Monoids for Monadic Composition

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Abstract

This paper deals with designing an asynchronous concurrent framework built to produce constraints of correct by construction by designing a mechanism where components can perform their operations independently without disturbing the order of their communication and by dealing concurrency side effects. We have developed three different types of monoids (function under composition) to establish communication and coordination between sender and receiver.

Keywords: Promise, Monads, Actors, Concurrency, Eventloop, Frameworks, single thread model, Correct by Construction.

I. INTRODUCTION

The actor model proposed by us uses two queue (Mailbox for storing message to process and callback queue for storing processed response) as shown in figure 1.

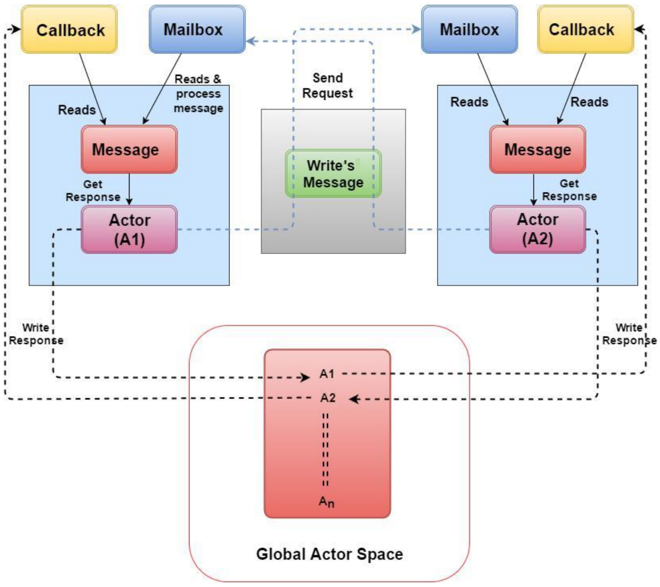


Fig. 1: Request/Reply in actor-based framework

Every actor writes their messages to other actor's mailbox for sending their request to be processed. The response sent by another actor is written back to callback queue of the actors. Every actor reads it's mailbox queue after reading the messages of it's callback queue. Finally, each actor is copied to global actor space of a single thread. Thus works as a single threaded model and each actor may work as publisher and subscriber. We are using our actor-based framework as shown in figure 1. It has different actors with their mailbox and callback queue.

The motivation for the presented research work is drawn based on answering the set of following questions and identifying the gaps in research reported in literature so far.

Why promises are required?

Why to design Promise Based Actor Framework(PBAF)?

How to design the PBAF?

Why not use any architectural language to represent architecture of PBAF system?

Why the Petri net has been selected as modeling language to model composed system?

What are the related works in Petri net based composition system and how the current model is different than others?

How the PBAF is flexible than already available component models?

What is the significant improvement by using asynchronous over synchronous communication and promises over callback ?

This dissertation tried to answer all of the questions in the consequent chapters. The following details mentioned in the table I, summarizes the issues addressed to find the research gaps. The table II summarizes the steps to logically conclude the requirement of promises and table III logically conclude the purpose and process adopted while designing Promise Based Actor Framework(PBAF).

Examples of pure actor languages include Erlang [6], SALSA [7], E [8], AmbientTalk [9], and Kilim [10]. The major benefit of pure actor languages is that the developer gets strong safety guarantees: low-level data races are ruled out by design. But java based actor libraries such as ActorFoundry [11], Actor Architecture[12],ProActive[13] AsyncObjects[14] , Javact[15] and Jetlang[16] have in common that they do not enforce actor isolation, i. e., they cannot guarantee that actors do not share mutable state. The java based actor libraries have been introduced prior to the release of java 8, thus do not use lambdas and monads as functional programming constructs. Motivated by Category theory[18] and paper[19] we decided to use promise as monads[20] to control concurrency and Actors to maintain state and provide message endpoints. This paper is organized as followed: Section II introduces the proposed concurrency based actor model framework and challenges associated in designing the framework, Section III discuss the hypothesis 1, that unifies object and thread to design actor model, Section IV discuss the hypothesis 3, which uses monoids to establish indeterministic monadic composition and side effects occuring due to concurrency. Finally Section VII introduces conclusion and future work.

TABLE I: Summary shows need of PBAF

Why to design Promise Based Actor Framework(PBAF)?				
1.	2009	Karmani et al.[21]	In order to deal with the concurrency issues, emphasis has been given to design isolated computations, Scheduling guarantees, Reflection with immutable values and pure functions.	All the sequential programming languages such as Java, C++ and Object C are not considered fit to implement Shared Memory concurrent communication, because they share mutable values which results race condition.
2.	2009	Karmani et al.[21]	Actor based functional languages e.g. Scala, Salsa etc. addresses the concurrency constructs such as immutability and pure functions	These actor based functional frameworks uses continuation mechanism to implement synchronization which suffers with inversion of control issues.
3.	2012	Elkady et al.[22]	represents the survey of different existing component models such as MARIE, OROCOS, ROS etc.	They have been designed using high level languages and they do not support concurrency by default.
4.	2008	William Zwicky. [23]	Focus on designing Java based actor frameworks.	These frameworks designed on Java do not support promise based construction and also do not provide separation of concerns for coordination. These frameworks have been designed prior to release of Java 8, thus do not support functional programming construct necessary for immutability. Hence these frameworks are error prone to race conditions.

TABLE II: Logical conclusion of promise requirement

Why Promises are Required?				
Sr.No.	Year	Author	Approach & Process	Existing Problem
1.	2005	Joseph Sifakis[24]	Three existing sources of heterogeneity: interaction, execution and abstraction have been identified. Designed BIP framework	BIP is a theoretical framework. No real implementation of this framework exists.
2.	2015	Sharma et.al.[25]	Various architectures have been suggested to address issues of Heterogeneity	No formalism of architecture composition has been mentioned
3.	1997	Medvidovic et al. [26]	Architecture is represented using languages AADL and UML	These languages are not good in representing functional and Non functional attribute of an architecture
4.	2016	Attie, Sifakis et.al.[27]	Architecture composition for coordination using associative, commutative and identity operator	Coordination produces concurrency and no real construct in implementation language to represent coordination constraints
5.	2009	Haller and Odesky[28],Lee	Shared memory vs. messages passing implementation of concurrency using multi threaded request/response, topics or queues	Languages such as Java,C++ are synchronous due to underlying hardware synchronous constraint. Thus they do not use non blocking asynchronous communication of concurrency. Concurrency is hard in Imperative Languages
6.	2008	William Zwicky[23]	Non blocking asynchronous functionality is provided using Actor model	Model has got non blocking asynchronous support but they must be synchronized to coordinate
7.	2015	Brodu, Etienne et.al.[29]	Synchronization of non blocking asynchronous communication using listeners, callbacks & promises. Suggested to use promises to address Callback Hell issues	Callback mechanism for synchronization produces problem of callback hell due to inversion of control.

TABLE III: Logical conclusion of purpose and processes required in designing PBAF

How to design Promise Based Actor Framework(PBAF)?		
Sr. No.	**Purpose**	**Process**
1.	To include built in functionality of concurrency in the framework developed using language Java i.e. concurrency in communication	To support built in concurrency, it is upposed to design non blocking asynchronous support by implementing Actor concept using Java language
2.	Concurrent framework must implement synchronization due to the constraints of underlying hardware synchrony i.e. concurrency in computation	Provide non blocking synchrony using single thread event loop architecture.
3.	To implement the coordination mechanism between the process exhibiting concurrent behaviours i.e. Concurrency coordination.	Actors communicate with another actor directly as peer to peer communication. Enqueue() method of actors enqueuer the messages of other actors in their mailboxes. Coordination among actors are provided through monoids. Monoids are constructed based on the concept of pipelining, continuation and termination.
4.	To implement the configuration mechanism between the process exhibiting concurrent behaviours i.e. Concurrency configuration	The framework provides support for dynamic configuration using enqueue and dequeue operation to read and write values from the mailboxes of actors. To support type safety and possibility to inheriting actors framework uses Actor Proxy as a wrapper of a real actor. So composition is supported through proxy.

II. PROPOSED CONCURRENCY ACTOR MODEL

We want to develop a framework which accepts the request as a promise and produces the response as promise. The request as a promise is handled by actor proxy. This promise as a request is passed to promise based concurrent abstraction layer that, provides facility of concurrency with side effects by composing two or more services. Consider a system like in figure 2, It contains a serving counter which accepts request from actors A1, A2, A3,......, A_n and serving requests provided by these actors only. So these actors act as dynamic requesters (sender) and server (receiver), dynamic because the requester may act as server and server may act as a requestor. The figure 3, shows customer and chef demonstration, where a customer may act as a chef and chef may act as a customer. The counter is like a message channel where the requests are enqueued. Actor A2 is requesting A1 to process the chicken message. This message will be enqueued in channel(counter) as fA2, A1, chickeng written in A1's mailbox for further processing. Similarly A1 orders A2 to process Egg, so channel enqueues f A1, A2, Eggg and A1 writes message Egg to A2's mailbox for further processing. Actors acting as chef reads messages from their mailbox, filter out the messages, process it and writes the response to its CallbackQueue. Finally, a customer reads the CallbackQueue and gets its response.

Thus, customers places their orders in the mailbox of receiving actors and receiving actors process those messages and they put the processed messages in the callback queue of sending actors. So here we have two queues, one for storing messages to be processed and another for processed messages. The purpose of taking these two queues is to separate the storage of sender and receiver. Sender uses callback quueue and receiver uses mailbox queue. Counter represents a loop which is always ready to accept messages as and when they arrive so it acts as an event loop.

An actor can be regarded as an advanced version of thread with data structures. So we can choose a dedicated thread to an actor or more than one actor assigned to a particular single thread. We get single threaded logic by binding data structure to a thread under execution.

In our framework, a message using a method call is exe-cuted asynchronously and a call to a method is automatically transformed into a message and later put into the queue(actor's mailbox). All the messages stored in the queue are processed asynchronously in a single threaded environment.

III. MONADIC COMPOSITION THROUGH MONOID

You can take any sequential program and turn it to purely functional program by doing continuation passing style(CPS) which transforms to basically sent state as argument to the continuation and we have sequential program that is totally functional if it was imperative. So there is a need of the concept of promise, if it is implemented in functional language which says about to a process of a message, what is the function that respond to the next message?

This promise is a monad which is indeterministic which means the timing of occurrences of events are not decided. This can be in 3 different states at a time i.e. resolved, unresolved & error. So composing these promises may produce side effects. The function under composition using these promises are monoids. The side effects in concurrency has been discussed further in this section. Concurrent Monadic Composition with Side Effects We have identified 4 different types of side effects in Concurrency:

i) Uncertainty

ii) Dependency

iii) Latency

iv) Failure

These side effects are dealt by designing the monoids. The three different kind of monoids named as Terminator, Pipelining and connector have been designed.

A. Uncertainty

Due to nondeterministic threading behavior promise may have 3 different possibility of states at any given time. When a program tries to access the object which checks the status of value in a promise and receives the value if ready. The program also interact with the proxy which has a reference to promise, proxy notifies promise to block /unblock the program. Promises provide unified control over both synchronous and asynchronous control. Promises are created by an explicit construct using lambda expression which delegates a thread for computing promise value. The value of promise can be consumed by passing it to proxy or callback.

The promise is created using following snippet of code presented in listing 1:

```
public Promise( T Error, Object Error){

this. Result= result;

this.error=error;

hadResult=true;

}
```

Callback and the Promise both are lambda function. Callback is created at caller side and runs on the callee. Promise is created at callee side and the caller then registers a lambda receiving the result thrown by the callee. Promises(Monadic Composition) are the value of asynchronous computation i.e. a Monad[20] describing an effect.

Promises are a kind of wrapper for values in asynchronous context and they can be in any one of 3 different states i.e. unresolved, resolved and exception. Promises holds the value and value can be represented as function and function can be represented as value in functional programming language. So the value or function producing the value held by promises can be brought from a context to asynchronous context and can be tossed anywhere in the program using lambda expression, lambdas facilitates closures(capturing thing out of scope).

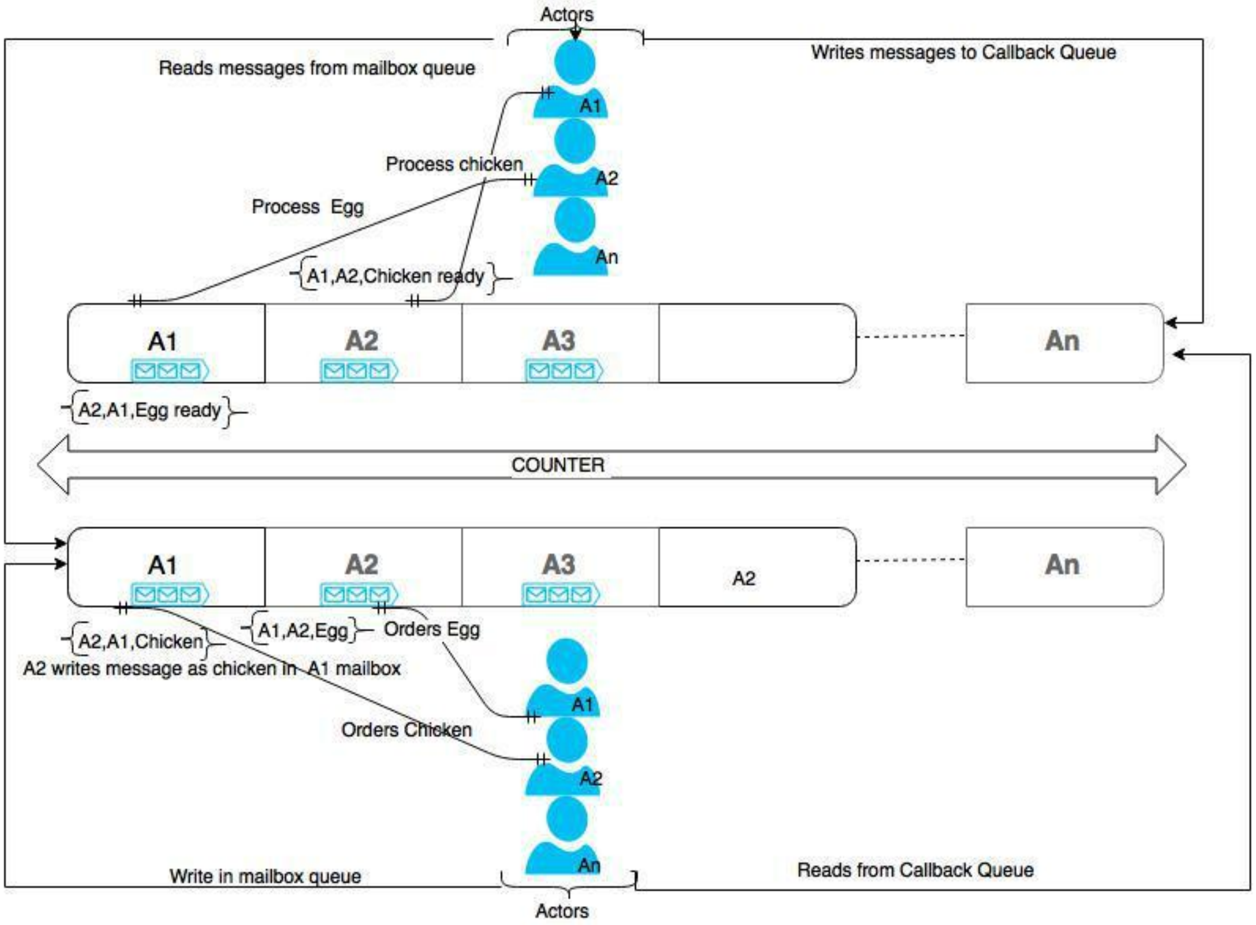


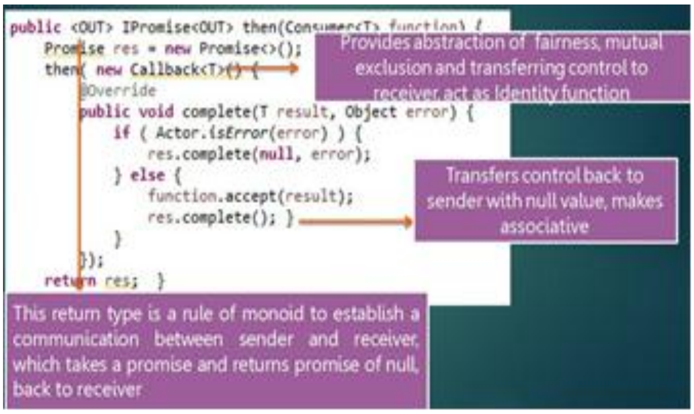
Fig. 2: Message exchange mechanism by Actors

A value can be substituted from one context to another using lambda expression. So its a unit function returns lambda expression. Unit because the function takes a single value from the environment and does not change value except put it to different container or context (thread) environment. To put a function from one context of sender to another context of receiver (i.e. a functor), instead of value, can be implemented by applying function complete(Object result, Object error) and put this to different context promise. So complete(Object result, Object error) method is called twice once by callback to retrieve value if its not available and put it to promise context and called by promise listener to retrieve a value from the promise. Using the complete method as callback we ensure to deal the uncertainty of double firing of callback, receiving value using callback listener and finally promise listener on **complete(Object result, Object error)** method is used to retrieve a value from promises. Hence lambda expression as unit function puts the value from one context to another context and complete(Object result, Object error) function puts a function from one context to another context.

B. Dependency

Promises are objects so it must have getters and setters. Getters are used to retrieve a value from the promise and as stated many a times these values can be either in a state of resolved, unresolved or error. Similarly, setters are used to set values for properties resolved as result or error i.e. value settled in time. The monoids discussed below solves the issues of dependency.

1. Termination Monoid: This is a termination monoid where ”after sending value to receiver, sender does not get any response back from receiver”. In figure 3, Methods can have either void or promise return type, promises are used only when we need to synchronize method calls with other methods, we may have functions they don’t return any type in the case, functions acting as terminating function. In listing 1, boolean variable ”hadResult”, inside the promise constructor shows that promise can have three states, resolved, unresolved or error so it represents a function having side effects i.e. monad. So promise is a monad. The unresolved state help in providing non blocking facility with synchronization where as resolved state provides completion or termination of sender/receiver with ordered message execution.



```
public <OUT> IPromise<OUT> then(Consumer<T> function) {
    Promise res = new Promise<>();
    then( new Callback<T>() {
        @Override
        public void complete(T result, Object error) {
            if ( Actor.isError(error) ) {
                res.complete(null, error);
            } else {
                function.accept(result);
                res.complete(); }
            }
        });
    return res;  }
```

Provides abstraction of fairness, mutual exclusion and transferring control to receiver act as Identity function

Transfers control back to sender with null value, makes associative

This return type is a rule of monoid to establish a communication between sender and receiver, which takes a promise and returns promise of null, back to receiver

Fig. 3: Termination Monoid

Using this monoid, sender is trying to send a value as parameter to receiver to be computed by receiver. So for transferring value, control must be switched from sender thread to receiver thread. So this monoid overrides function then(Callback()), which works as an abstraction to mutual exclusion, which further overrides the complete() method with fairness abstraction. Receiver computes its function once control is transferred to it and again calls complete() method with no arguments to transfer control back to sender with promise having no value. So this monoid has function of fairness abstraction, mutual exclusion abstraction and receiver function under composition.

2) **Pipelining Monoid:** The representation of above algo-rithm in code structure is shown in listing 2. This is a pipelining monoid where after sending value to receiver, sender gets response back from receiver.

Listing 2: Pipelining Monoid

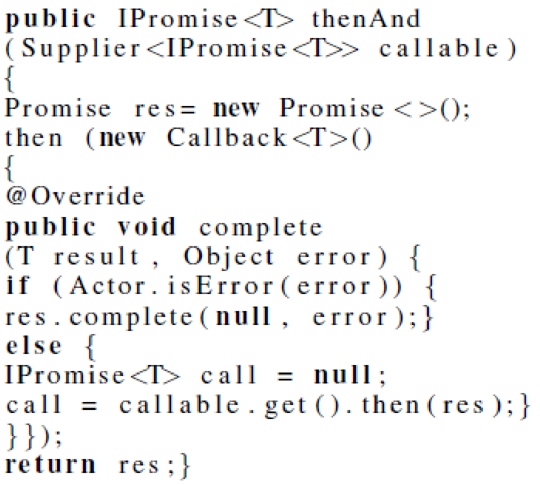
```
public <OUT> IPromise<OUT>
thenAnd(final Function<T,
IPromise<OUT>> function)
{        Promise res
= new Promise<>();
then (new Callback<T>() {
@Override
public void complete
(T result, Object error) {
if (Actor.isError(error)) {
res.complete(null, error);
}else {
function.apply(result).then(res);
```

The code structure method thenAnd () presented in listing 2, shows that, a monoid which takes a function as a parameter (because it’s a functional composition) and that function run outside the context of this monoid i.e. running on some other thread separately. The job of the monoid function thenAnd () is to create a promise and wrap the transformed promise inside the promise created. So this thenAnd monoid returns a promise of promise. The significance of this is that it holds a promise computed by a function which may be in three different states at a time. For example if P1=new promise() and p2=add(int 2, int 2), so res above in figure will return P2(4), so it will be equivalent to P1=promise(P2) i.e. p2 of type promise. So <OUT> here is p2 and outer most <OUT> is p1. Function thenAnd() monoid is a sender function which has the reference of receiver function as the parameter function.

Return type of thenAnd () shows that it returns promise of promise i.e. a kind of pipelining, a monoid type and this monoid obeys rule of associativity by using then(res) which makes communication complete from sender to receiver & receiver to sender, and switch is provided through identity function then(Callback) discussed previously because it tansfers the same promise to different context(Sender/Receiver) for further computation.

3) Connector Monoid: The representation of above algo-rithm in code structure is shown in listing 3. This monoid gets the promise from supplier and transfer the control to receiver. So in this case ”sender is borrowing input as promise from some other supplier and then this promise is transfered to receiver for the purpose of processing”.

Listing 3: Connector Monoid



```
public IPromise<T> thenAnd
(Supplier<IPromise<T>> callable)
{
Promise res= new Promise<>();
then (new Callback<T>()
{
@Override
public void complete
(T result, Object error) {
if (Actor.isError(error)) {
res.complete(null, error);}
else {
IPromise<T> call = null;
call = callable.get().then(res);}
}});
return res;}
```

IV. CONCLUSION AND FUTURE WORK

Promises as an input and output produced by this framework facilitates correct by construction mechanism. The promises as input is supplied to framework by using 3 different monoids. The monoids are functions under monoids”. In Terminator monoid receiver accepts value from sender & does not produce any response, in pipelining monoids, sender receives response from receiver for it’s request. Whereas in Connector monoids sender supplies input to receiver by 3rd party or supplier. These monoids abstract mutual exclusion, fairness, communication and coordination, that was dealt explicitly in earlier practices of concurrency using multi thread programming.

This framework may further be extended to support distributed application. Callback searilization will definately be interesting to solve in case of distributed programming.

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