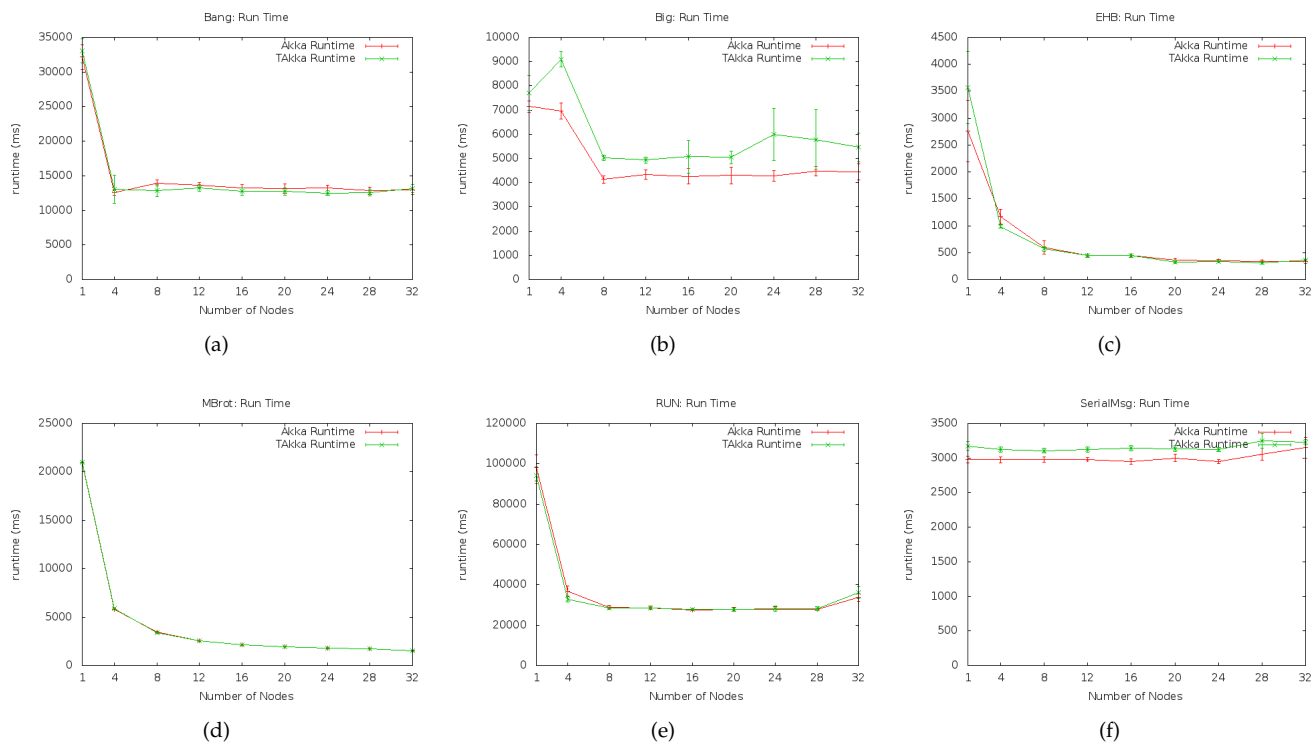


Figure 18. Runtime Benchmarks 2

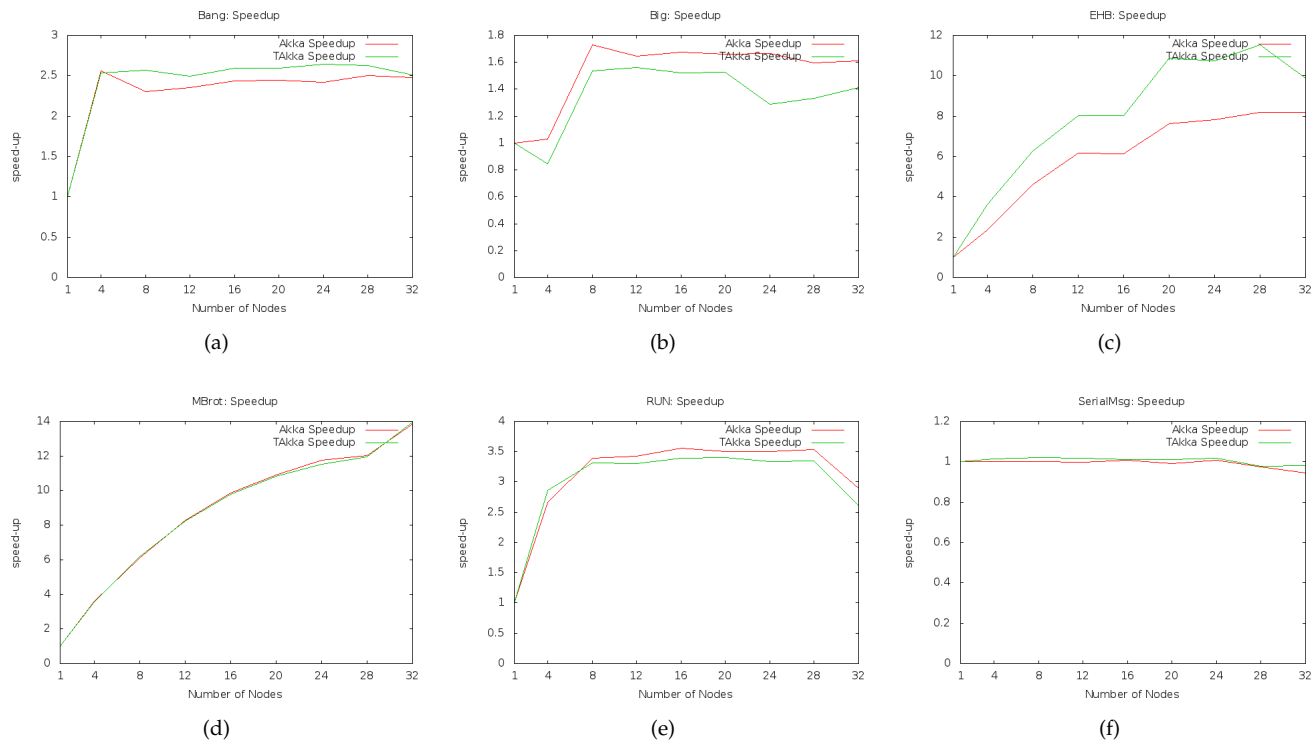


Figure 19. Scalability Benchmarks 2

Mode	Failure	Description
Random (Default)	Random Failures	Randomly choose one of the other modes in each run.
Exception	Raise an exception	A victim actor randomly raise an exception from a user-defined set of exceptions.
Kill	Failures that can be recovered by scheduling service restart	Terminate a victim actor. The victim actor can be restarted later.
PoisonKill	Unidentifiable failures	Permanently terminate a victim actor. The victim cannot be restarted.
NonTerminate	Design flaw or network congestion	Let a victim actor run into an infinite loop. The victim actor consumes system resources but cannot process any messages.

Table 5. Takka Chaos Monkey Modes

The third safe calculator, *S3*, stops the child when it fails. Finally, we set-up the a Supervision View test which captures the supervision tree every 15 seconds, and a Chaos Monkey test which tries to kill a random child calculator every 3 seconds.

A test result, given in figure 21, gives the expected tree structure at the beginning, 15 seconds and 30 seconds of the test. Figure 21(a) shows that the application initialized three safe calculators as described. In Figure 21(b), *S2* and its child are marked as dashed circle because it takes the view master more than 5 seconds to receive their responses. From the result of this test, we cannot tell whether the delay is due to a blocked calculation or a network congestion. Comparing to Figure 21(a), the child of *S3* is not shown in Figure 21(b) and Figure 21(c) because no response is received from it until the end of the test. As the test only runs for slightly more than 30 seconds, no responses to the last request are received from *S2* and its child. Therefore, both *S2* and its child are not shown in Figure 21(c). *S1* and its child appear in all three Figures because either they never fail during the test or they are recovered from failures within time. In both cases, they are considered as alive in this test.

6.4.3 BenchErl Examples with Different Supervisor Strategies

To testing the behaviour of applications with internal states under different supervisor strategies, we apply the *OneForOne* supervisor strategy with different failure actions to the 8 BenchErl examples and test those examples using Chaos Monkey and Supervision View. The master node of each BenchErl tests is initialized with an internal counter. The internal counter decrease when the master node receives a finishing messages from its children. The test application stops when the internal counter of the master node reaches 0. We set the Chaos Monkey test with the *Kill* mode and

randomly kill a victim actor every second. When the *Escalate* action is applied to the master node, the test stops as soon as the the first *Kill* message sent from the Chaos Monkey test. When the *Stop* action is applied, the application does not stop and, eventually, the supervision view test only receives messages from the master node. When the *Restart* action is applied, the application does not stop but the supervision view test receives messages from the master node and its children. When the *Resume* action is applied, all tests stops eventually with a longer run-time comparing to tests without ChaosMonkey and Supervision View tests.

7. Conclusion

Existing actor systems accept dynamically typed messages. The Takka library introduces a type-parameter for actor-related classes. The additional type-parameter of a Takka actor specifies the communication interface of that actor. With the help of type-parameterized actors, unexpected messages to actors are rejected at the compile time.

In addition to eliminating programming bugs and type errors, programmers would like to have a failure recovery mechanism for g unexpected run-time errors. We are glad to see that type-parameterized actors can form supervision trees in the same way as regular actors.

Lastly, tests show that building type-parameterized actors on top of Akka does not introduce significant overheads, with respect to program size, efficiency, and scalability. The above test results are encouraging in the sense that many previous actor library implementations can be re-used. We expect similar results can be obtained in other OTP-like libraries such as future extensions of CloudHaskell [Watson et al. 2012].

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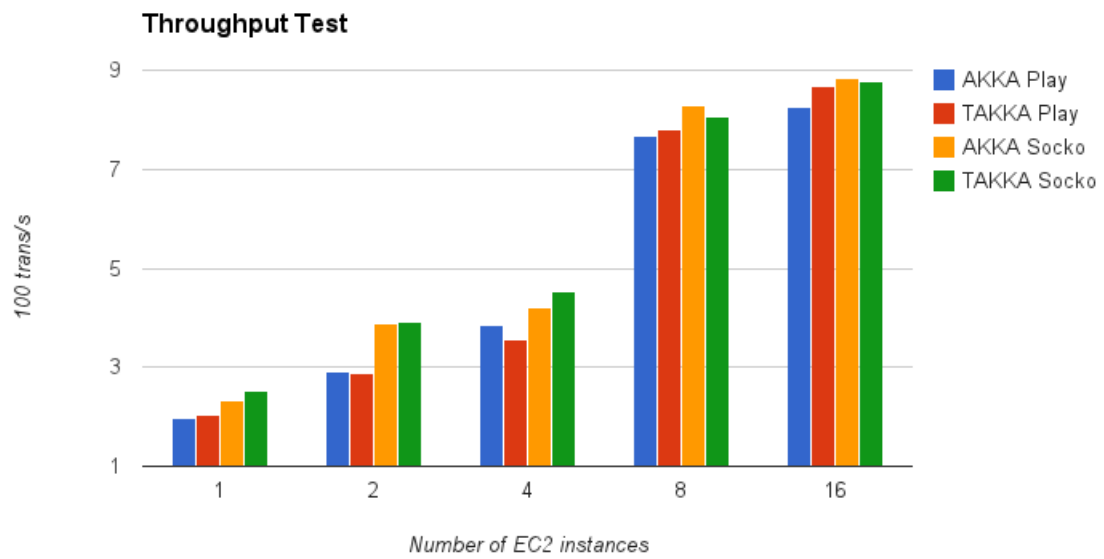


Figure 20. Throughput Benchmarks

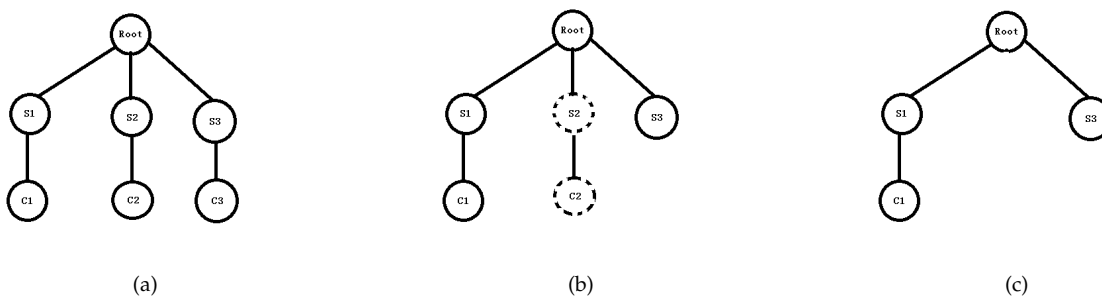


Figure 21. Supervision View Example