A STUDY AND TOOLKIT FOR ASYNCHRONOUS PROGRAMMING IN C#

Semih Okur

David Hartveld

Danny Dig

Arie van Deursen

Unresponsive UI Is Frustrating!

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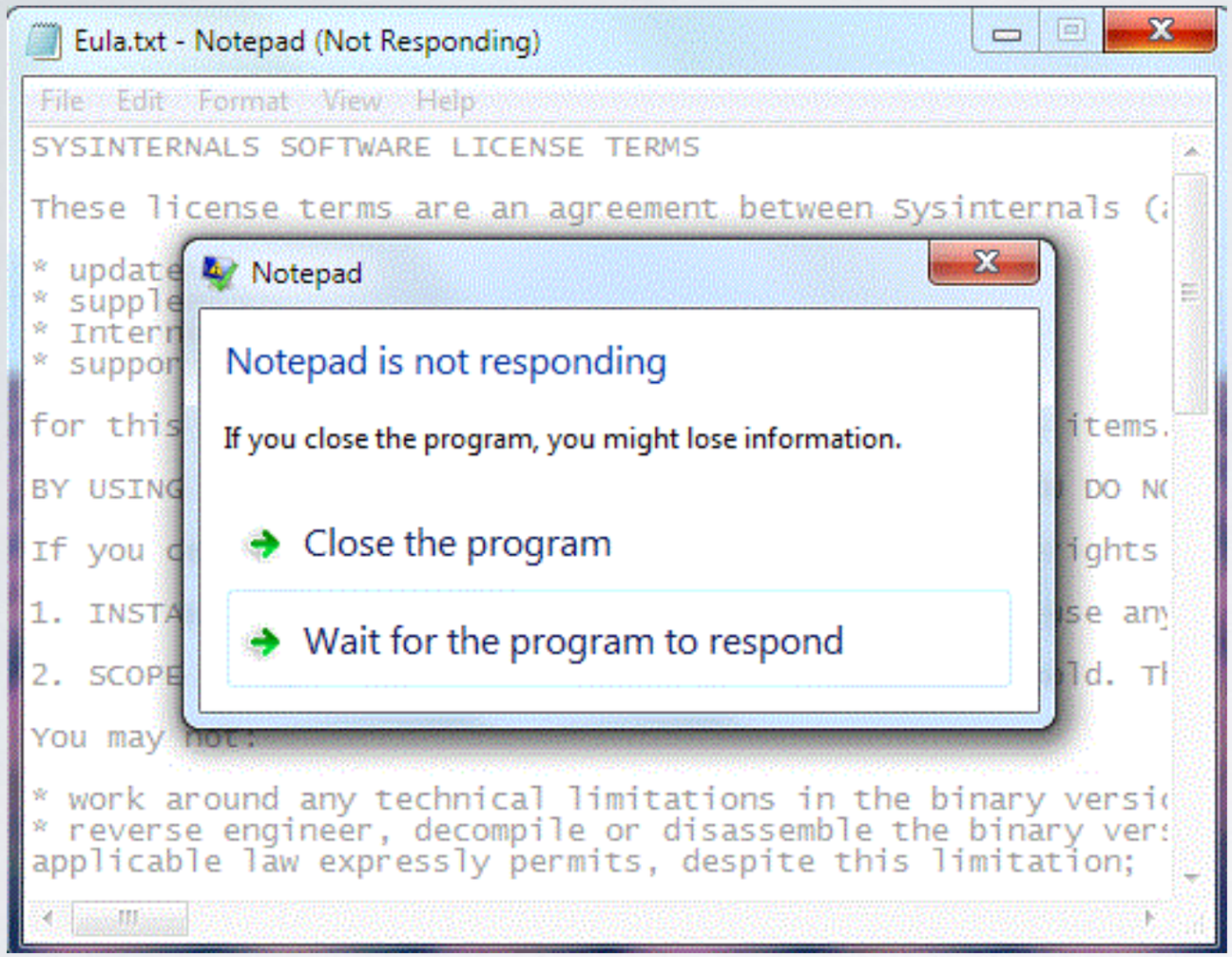

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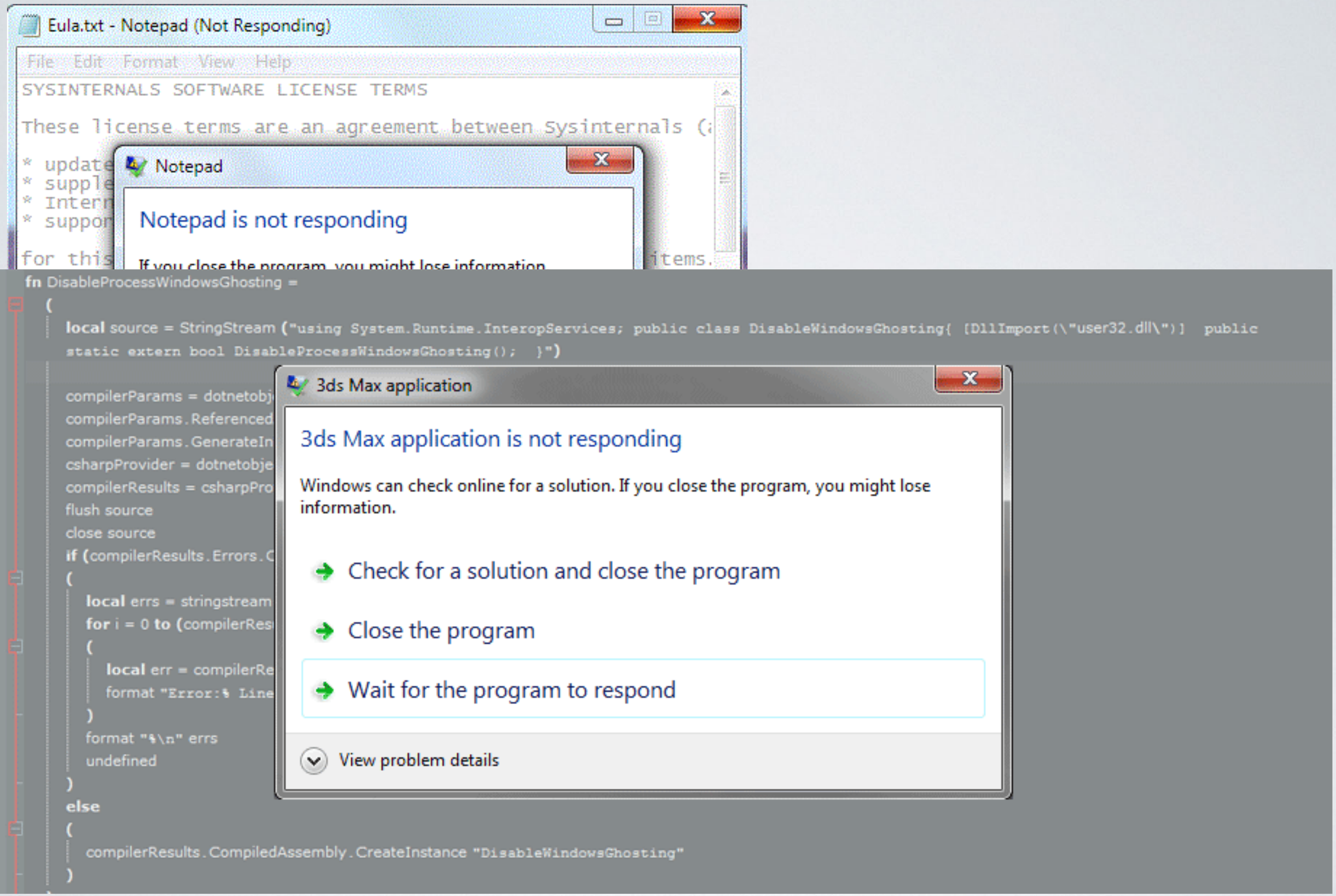

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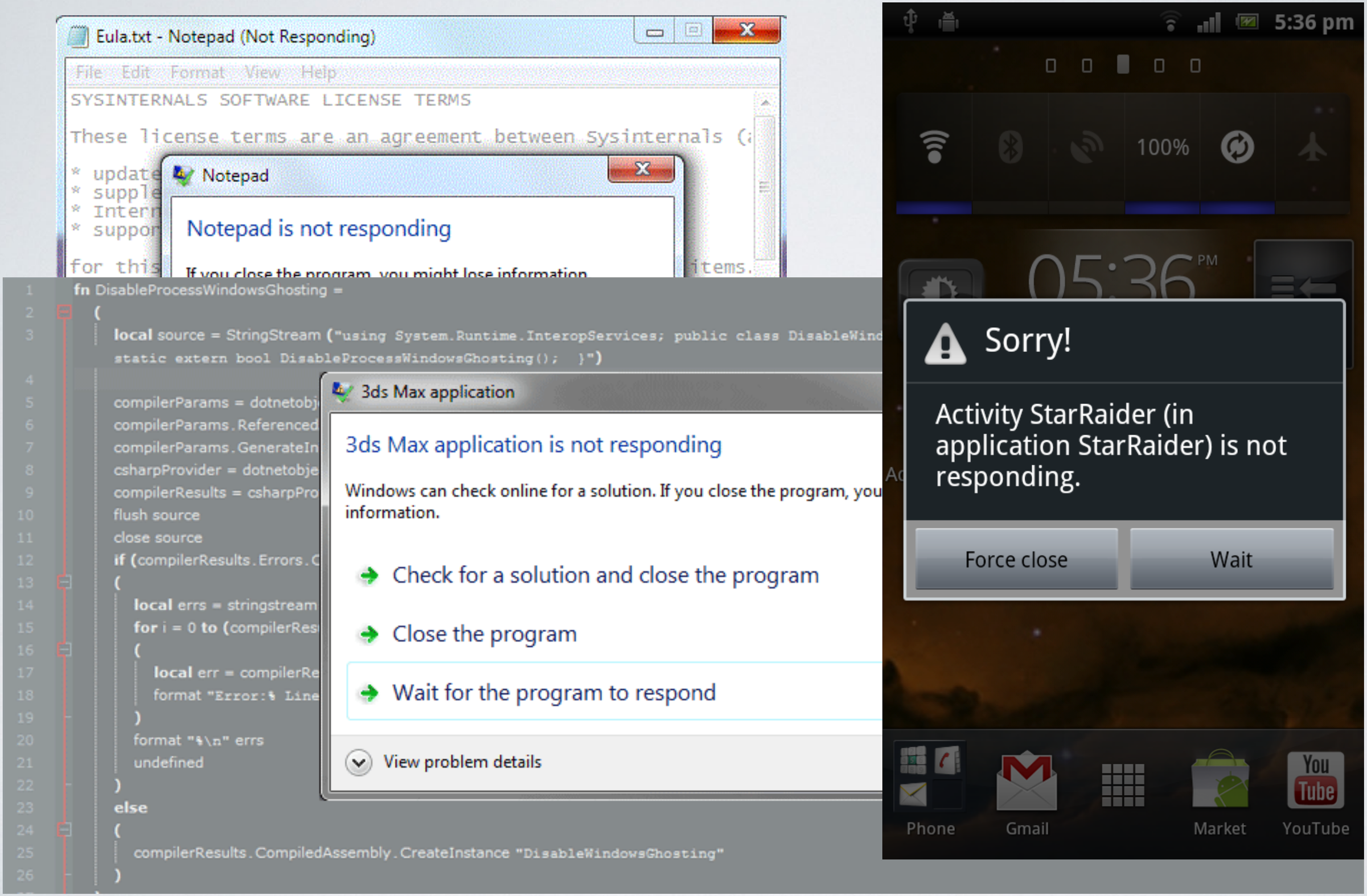

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UI thread is running as an event loop

If processing one event takes too much time, the event loop does not proceed

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Frozen UI

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Frozen UI

(i) Long running CPU-bound (ii) Blocking I/O operations

Our Approach

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(P1) No prior knowledge about (mis)use of asynchronous constructs => wrong assumptions

Thus, we conducted a formative study

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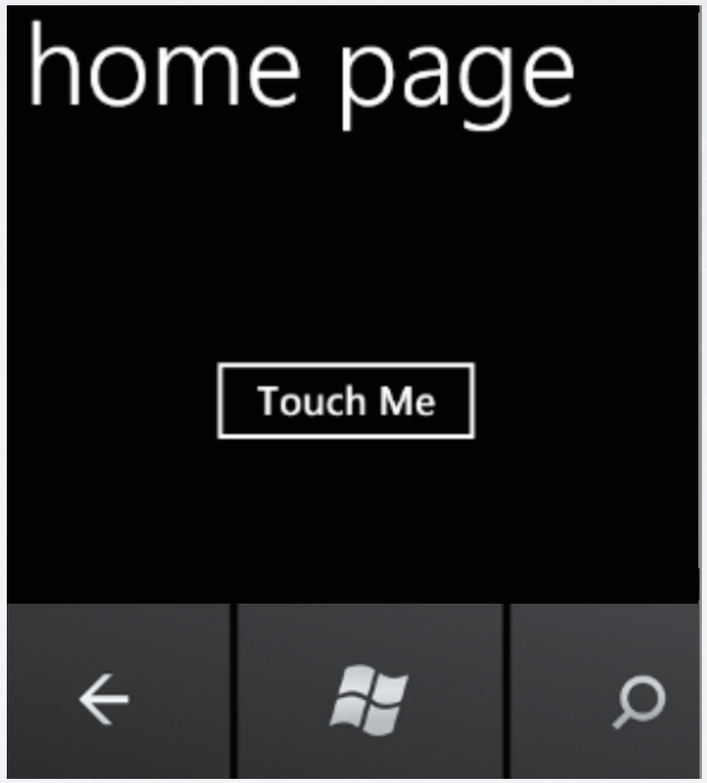
(P2) Asynchronous programming is hard to use

Thus, we provide (1) refactoring and (2) bug fixing tools

Example - Synchronous



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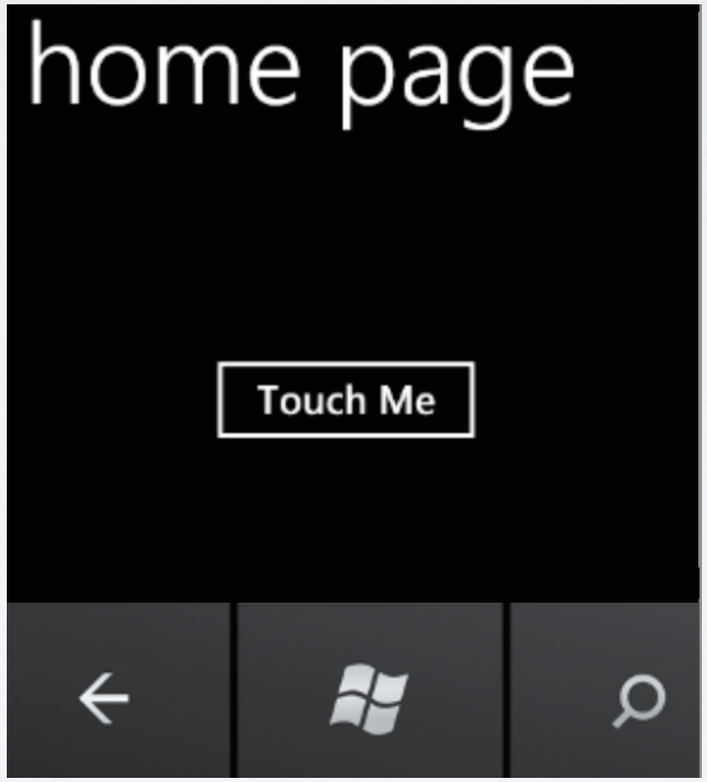

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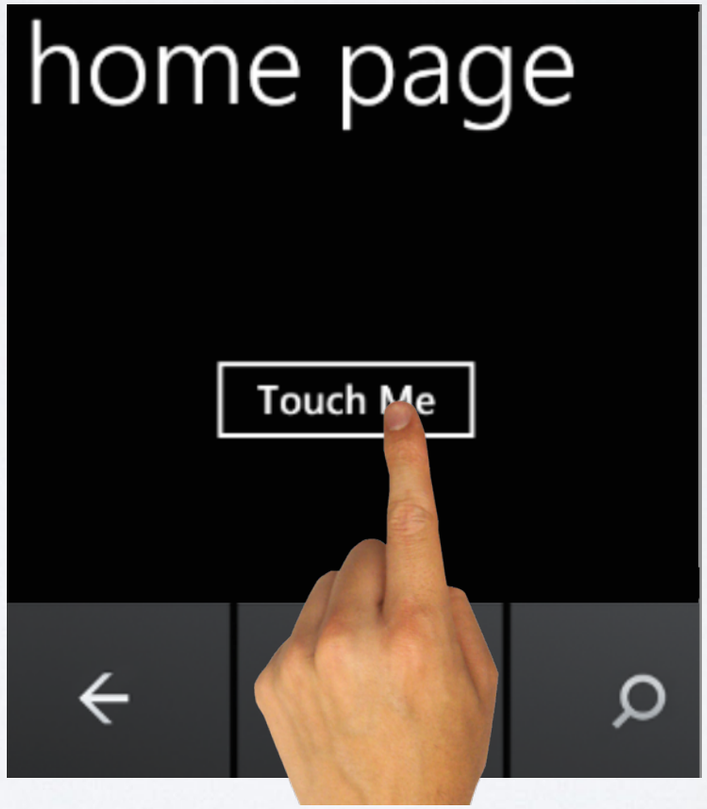

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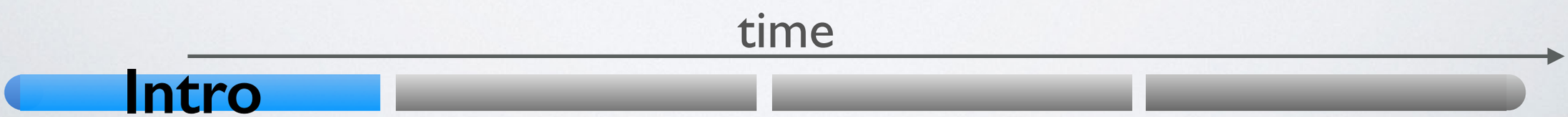
UI thread

Threadpool

OS/Library



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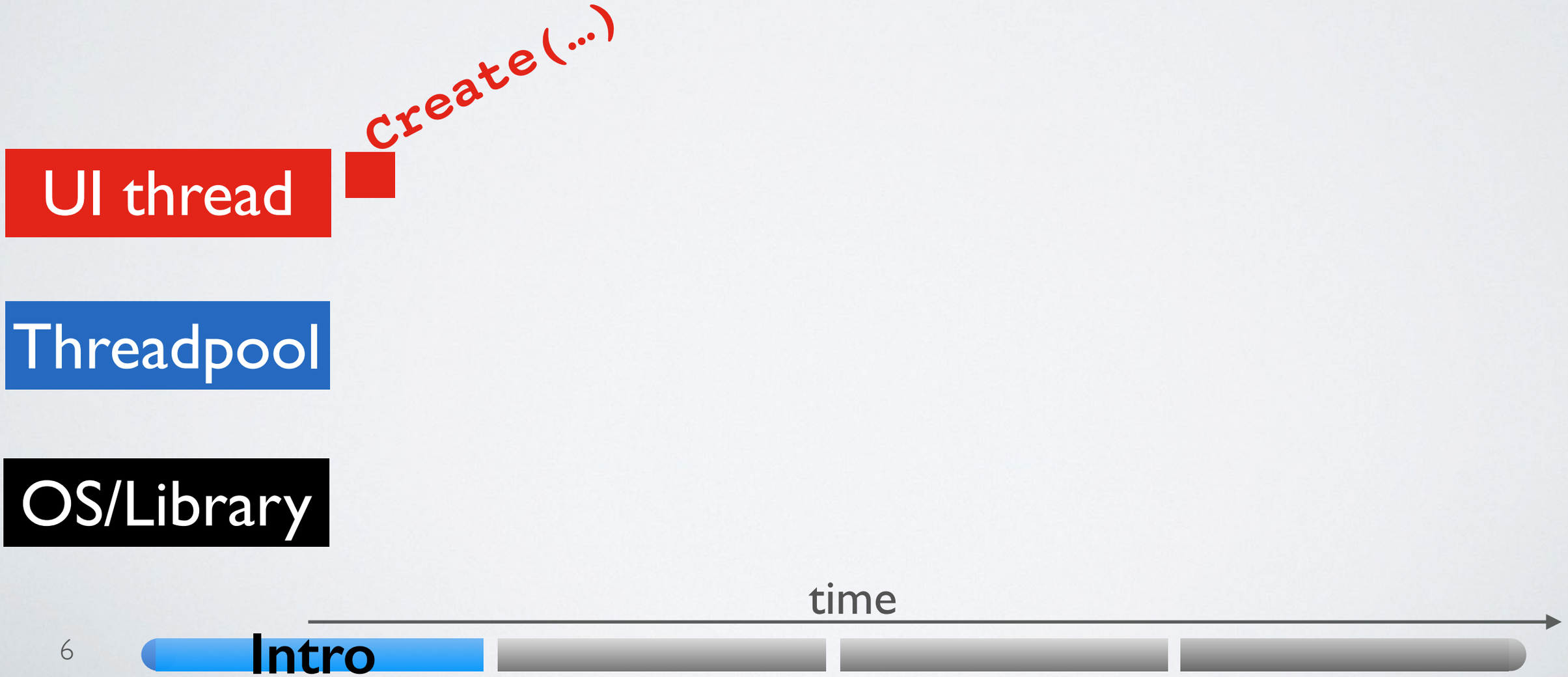

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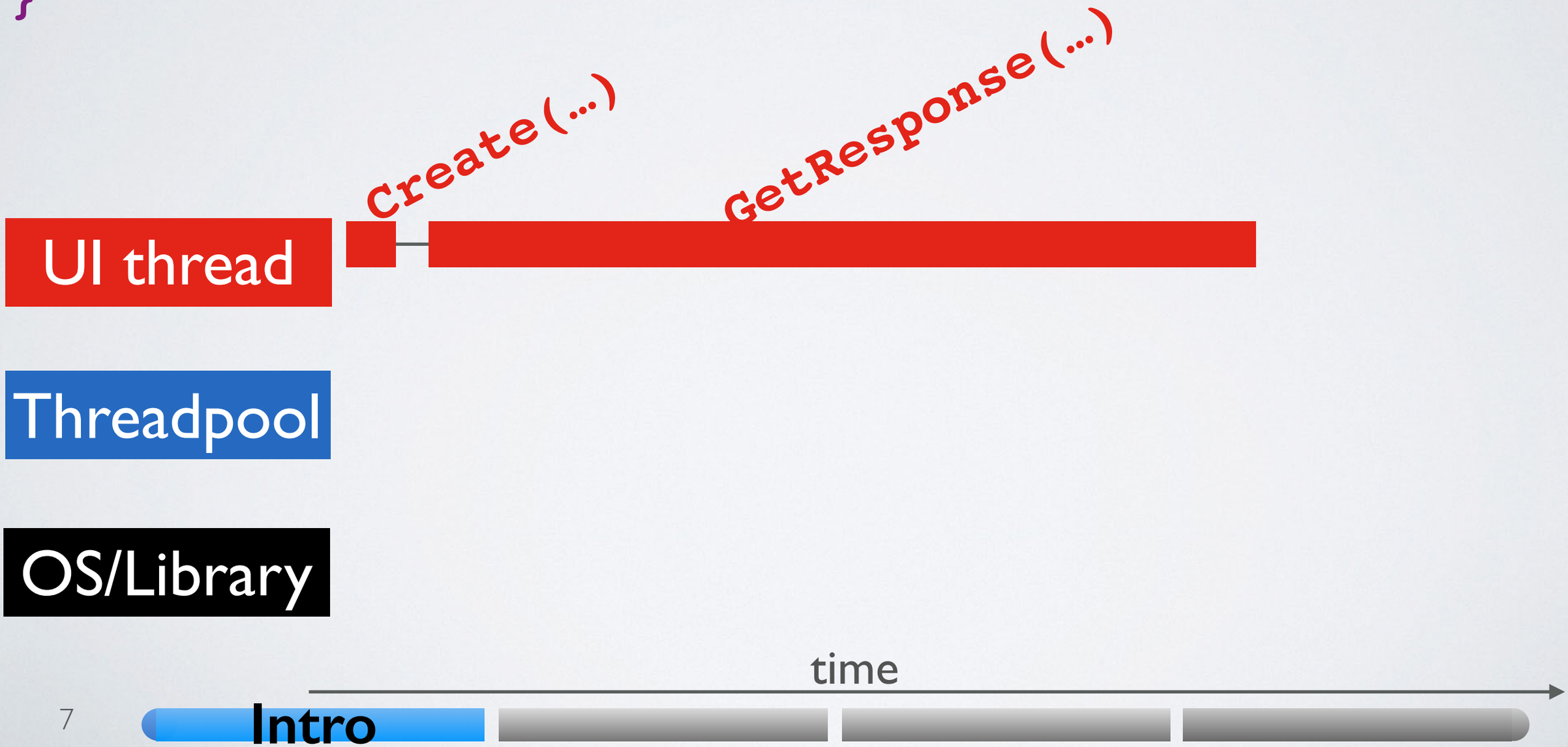

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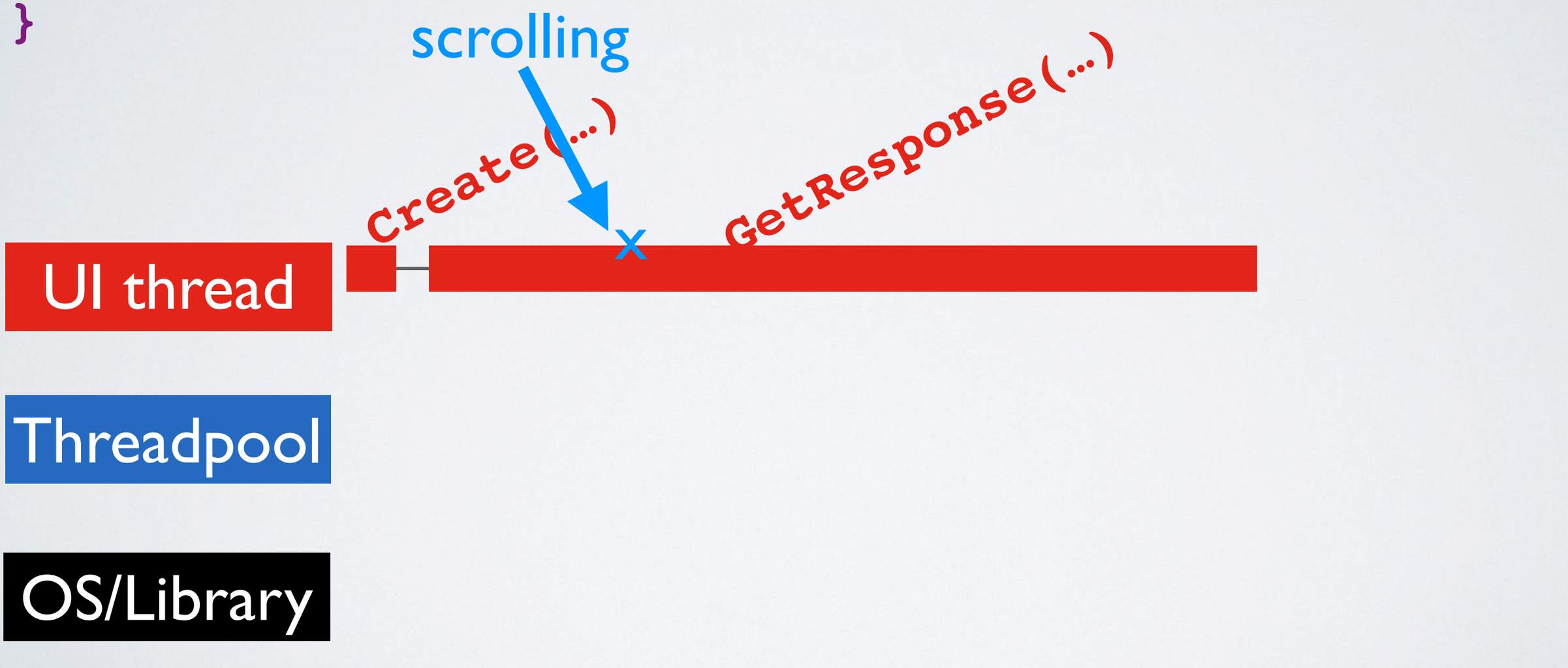

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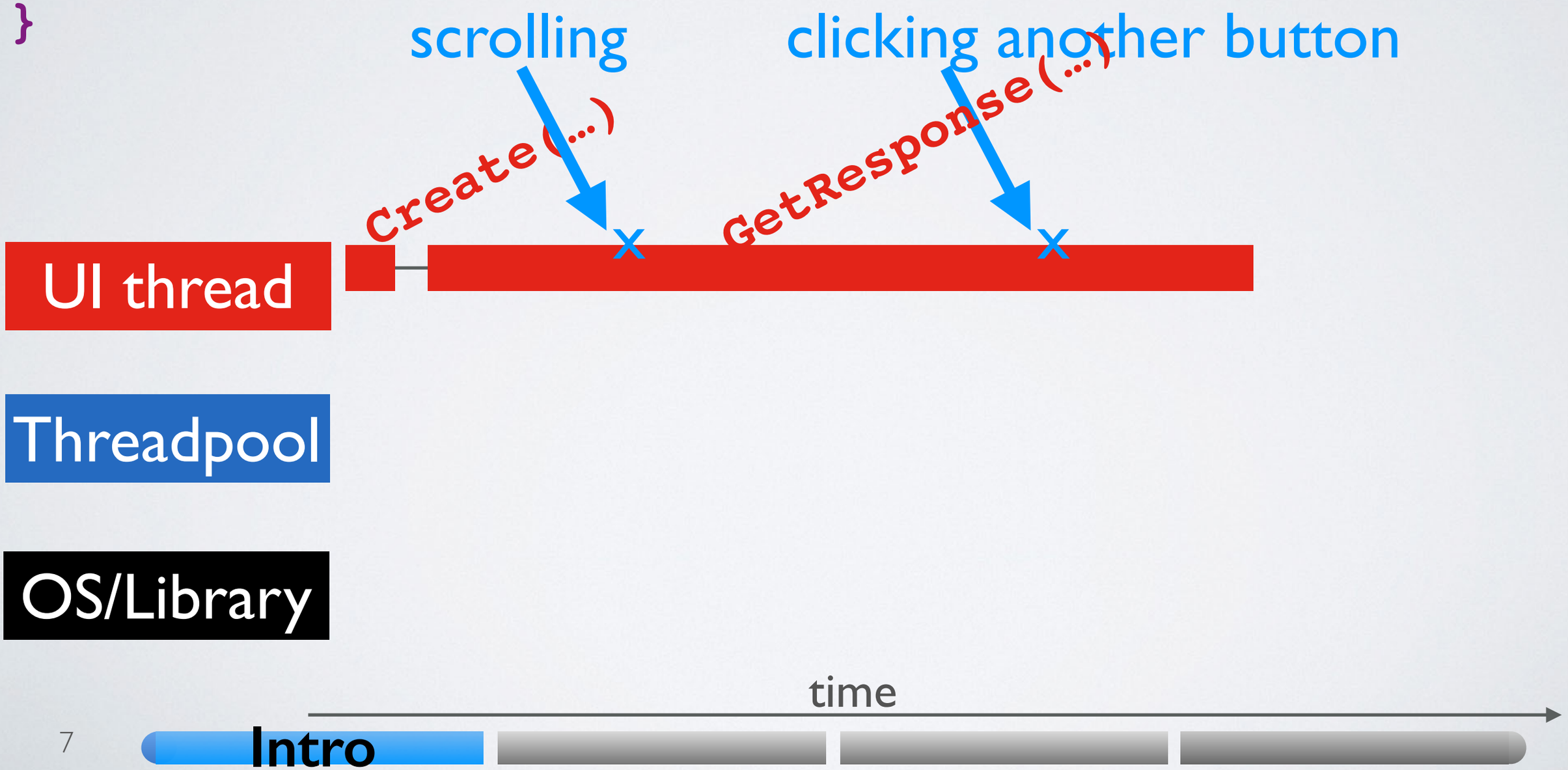

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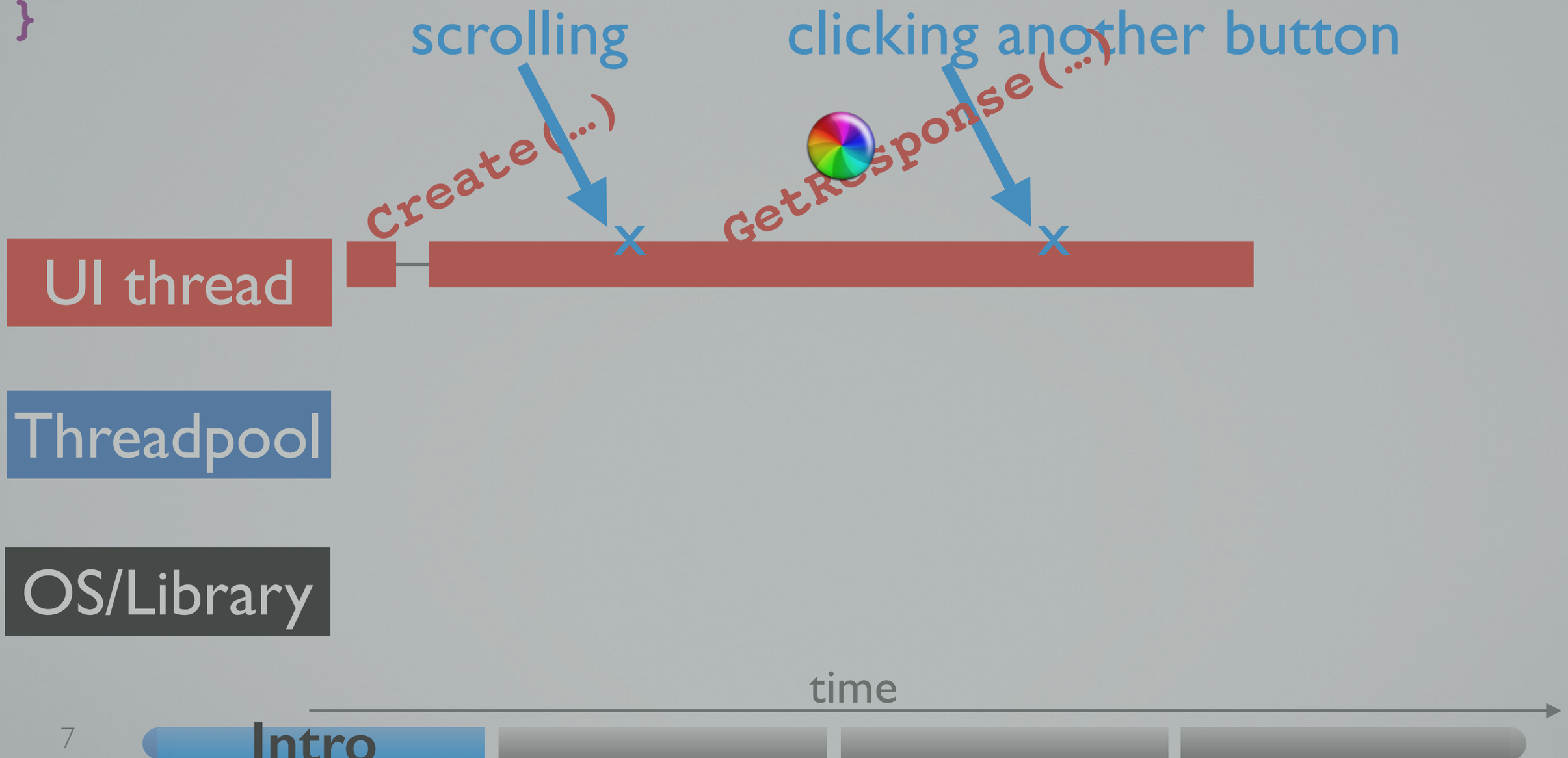

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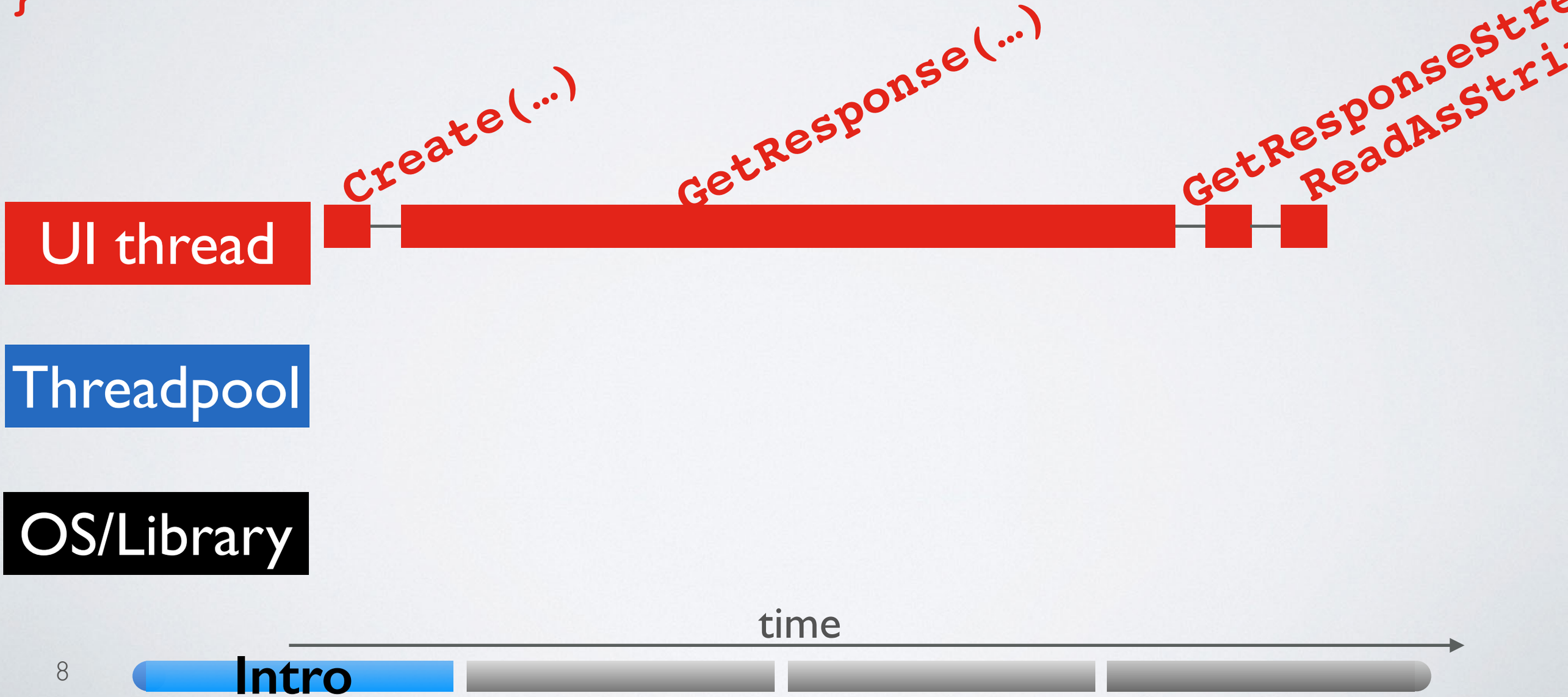

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To access web:

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`BeginXYZ(callback,…)` initiate the asynchronous operation

`EndXYZ(…)` get the result of the asynchronous operation

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Threadpool

OS/Library

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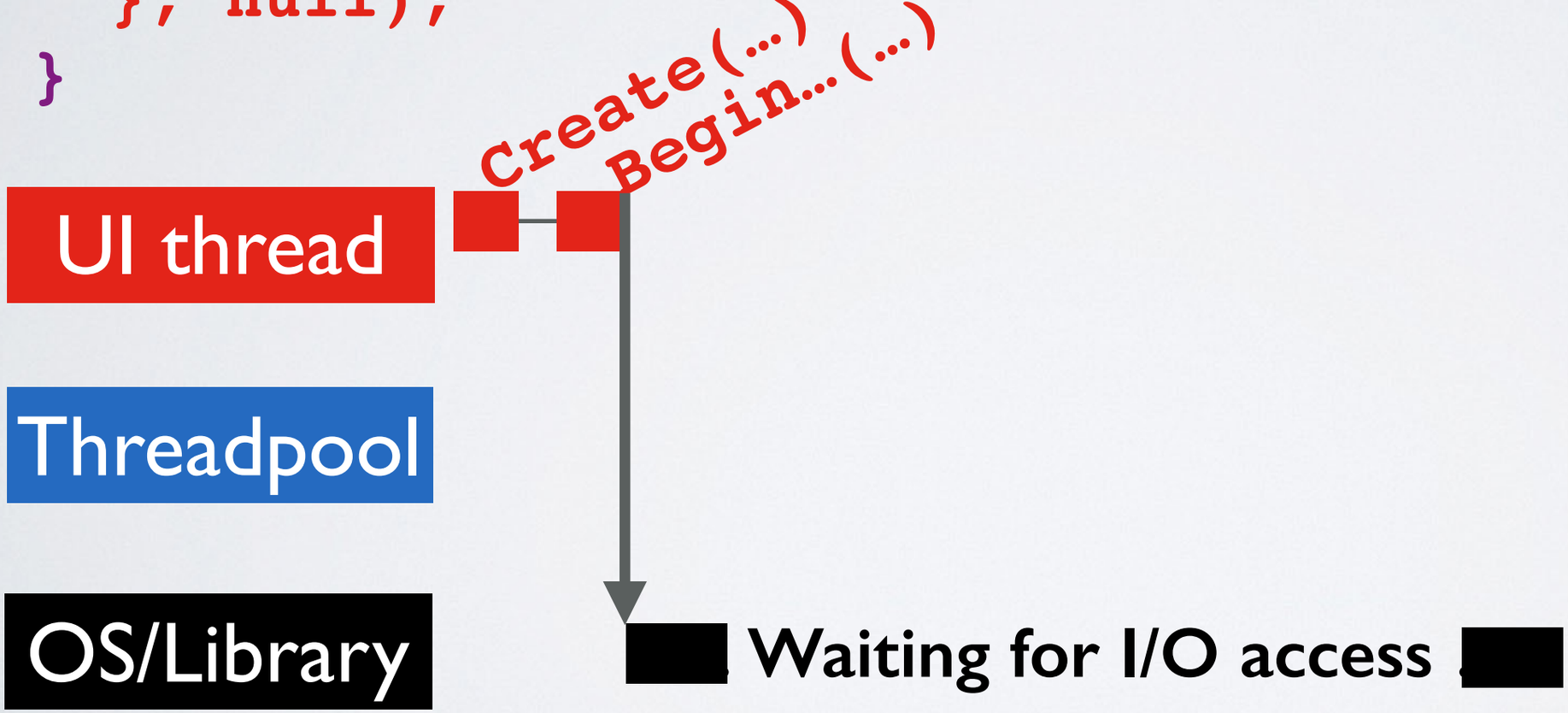

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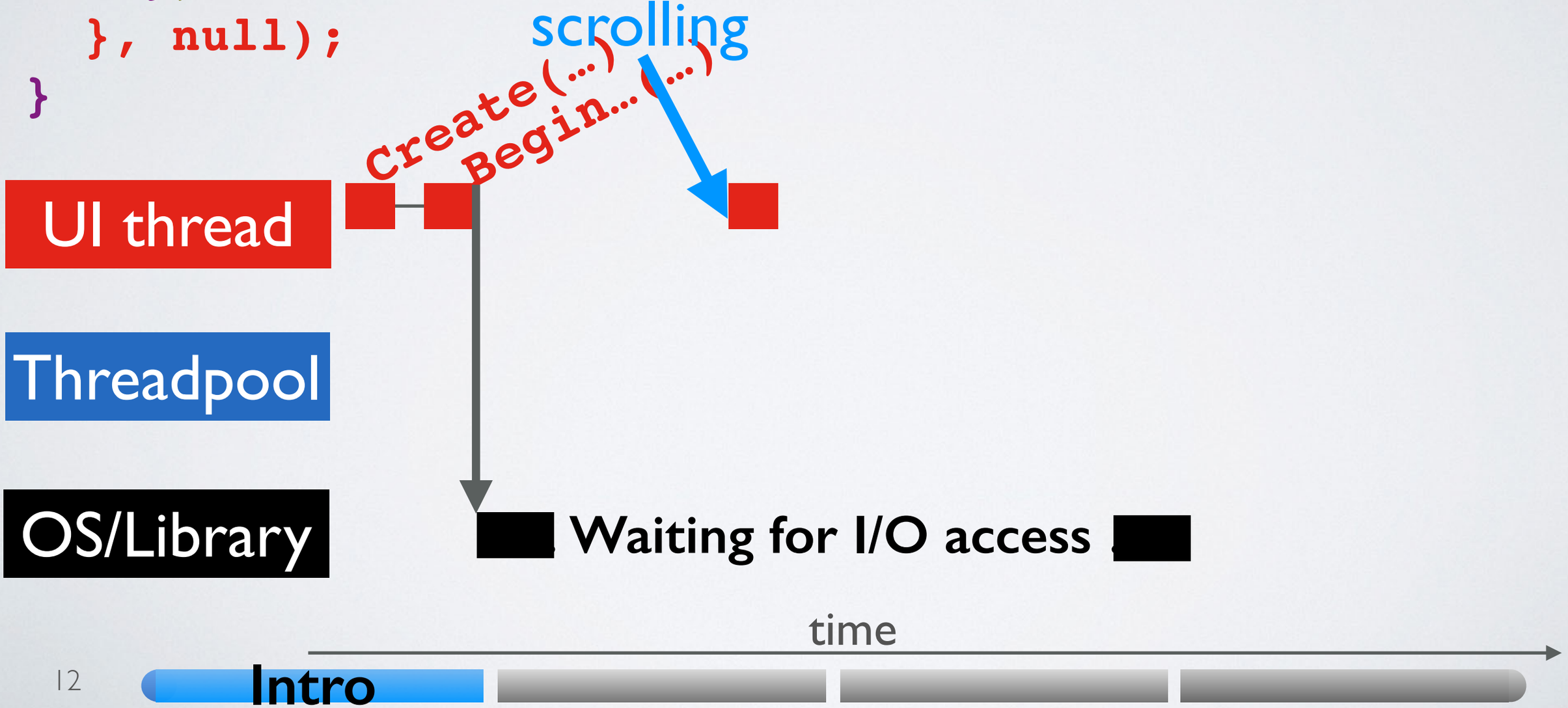

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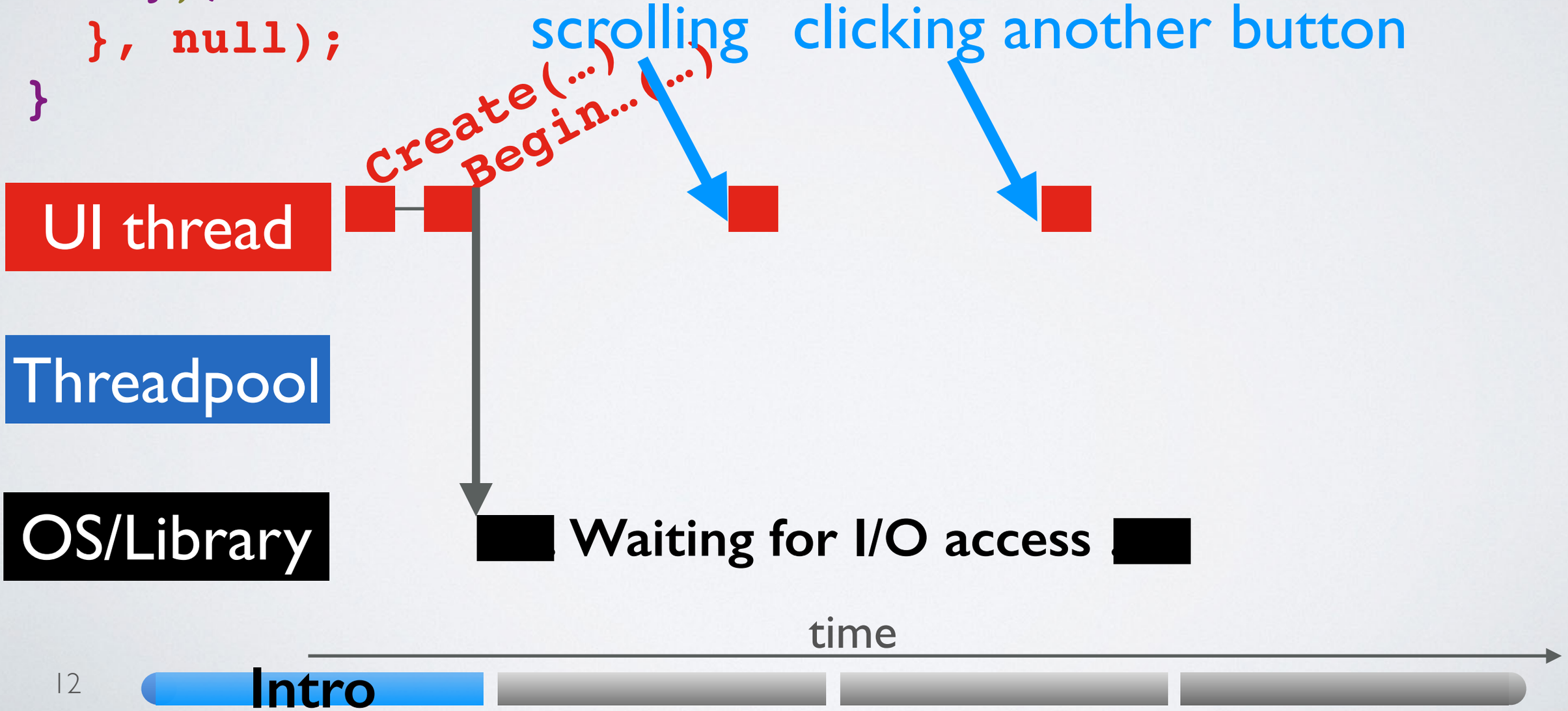

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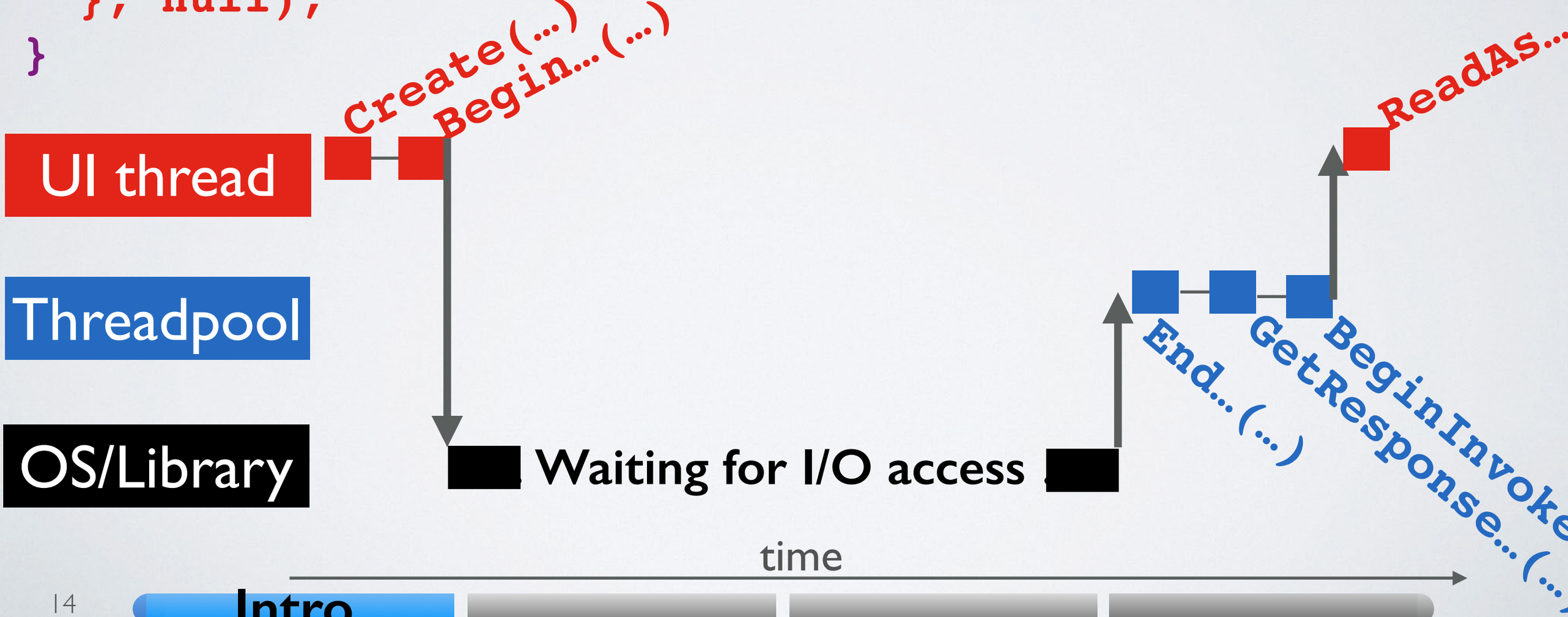

Callback Hell!

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private void SnapAndPost ()
{
    Busy = true;
    UpdateUIStatus ("Taking a picture");
    var picker = new Xamarin.Media.MediaPicker ();
    var picTask = picker.TakePhotoAsync (new Xamarin.Media.StoreCameraMediaOptions ());
    picTask.ContinueWith ((picRetTask) => {
        InvokeOnMainThread (() => {
            if (picRetTask.IsCanceled) {
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            } else {
                var tagsCtrl = new GetTagsUIViewController (picRetTask.Result.GetStream ());
                PresentViewController (tagsCtrl, true, () => {
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- Invert the control flow
- Obfuscate the intent of the original synchronous code
- Don’t scale to large programs

Async/Await Keywords

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Make asynchronous programming a first-class citizen!

Possible to express efficient asynchronous code in a familiar direct style

`async`: method identifier

`await`: used to define pausing points

To access web: `<Task> GetResponseAsync(…)`

Example - Pause'n'play With Async/Await

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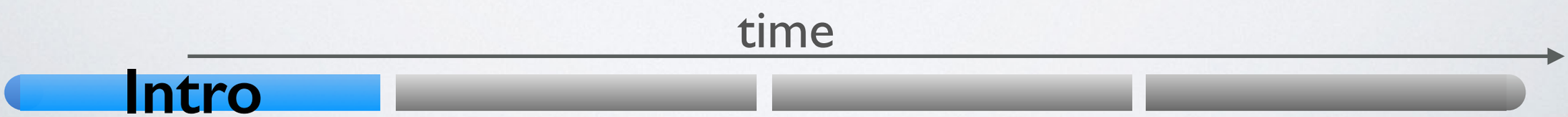

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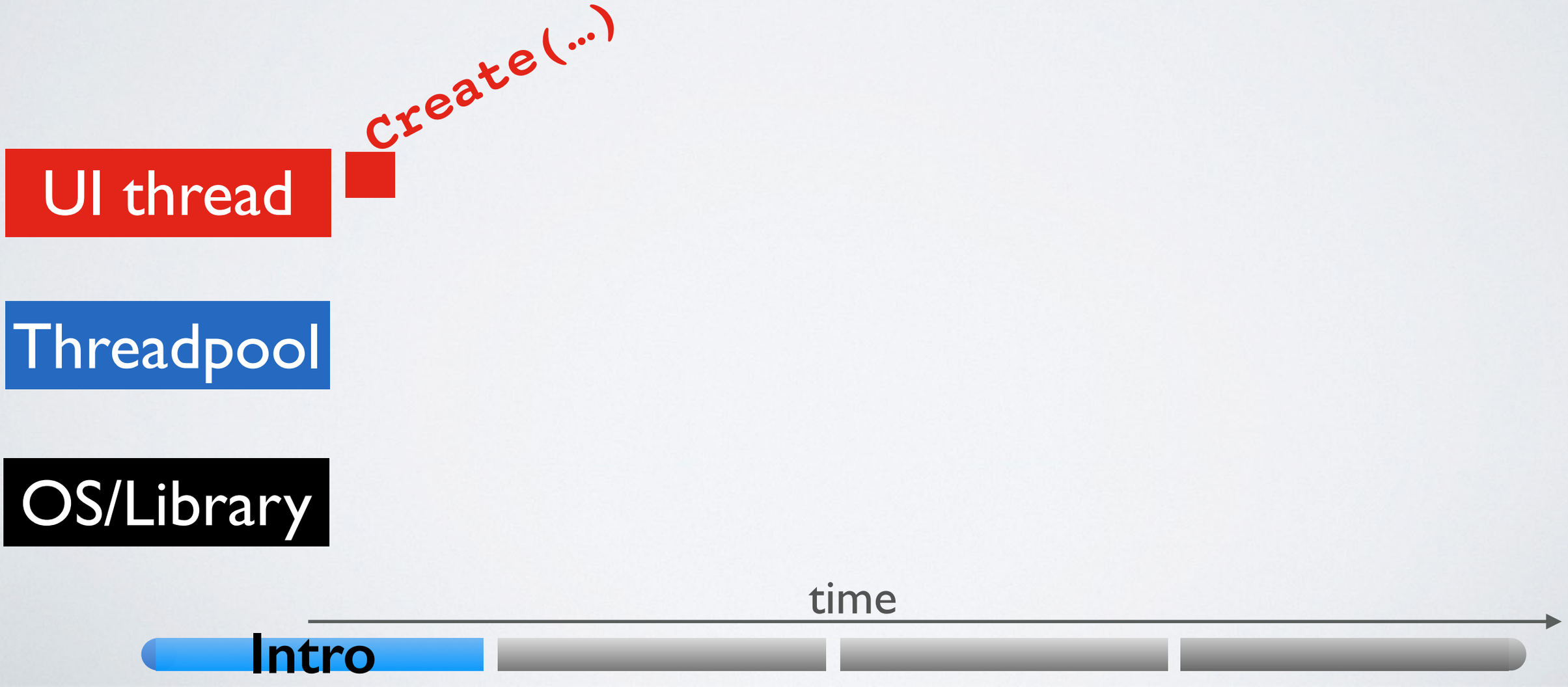

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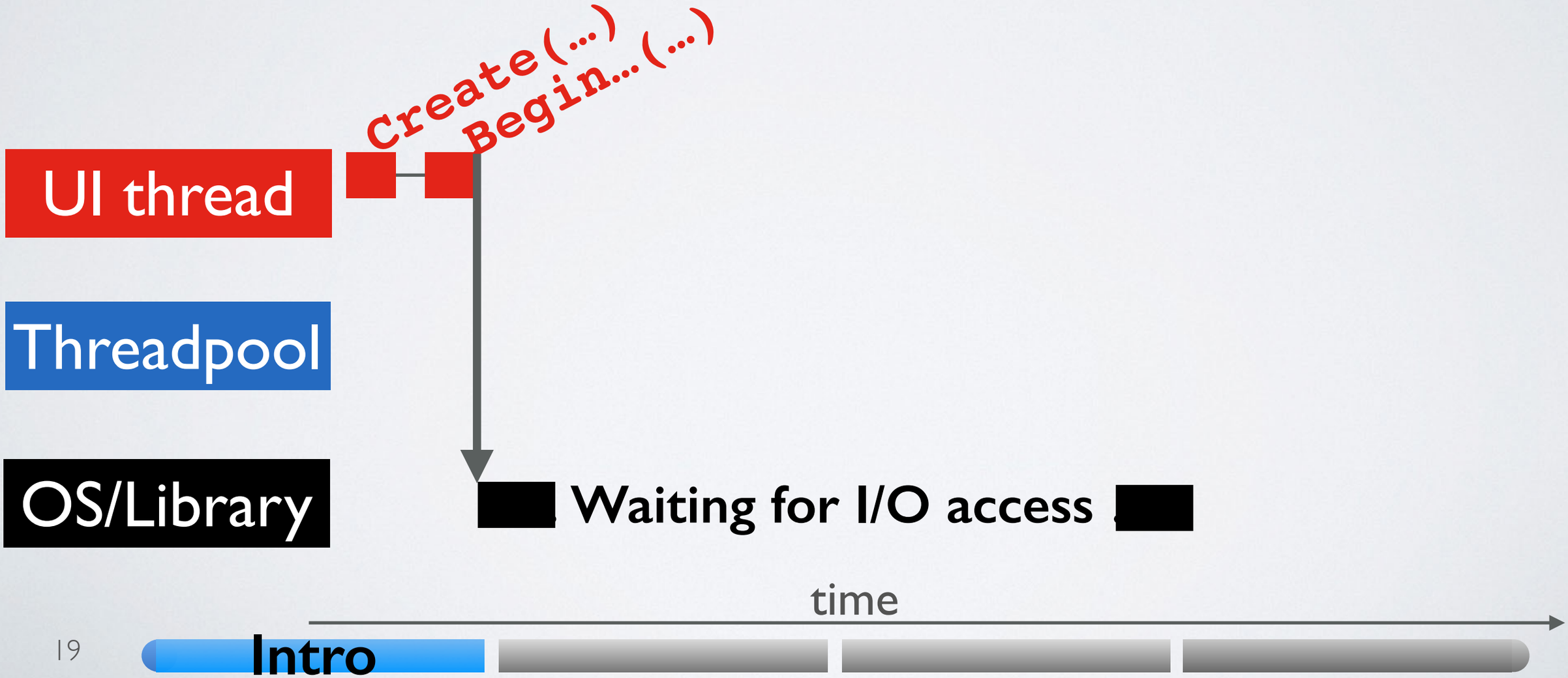

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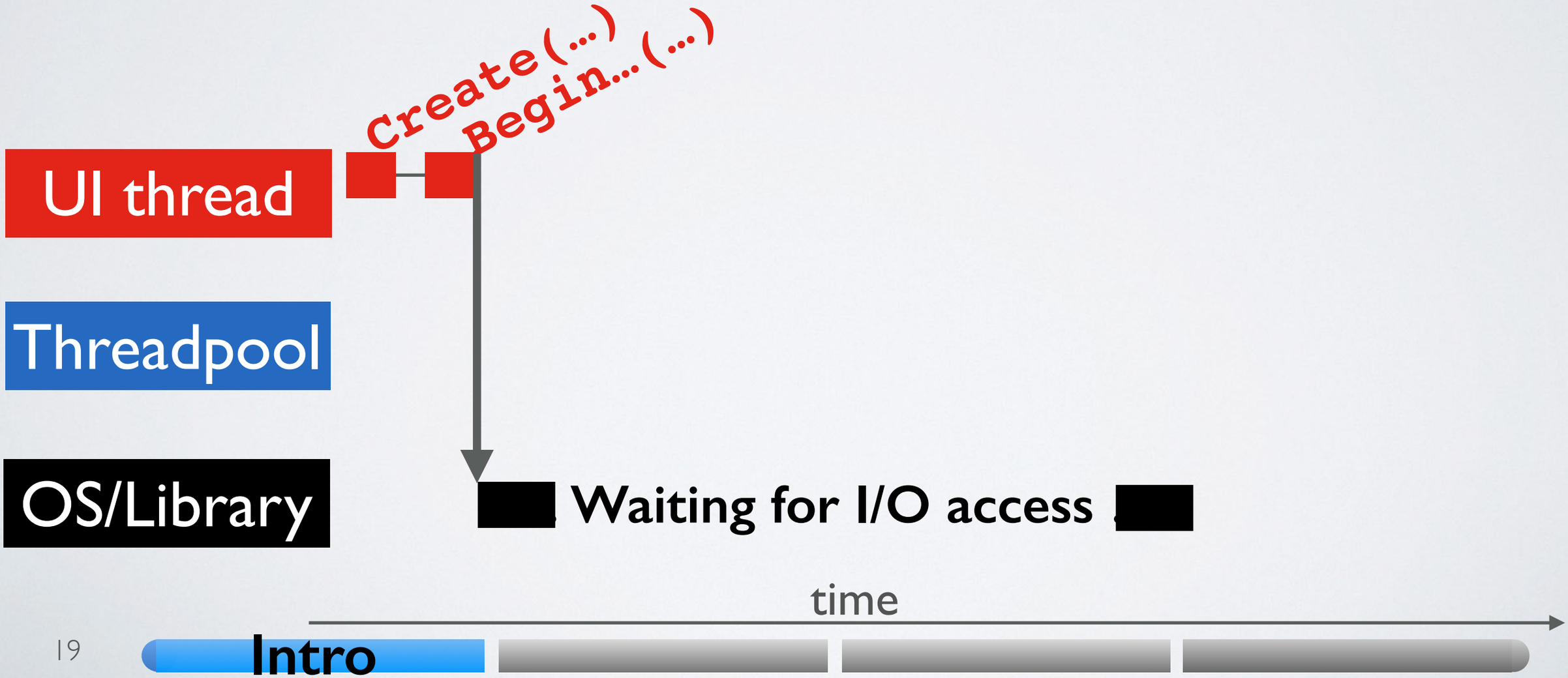

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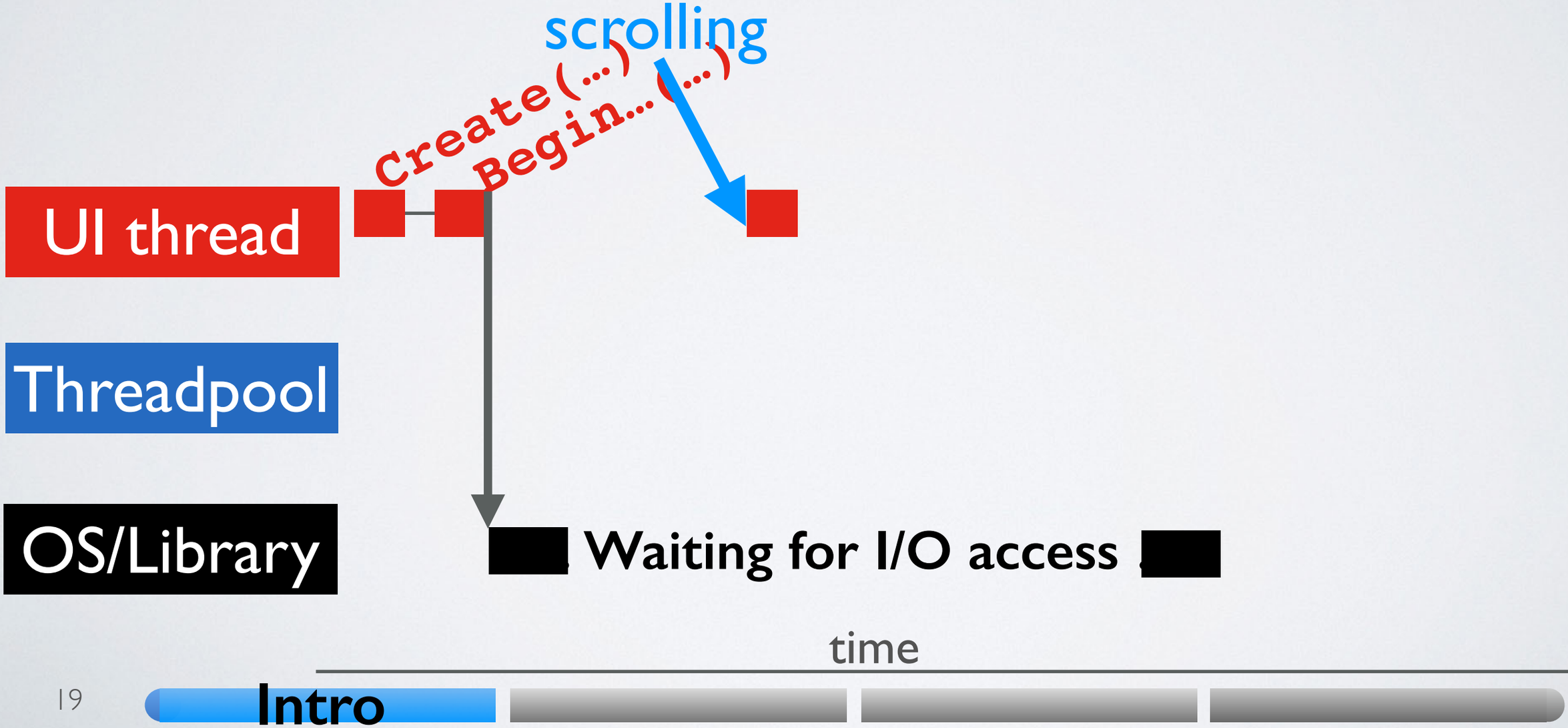

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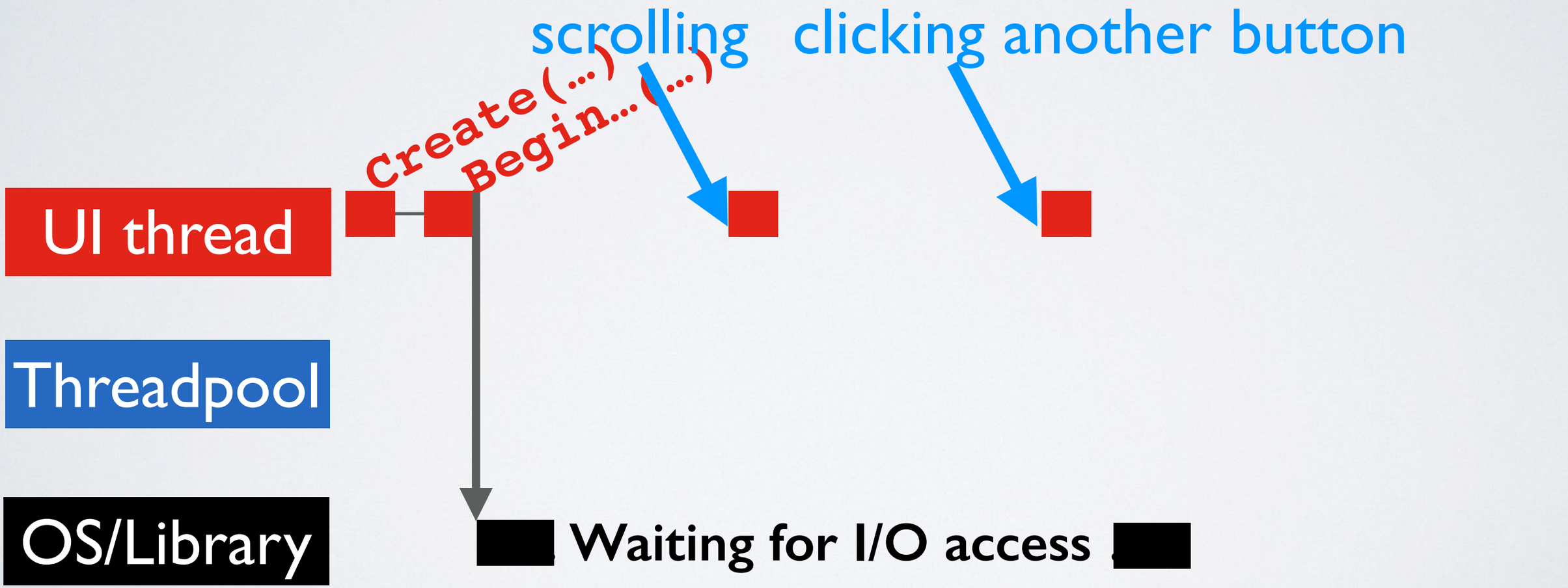

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Asynchronous Async/Await Code

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Q2) Do developers misuse async/await?

Built `Corrector`, a bug fixing tool.

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A detailed information about creating code corpus is available in the paper

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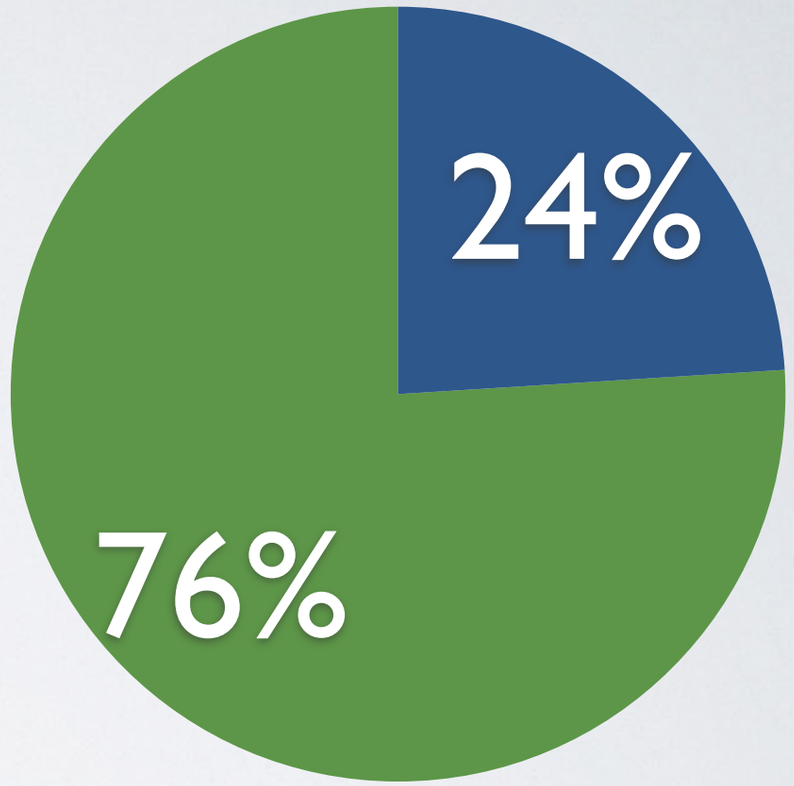
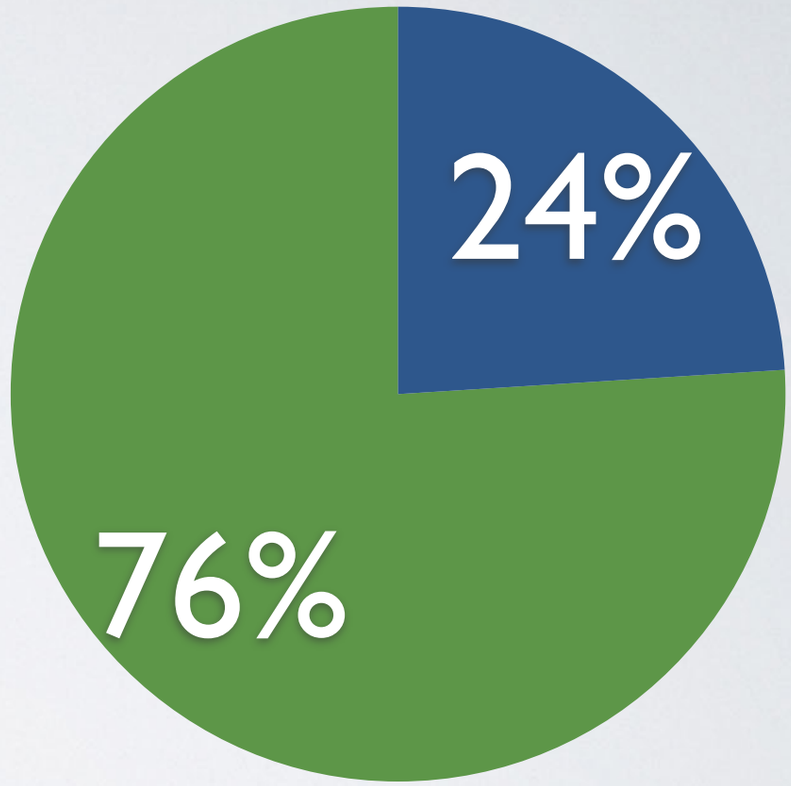


RQ1) How Do Developers Use Asynchronous Programming?

Analyzed I/O bound operations:

- Callback-based async idioms
- Task-based new async idioms (can be used with async/await)



Much more about CPU-bound and I/O-bound operations in the paper

Developers Need a Refactoring Tool: ASYNCIFIER

Developers heavily use callback-based operations

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We built ASYNCIFIER:
a refactoring tool to upgrade callback code to async/await

It Is Not One-To-One Mapping Between Old And New Operations

```
private void Button_Click(object sender, EventArgs e){
   var request = WebRequest.Create("icse-conferences.org");
   request.BeginGetResponse((asyncResult)=> {
      var response = request.EndGetResponse(asyncResult);
      var stream = response.GetResponseStream();
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}
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`BeginXYZ(…)` initiate the asynchronous operation

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Asyncifier

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`EndXYZ(…)` get the result of the asynchronous operation

`XYZAsync(…)` initiate & get the result of the operation

(1) Inlining Lambda Statements

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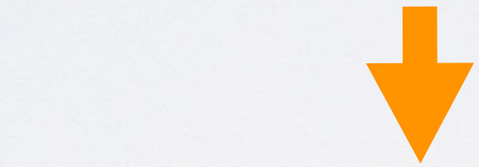

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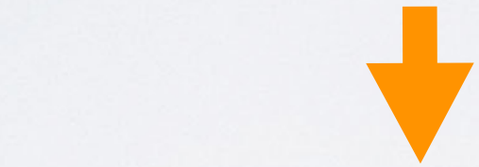

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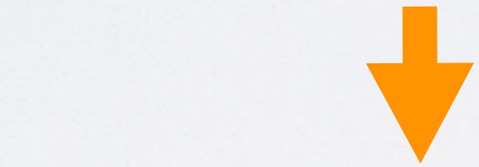

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Asyncifier

(2) Introduce Async/Await Method

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Asyncifier

(3) Preserve Original Behavior

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      textBox.Text = stream.ReadAsString();
   });
}
```

```
private async void Button_Click(…){
   var request = WebRequest.Create("icse-conferences.org");
   var response = await
request.GetResponseAsync().ConfigureAwait(false);
   var stream = response.GetResponseStream();
   Dispatcher.BeginInvoke(() => {
      textBox.Text = stream.ReadAsString();
   });
}
```

(3) Preserve Original Behavior

```
private async void Button_Click(…){
   var request = WebRequest.Create("icse-conferences.org");
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Asyncifier

Challenges

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```
private void Button_Click(object sender, EventArgs e){
   var request = WebRequest.Create("icse-conferences.org");
   request.BeginGetResponse((asyncResult)=> {
      IntermediateMethod(request, asyncResult);
   }, null);
}
public void IntermediateMethod(...){
   var response = request.EndGetResponse(asyncResult);
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(3) The exception behavior is different

RQ2) Do Developers Misuse Async?

Misuse: anti-patterns which hurt performance and might cause serious problems like deadlocks.

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i. 14% of methods that use async/await keywords do this unnecessarily.

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iii. 1 out of 5 apps misses opportunities in async methods to increase asynchronicity

iv. In 99% of cases, developers unnecessarily capture context => performance problems, deadlocks

Developers Need A Bug Fixing Tool: Corrector

Developers frequently misuse async/await keywords

in the paper

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Will mention just one of them, the other three anti-patterns

in the paper

Unnecessary Async/Await Methods

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public async Task<…> ChangeTemperatureAsync(...) {
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26% of the apps have at least one such an async method.

Corrector Eliminates Unnecessary Async/ Await

```
public async Task<CacheResponse> RequestAsync(CacheRequest request)
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    return await downloaderPluginBase.RequestAsync(request);
}
```

Unnecessary await in async method

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Remove unnecessary async/await

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Used the same code corpus from the Formative Empirical Study: 1378 WP apps, 12M SLOC

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(4) Are the transformations useful?

(1) Our Tools Are Highly Applicable

54% of 1245 callbacks passed the preconditions.

ASYNCIFIER refactored 54% of callbacks.

We manually verified that 10% of the instances are correct.

The reasons for un-refactored 46% of 1245 callbacks:

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Our tools can be applied to any platform written in C# (not only Windows Phone)

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suitable for an interactive usage in an IDE

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"That you have pointed out is correct. This time, performance has been improved to 28 milliseconds from 49 milliseconds." *Softbuild.Data app*

Implications

Developers

LearnAsync.NET: hundreds of real-world positive and negative examples of asynchronous idioms

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Usage Examples of Asynchronous Idioms

Developers learn a new programming construct through both positive and negative examples. We provide hundreds of real-world examples of all asynchronous idioms. Because developers might need to inspect the whole source file or project to understand the example, we link to highlighted source files on GitHub.

Long-running CPU-Bound Operations	
New Thread	Link to Usage Examples
Background Worker	Link to Usage Examples
Threadpool	Link to Usage Examples
New Task	Link to Usage Examples
Blocking I/O-Bound Operations	
Callback-Based APM Idioms	Link to Usage Examples
Task-Based TAP Idioms with async/await	Link to Usage Examples
Misuse of Async/Await	
Fire-Forget async Methods	Link to Usage Examples
Unnecessary async Methods	Link to Usage Examples
Long-running Operations Under async Methods	Link to Usage Examples
Unnecessarily Capturing Context Under async Methods	Link to Usage Examples

Implications

Language and Library Designers

async/await will be available in other languages too
Provided a detailed insight about why async/await is misused

New concepts require not only documentation but also IDE support.

Conclusions

First large-scale formative study on the usage of asynchronous programming

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Some part of CORRECTOR will ship with official Visual Studio 2014