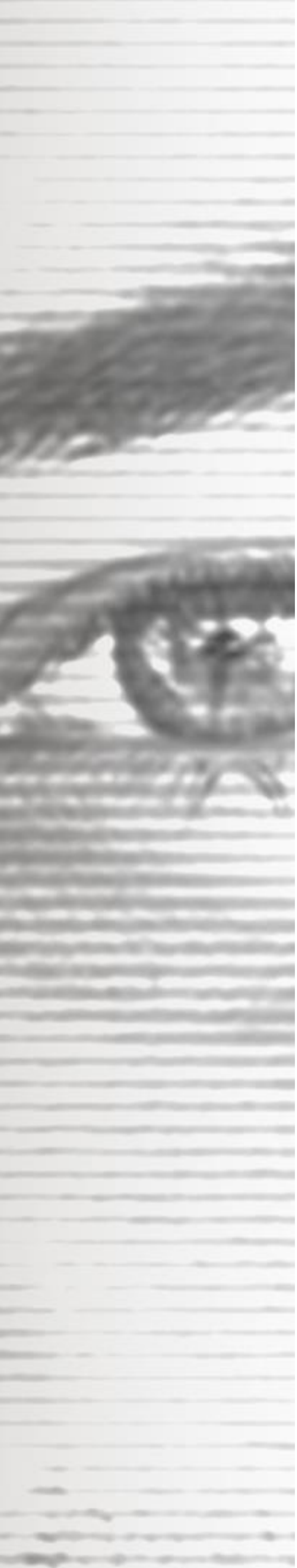


# Developer’s Guide

## Tobii EyeX SDK for C/C++

September 5, 2014
Tobii Technology

NOTE: Preliminary version, subject to change

The Tobii EyeX SDK provides you with the tools needed to build eye-gaze enabled applications faster and easier than ever before, by building on the services provided by the Tobii EyeX Engine.

# Contents

# Introduction

The Tobii EyeX SDK provides you with the tools needed to build eye-gaze enabled applications faster and easier than ever before, by building on the services provided by the Tobii EyeX Engine.

Building a great user experience starting from eye-gaze coordinates is a challenging task. The Tobii EyeX Engine takes care of the groundwork for you, so you don't need to worry about hardware configuration, calibration, or data processing. The interaction modes provided by the Tobii EyeX Engine give you the benefit of Tobii's extensive experience with eye-gaze interaction, and let you avoid common design pitfalls. The EyeX Engine provides a faster way to create a consistent user experience across the entire operating system.

The EyeX SDK is available on the same platforms as the EyeX Engine: currently Windows 8.1, Windows 8, and Windows 7.

The EyeX SDK is available in three variants, one for C/C++, one for .NET and one for the Unity game engine. More will follow and they are all available for download from the Tobii Developer Zone.

*Note: If your application is intended to run in an embedded or single-application[1] environment, or if it needs to run on platforms where the EyeX Engine isn't available, then the low-level Gaze SDK from Tobii might be a better match for your needs. The Gaze SDK is available for download at the Tobii Developer Zone.*

# Getting started

## "Ladies and Gentlemen, start your engines!"

As the EyeX SDK builds on the API provided by the EyeX Engine, the first thing that you need to do, in order to start writing eye-gaze enabled applications, is to install the Tobii EyeX Engine software, and ensure that it works with your Tobii EyeX Controller or other Tobii eye tracker.

Now, does it track your eyes properly? Good, then you're ready for the next step.

## Building and running the code samples

This guide assumes that you have installed Microsoft Visual Studio 2012 or later on your development machine. It should be possible to use the SDK with other editors and compilers as well, but then you'll have to find out how to set include paths, etc, yourself.

The EyeX SDK is distributed as a plain zip file. Extract it to, for example, c:\EyeXSDK. Then browse to the new SDK directory and locate the subdirectory called "samples". There you will find a Visual Studio solution file that includes all the C and C++ code samples:

- The **ActivatableButtons** sample which demonstrates the *activatable behavior*, also known as *eye-gaze clicking*, with two simple activatable buttons. This sample is about as small as it gets for an application using the activatable behavior. It is written in C++ and uses GDI+ for the user interface.

[1] Single-application means that the application replaces or hides the Windows shell, so that no other applications are visible. For example, in an information kiosk or ATM.

- The **ActivatableBoardGame** sample which demonstrates the *activatable behavior* in the context of a five-in-a-row board game. This sample is slightly more elaborate than the ActivatableButtons sample. It is written in C++ and uses GDI+ for the user interface.
- The **MinimalGazeDataStream** sample which demonstrates the *lightly filtered Gaze point data stream*. This is a console application written in C.
- The **MinimalFixationDataStream** sample which demonstrates the *fixation data stream*. This is a console application written in C.
- The **MinimalStatusNotifications** sample which connects to the EyeX Engine and shows *tracking status, screen settings* and *presence* information. This is a console application written in C.

The sample applications are plain Visual Studio projects, which can be built and run from within Visual Studio. So give them a try!

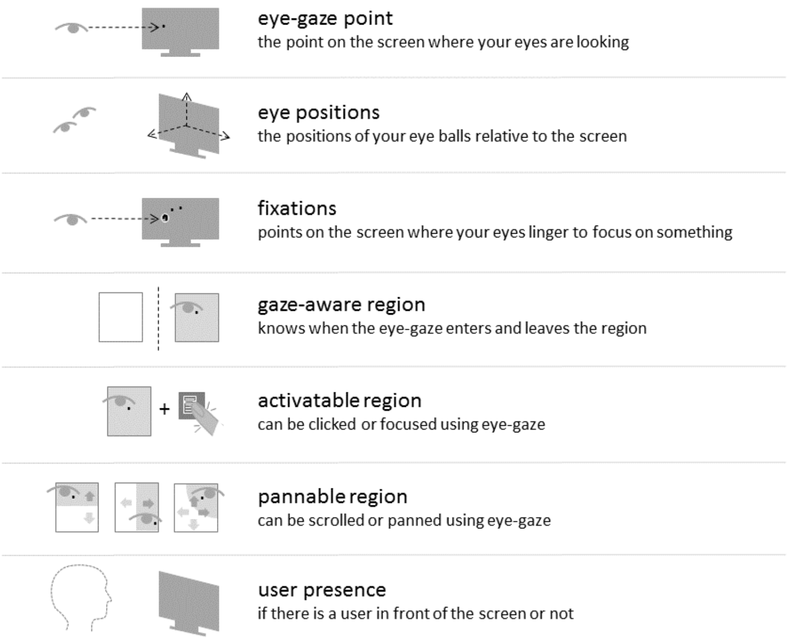
## Where to go from here

We strongly recommend browsing through the rest of this Developer's Guide, because it will give you a big picture view of the EyeX Engine and its API.

Apart from that, it depends on what you want to do—or what you want your application to do. Remember that the Tobii Developer Zone is there for you if you need inspiration or if you get stuck.

# An introduction to the EyeX Engine API

The Tobii EyeX Engine is a piece of software that ties the EyeX Controller and other user input devices together with gaze-enabled applications to create the Tobii Eye Experience. The EyeX SDK provides you with access to the EyeX Engine API so that your application can be one of these gaze-enabled applications. The EyeX Engine takes care of all the groundwork needed in terms of eye tracker hardware configuration, calibration and gaze data filtering, and presents the gaze data and user input to the applications in a format relevant to the applications.



eye-gaze point
the point on the screen where your eyes are looking

eye positions
the positions of your eye balls relative to the screen

fixations
points on the screen where your eyes linger to focus on something

gaze-aware region
knows when the eye-gaze enters and leaves the region

activatable region
can be clicked or focused using eye-gaze

pannable region
can be scrolled or panned using eye-gaze

user presence
if there is a user in front of the screen or not

**Figure 1 A somewhat simplified view of what the EyeX Engine API can do for you.**

The EyeX Engine is always running when a user is logged on to Windows, and is restarted automatically each time Windows switches users.

Anything that the user can interact with using eye-gaze is called an **interactor** in the language of the EyeX Engine. For example, an interactor can be an activatable (clickable) button, or a widget that is expanded when the user's gaze falls within its bounds. An interactor can also be a stream of filtered data where the user interacts by moving the head or by appearing in front of the screen after being away from it.

It is the gaze-enabled application's job to keep track of its interactors and present them to the EyeX Engine. The application describes what kinds of interactions the user can do with a certain interactor by giving it one or more **behaviors**. The engine's job is to compile the information about interactors from all connected applications, combine it with eye-gaze data and other user input, and decide which interactor the user is currently interacting with—and how. The engine then sends **events** to the application that owns the interactor, with information about the user's interaction. For example, the engine might inform the application that: "The user just activated interactor A", "The user's eye-gaze is within interactor B", "The user's current eye position is (x,y,z)".

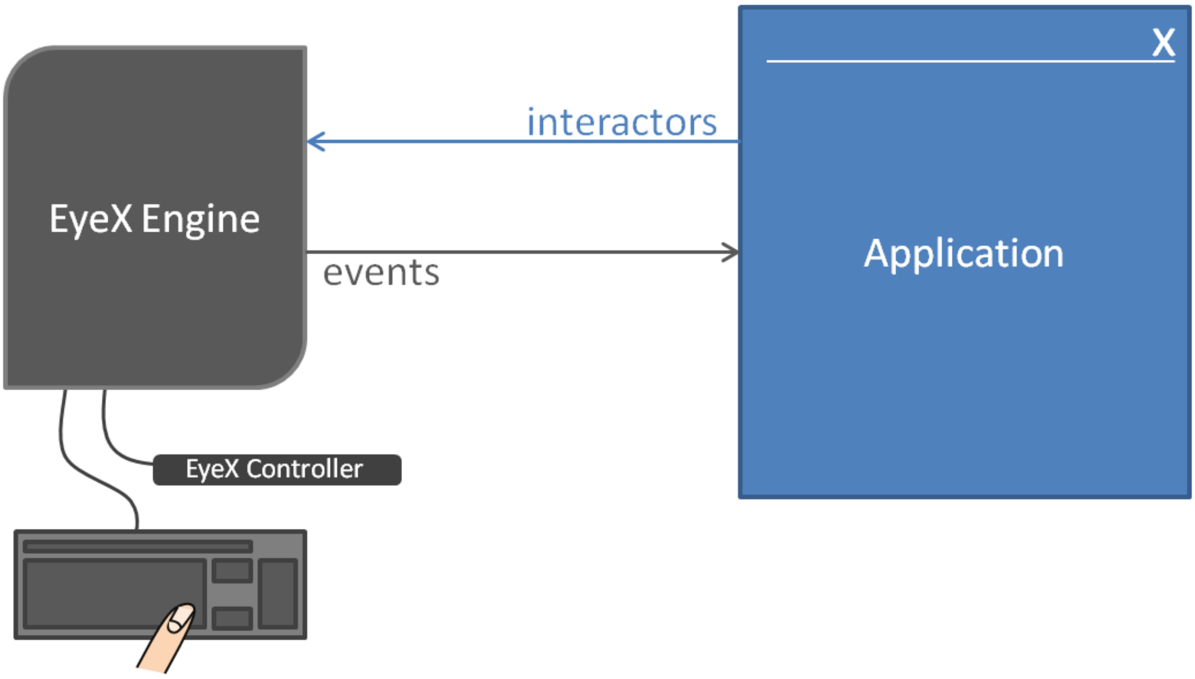


Figure 2 The Tobii EyeX Engine combines information about available interactors with eye-gaze data and user input, concludes what kind of interaction is going on, and informs the application via events.

## A step-by-step interaction example

The EyeX Engine receives eye-gaze data from the EyeX Controller. The EyeX Controller is an eye tracking device that can calculate the point on the screen plane the user's eyes are directed at. This point is called the gaze point. In addition to the gaze point, the eye-gaze data also contains information about the positions of the eyes in 3D space relative to the controller.

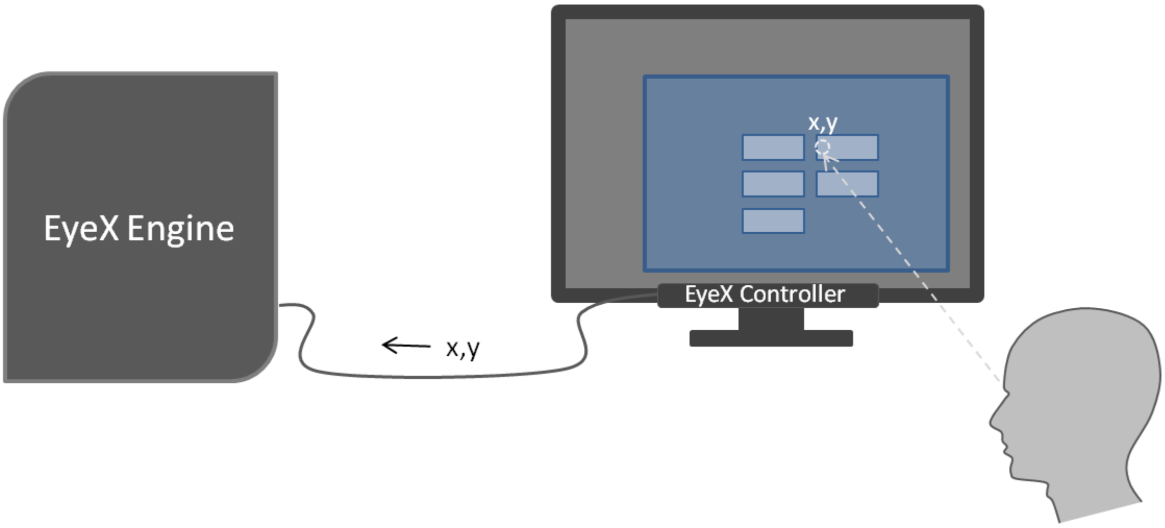


Figure 3 The Tobii EyeX Controller provides the EyeX Engine with eye-gaze data.

Based on the current gaze point, the EyeX Engine will ask the application to provide information about its interactors in a region of interest around the gaze point. The question is sent in the form of a query with the bounds of the region of interest.

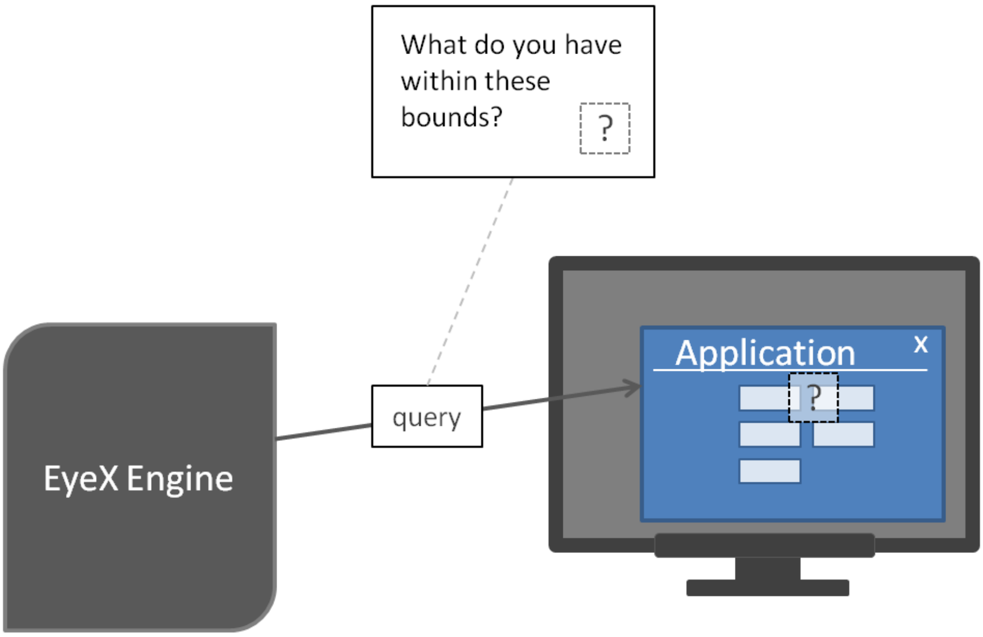


Figure 4 The EyeX Engine asks the application for information about a region of interest around the gaze point.

The application will find all interactors that are within or partially within the query bounds and send information about them to the EyeX Engine.

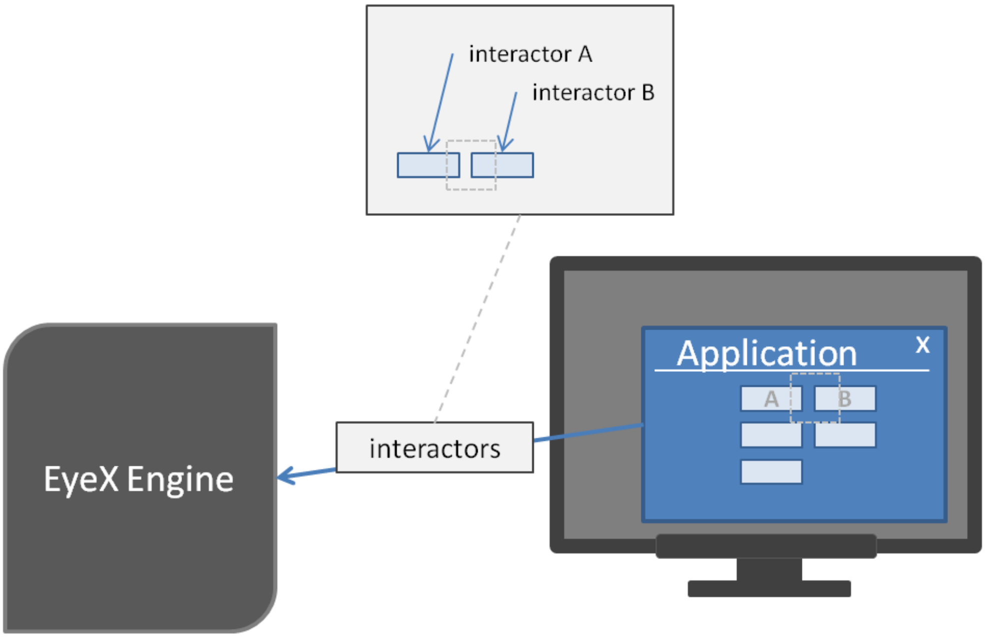


Figure 5 The application sends its interactors to the EyeX Engine.

The especially assigned keyboard keys for the different EyeX interaction behaviors are monitored by the EyeX Engine. For example, by default, the EyeX Click is assigned to the Windows Applications/Context key.

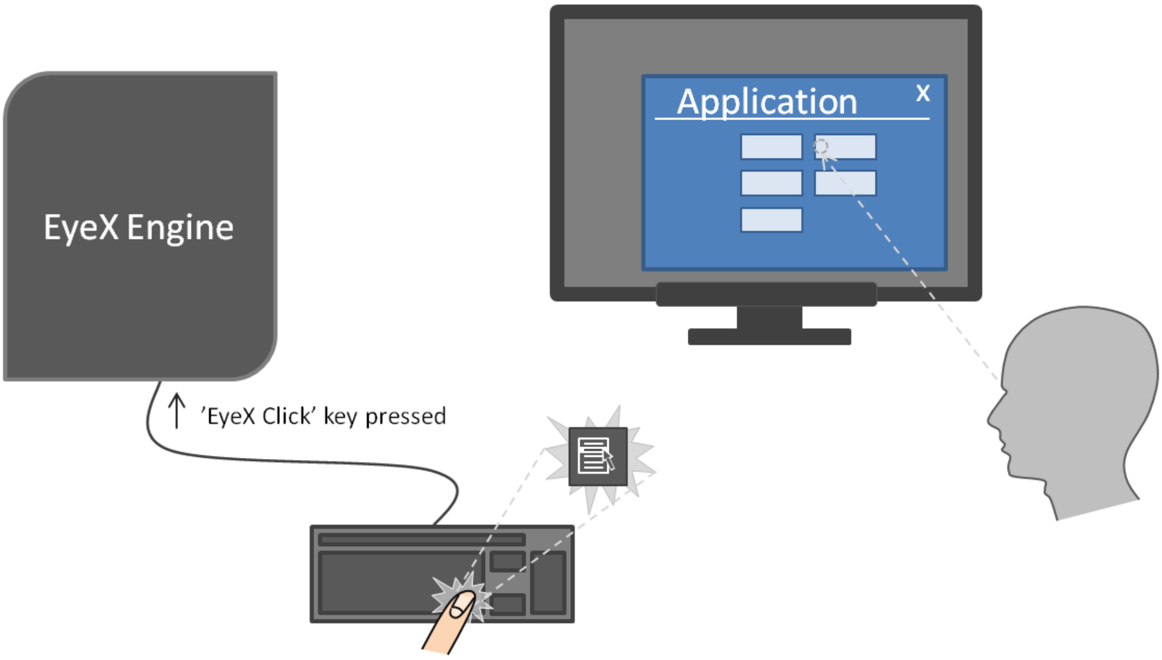


Figure 6 The EyeX Engine combines key pressed events with the current gaze point and information about interactors.

The EyeX Engine combines key press event with the current gaze point and information about the interactors around the gaze point. It then concludes which interactor the user is interacting with and how, and sends an event informing the application what is happening.

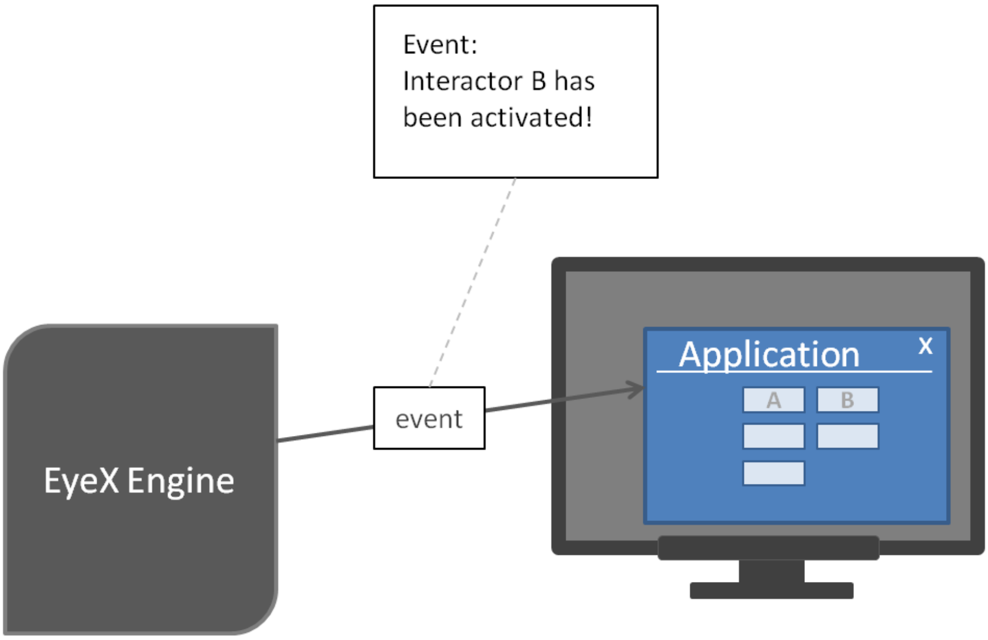


Figure 7 The EyeX Engine sends events to the application to inform it about ongoing interactions.

The application receives the event and handles it. It could mean animating some visual feedback that a button has been clicked, and performing the corresponding action.

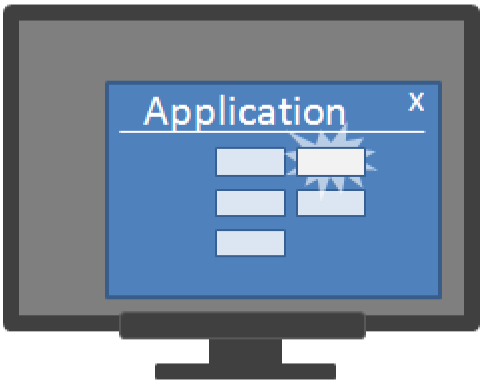


Figure 8 The application handles the event and respond to the user's interaction.

# EyeX Engine API reference

## The Client application

Whenever you find the term **client application**, or just application, in this document, it refers to *your* application. Or to one of the sample applications, or any other application that makes use of the services provided by the EyeX Engine—which plays the part of the server in this instantiation of the classic Client/Server architecture.

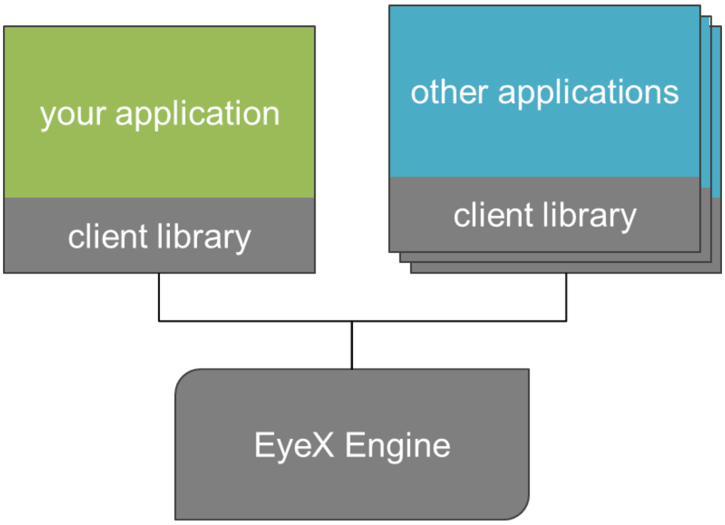


Figure 9 Your application and its relationship to the EyeX Engine.

Something that all client applications have in common is that they use a client library provided with the SDK to connect to the engine.

## Interactors

Anything that the user can interact with using eye-gaze is called an **interactor** in the language of the EyeX Engine. For example, an interactor can be an activatable (clickable) button, or a widget that is expanded when the user's gaze falls within its bounds. An interactor can also be a stream of filtered data where the user interacts by moving the head or by appearing in front of the screen after being away from it.

Some modes of eye-gaze interaction take place within a particular region on the screen, as in the case of the button and widget examples above. Other eye-gaze interaction modes are not tied to any particular region of the screen, as in the case of a stream of eye-gaze data. For example, an information kiosk application or ATM could use an eye-gaze data stream to sense that a user has appeared in front of it, and switch its user interface into a different mode at that point.

The EyeX Engine treats the interactors which are used for eye-gaze interaction within a particular screen region quite differently from those interactors that are not. To clearly distinguish the one kind from the other, we will refer to the former kind as **region-bound interactors**, and the latter kind as **global interactors**. Both will be described in more detail below.

### Region-bound interactors

Region-bound interactors usually map one-to-one with the visual elements/components in the GUI framework used to create the application. This is by convenience and not a requirement: it makes sense, because it is it easier to maintain the relations between the interactors, and because end users expect objects to respect visual hierarchies and window bounds.

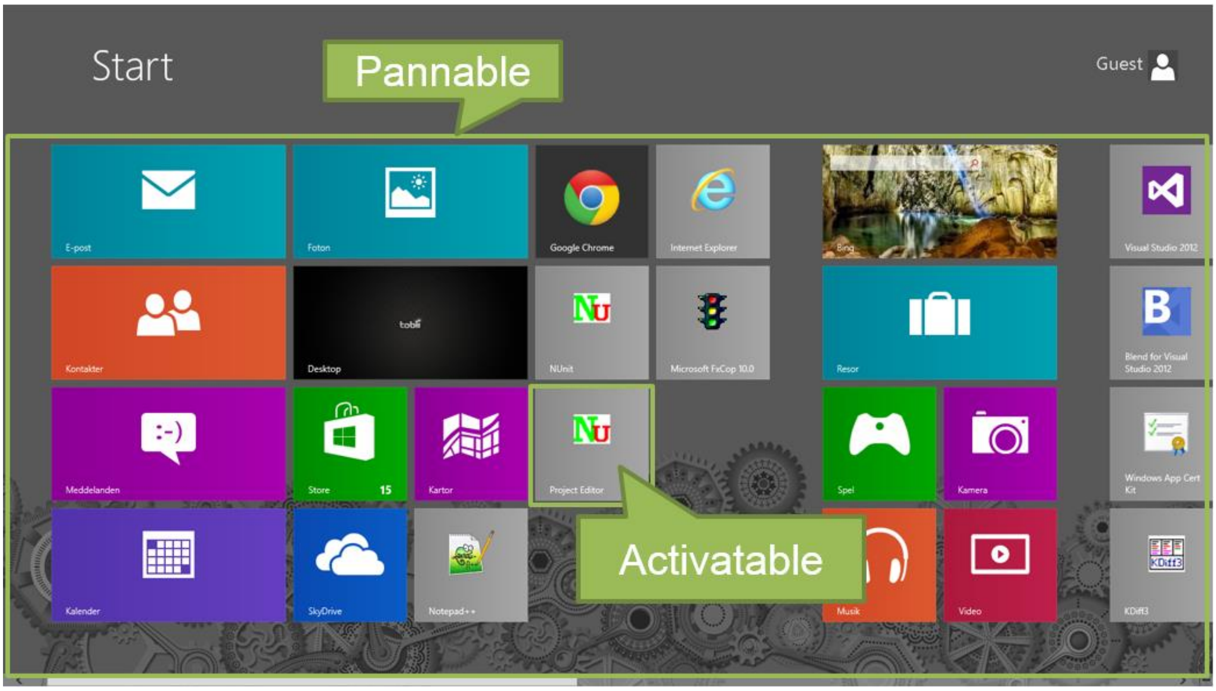


Figure 10 Examples of region-bound interactors

The EyeX Engine considers all region-bound interactors to be transient. The engine will continuously query the application for region-bound interactors based on the user's gaze point. It will remember the interactors long enough to decide what interaction is currently going on, but then it will discard the information. As the user's gaze point moves to a new region of interest, new queries are sent to the application and a new batch of interactors are sent back to the engine. And so on.

### Non-rectangular interactors

By default, a region-bound interactor has a rectangular shape. To define non-rectangular shapes, you need to define a **weighted stencil mask** (or just **mask**) on the interactor. A weighted stencil mask is a bitmap that spans the area of the interactor. The interactable parts of the area are represented by non-zero values in the bitmap. The rest of the area is considered transparent, and cannot be interacted with. The resolution of the bitmap does not need to be as high as the screen resolution. Usually, a low-resolution bitmap works just as well and is better from a performance point of view.

### Global interactors

Global interactors are used for subscribing to **data streams** that aren't associated with any specific part of the screen.

Once you have told the EyeX Engine about a global interactor, the engine will remember it as long as the connection with your application remains, or until you explicitly tell the engine to remove the interactor. So, while region-bound interactors are committed continuously in response to queries from the engine, a global interactor is usually only committed once per established connection.

A common usage pattern is to set up a global interactor when the application starts, and to send it to the engine as soon as the connection is established, or re-established—for example, due to a switch of users. (The EyeX Engine restarts automatically every time Windows switches users.)

### Interactor ID's

The one thing that makes the EyeX Engine recognize an interactor, regardless of how it moves around and how its behaviors change, is the interactor's ID. It is your responsibility, as a developer, to ensure that all interactor IDs are indeed unique—at least within their respective contexts, as described below.

The interactor IDs can be any string values, and since almost anything can be converted to a string, that leaves you with plenty of options. So, what does a good interactor ID look like?

In the rather common case when an interactor maps directly to a user interface component, and that component already carries a sufficiently unique ID, it's good practice to let the interactor ID match the component ID. Not only will that give you reliable, unique, constant ID's; it will also simplify the mapping between interactors and components.

In other cases there are no clear-cut guidelines. Just try to choose ID's that make sense in your domain.

## Interaction Behaviors

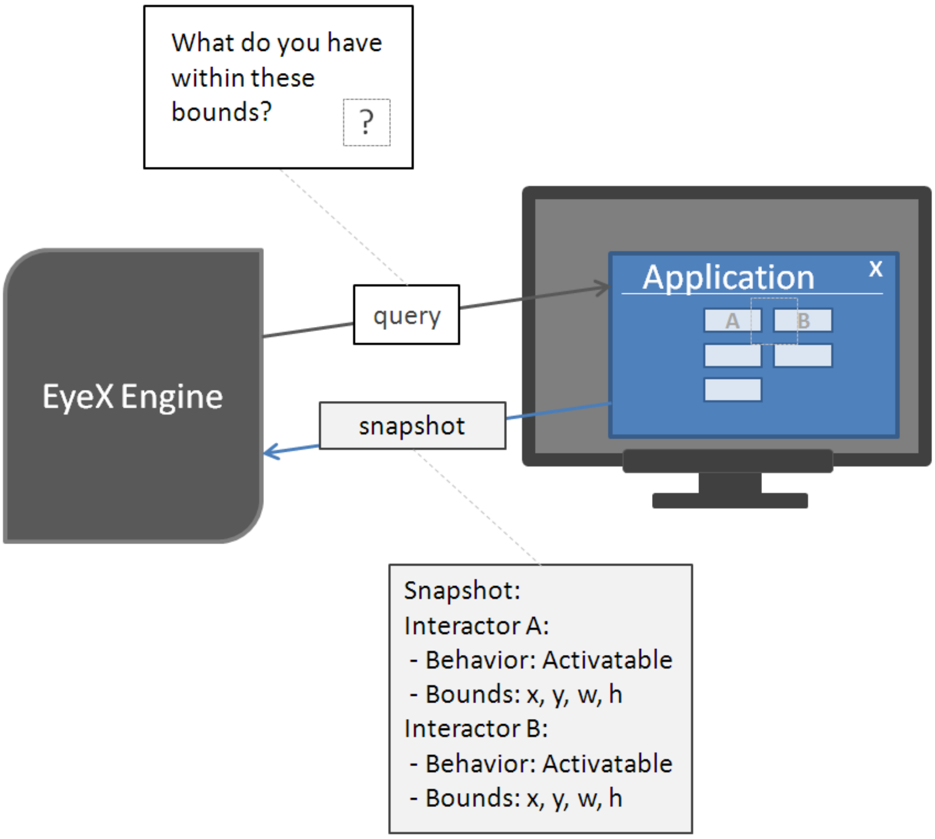
An interaction behavior, or **behavior** for short, is a particular mode of eye-gaze interaction that an interactor may provide. The catalog of behaviors is by far the most important part of the EyeX Engine API, because each behavior represents a piece of functionality that your application can use. The available behaviors are described in more detail later in this document.

Some behaviors are intrinsically region-bound, and some are not. It is really the behaviors that determine whether an interactor should be region-bound or global.

So, how much use would an interactor be if it didn't have any behaviors? Actually, there is a case where behavior-less interactors are indeed quite useful. A region-bound interactor without behaviors is effectively just preventing eye-gaze interaction on the part of the screen that it covers, and is commonly called an *occluder*.

The EyeX Engine adds occluders representing all top-level windows[2] automatically, in order to prevent any parts of a window which are covered by other windows to take part in eye-gaze interaction. The interactors defined by your application will be considered as children to the top-level window interactors.

## The Query-Snapshot cycle



Snapshot:
Interactor A:
- Behavior: Activatable
- Bounds: x, y, w, h

Interactor B:
- Behavior: Activatable
- Bounds: x, y, w, h

Figure 11 The Query-Snapshot cycle.

A key design principle of the EyeX Engine is that it senses what is on the screen one piece at a time, by making **queries** to the client applications. That is, it does *not* expect the applications to declare their entire gaze enabled user interface up front, but rather to feed the engine with information continuously, on request.

Note that this design principle doesn't prevent an application from keeping a repository, or cache, of its region-bound interactors, and respond to the engine's queries with cached information. Whether or not to use a repository is a design decision left to the application developer.

The queries roughly follow the user's gaze point. Queries are always specified with bounds, that is, a rectangular region on the screen, and with one or more window IDs. In areas on the screen where windows from different client applications are close, the query is sent to all applications, and each is

[2] "Top-level window" is a Windows term for a window that doesn't belong to another window. Top-level windows are typically displayed on the taskbar. Applications typically display one top-level window for the application itself, or one top-level window for each document opened in the application.

responsible for keeping the engine updated on the region-bound interactors within its window(s). The window IDs in the queries identify the top-level window(s) that the engine wishes to receive interactor information for.

The packet of data that the client sends in response to a query is called an interaction snapshot, or **snapshot** for short. It contains the set of region-bound interactors that are at least partially within the query bounds, a timestamp, and the ID of the window that the snapshot concerns.

There is no one-to-one correspondence between queries and snapshots. If an application doesn't respond in a timely fashion, then the engine will simply assume that it didn't have any region-bound interactors to report—which may or may not be what the application intended.

An application may also act proactively and send the engine snapshots that it didn't ask for. This is how applications usually inform the engine of its global interactors. Animated interactors whose screen bounds change over time is another case where application-initiated updates can be useful.

The information in a snapshot should be considered as the *complete* description of all region-bound interactors within the snapshot bounds. If two snapshots with the same bounds are committed after another, and the first committed snapshot contains an interactor that is not included in the second snapshot, the engine will interpret this as if that interactor has been removed. As a consequence: don't stop responding to queries when your last interactor has gone off-stage—instead, keep sending empty snapshots so that the engine will know that they are gone.

The exception to this guideline is an application that doesn't use any region-bound interactors at all. Such an application doesn't even have to handle queries, because the global interactors are handled separately, as described in the section on global interactors above.

## Events

As soon as the EyeX Engine has found that a particular kind of gaze interaction is taking place between the user and an interactor, it notifies the application that owns the interactor by sending it an **event**.

Events are used for both region-bound and global interactors, so an application should always be set up to receive and handle events from the engine.

Events are tagged with the ID of the interactor and the behavior(s) that triggered the event. Some events also include additional, behavior-specific parameters related to the interaction.

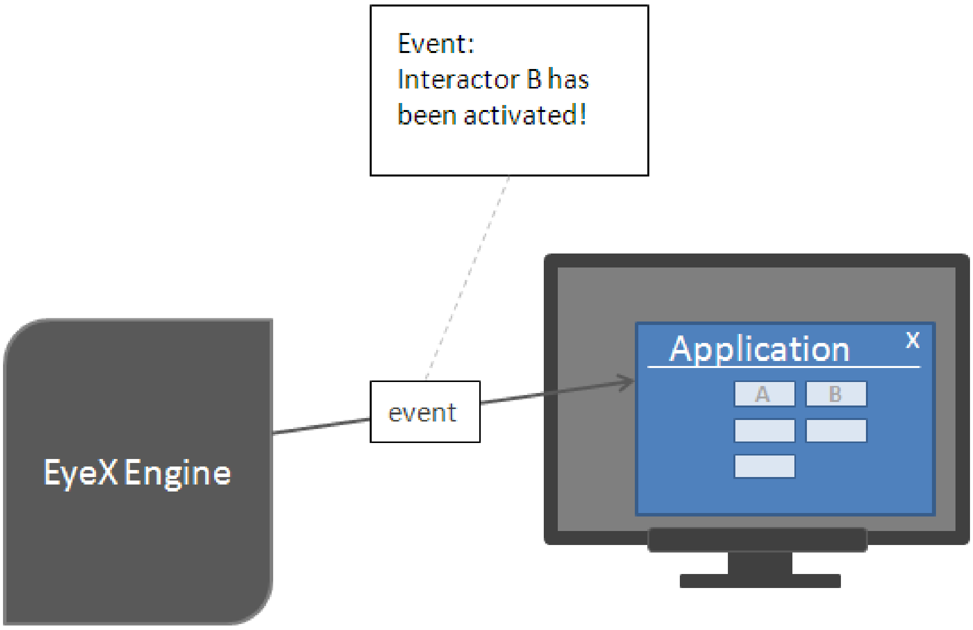


Figure 12 Event notification on a region-bound interactor

## Interactor bounds and nested interactors

A region-bound interactor is always associated with a region, as the name implies. This region is called the interactor's **bounds**, and is currently defined as an axis-aligned rectangle on the screen. (If a weighted stencil mask is applied on the interactor, non-rectangular shapes can also be defined).

A region-bound interactor is also associated with a top-level window, and its bounds cannot extend outside the window—or, rather, its bounds will be clipped to the bounds of the window. This might seem like a severe restriction at first, but do remember that it applies to region-bound interactors only—the global interactors by definition do not have this restriction.

User interfaces are typically built as tree structures: starting from the window, there are layout containers, scroll containers, etc, until we arrive at the actual content that is visible on the screen. The contents are often only visible in part, such as in the case of a long, scrollable list where only a few items can be seen at any time, or when another window is covering part of the view. Users typically expect the invisible parts to be excluded from interaction.

Using only the bounds information, all region-bound interactors would appear to lay flat next to each other. Suppose two of them were overlapping, which one should the engine pick as the candidate for eye-gaze interaction? Instead of forcing the application developer to avoid overlaps by adjusting the interactor bounds, the API provides **nested interactors** to help out. The engine will consider child interactors to be in front of all its ancestor interactors.

Region-bound interactors can be organized in a tree structure just like the user interface components. Each interactor provides the ID of its parent if it has one, or otherwise a special ID representing the top-level window. Interactors that are children of the same parent interactor should specify a Z order (highest on top) if they overlap. Specifying parent-child relationships like this can be thought of as nesting interactors inside each other.

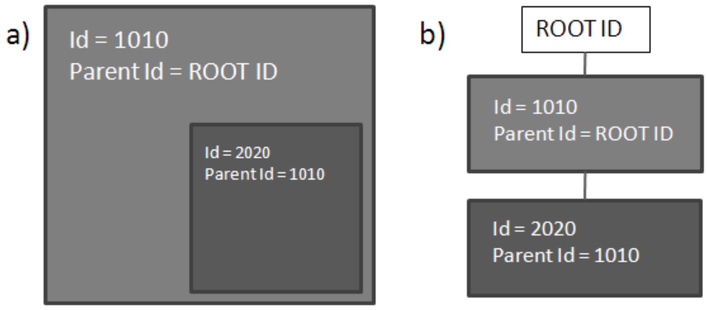


**Figure 13 a) Nestled interactors, where the child interactor is overlapping its parent interactor. b) The corresponding interactor tree-structure.**

The bounds of a child interactor may extend outside the bounds of its parent. Windows makes a distinction between *child windows* and *owned windows*, and a child interactor is more like an owned window than a child window in this sense.

When the EyeX Engine scans the area around the user's gaze point for interactors, it starts by determining which top-level windows there are in the region. Then it proceeds to search through the interactors attached to those windows, looking for interactors whose bounds contain or are close to the gaze point. During this process the engine makes use of both the parent-child relationships and the Z order information to decide what is on top of what.

The Z order is only compared between sibling interactors, and a sibling with a higher Z order will be considered to be in front of not only its sibling with lower Z order, but also to all children interactors of these siblings. Because of this, one has to be careful when constructing an interactor tree-structure so that the interactors overlap as intended. This is illustrated in Figure 14 and Figure 15.

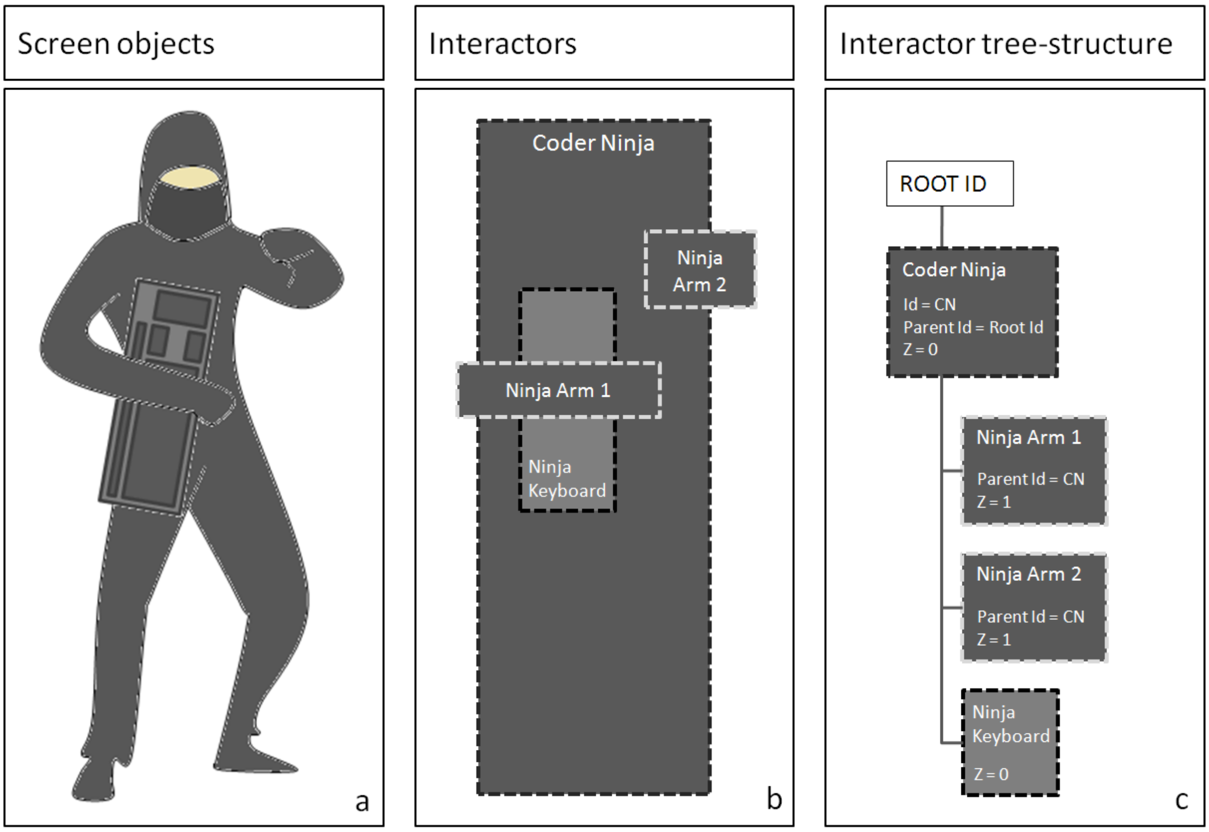


Figure 14 a) Coder Ninja with Ninja Keyboard b) Corresponding overlapping interactors. c) By making the Ninja Arm 1 and the Ninja Keyboard children of the Coder Ninja, but with different Z order, the EyeX Engine is told that they are both in front of the Coder Ninja, but that the arm is in front of the keyboard. The Z order of the other arm does not matter, since it does not overlap any of its siblings.

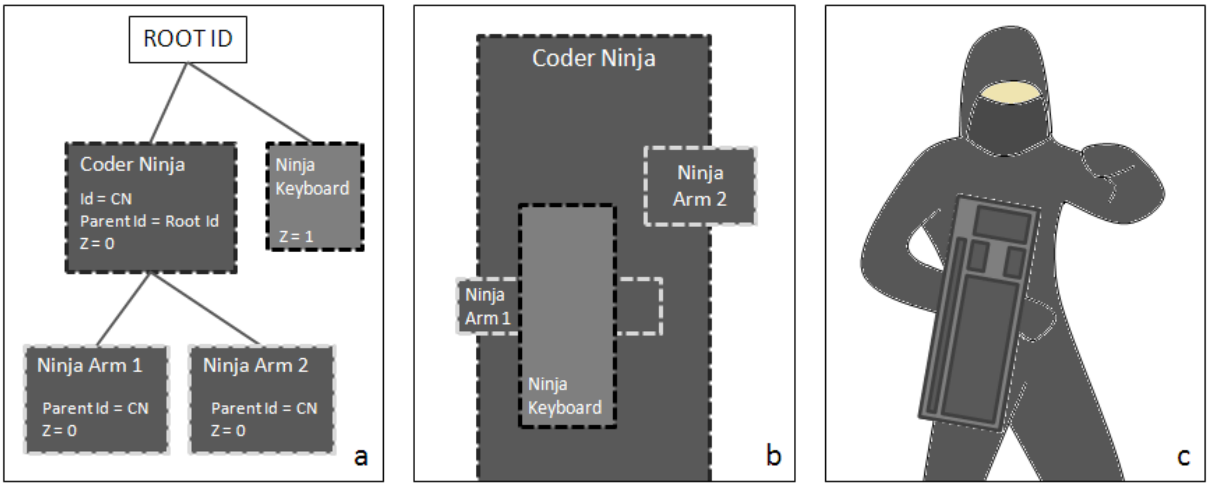


Figure 15 Making the Ninja Keyboard a higher Z order sibling of the Coder Ninja (a), would not only put it in front of the Coder Ninja but also all of Coder Ninja's child interactors, including the Ninja Arm 1 (b and c).

When the engine has identified the topmost interactor that is closest to the gaze point (if any) it looks at the interactor's behaviors to see what kind of user input it should expect and how to react on it.

The existence of nested interactors has some consequences for the application developer when preparing a snapshot:

- If an interactor in a snapshot references another interactor as its parent, then the parent interactor must also be included in the snapshot, even if it isn't within the snapshot (or query) bounds.
- If two interactors with overlapping bounds have the same parent interactor and the same Z order, then the EyeX Engine cannot decide which one is actually on top. The outcome will be random and the user experience inconsistent. So, ensure you are careful when defining the bounds and relationships of your interactors.

## Contexts

A **context** represents a connection between an EyeX client application and the EyeX Engine. Applications typically create a context during startup and delete it on shutdown.

The application uses the context to register query and event handlers, and also to create **interaction objects** such as snapshots. Queries and events are also interaction objects, but they are normally not created by the application. An interaction object always belongs to a certain context, and interaction objects cannot be shared between contexts.

## States

The EyeX Engine keeps track on a number of **states** that are related to eye tracking, user input etc. Examples of states are Connection State, Display Size (in mm), Screen Bounds (in pixels) and user presence. Each state has a unique path that a client application can use to retrieve the information if needed. It is also possible to setup state changed handlers to get notified when a state changes.

## 3D Coordinate system

The coordinate system used for 3D points in the EyeX Engine, for example for the Eye position data stream, is relative to the screen where the eye tracker is mounted. The origin is at the center of the screen. The x axis extends to the right (as seen by the user) and the y axis upwards, both in the same plane as the display screen. The z axis extends towards the user, orthogonal to the screen plane. The units are measured in millimeters.

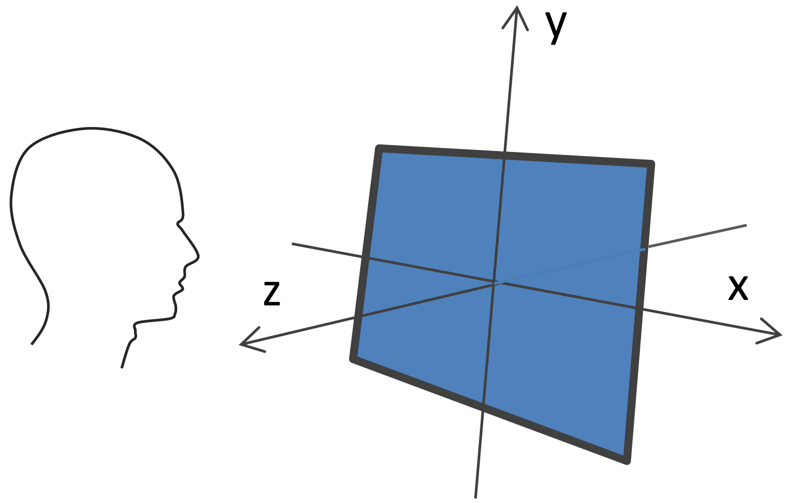


Figure 16 The 3D coordinate system used by the EyeX Engine.

Note that the y axes in the 3D coordinate system and the 2D coordinate system are different. The y axis in the 2D coordinate system crosses zero at the top of the screen and extends downwards; the y axis in the 3D coordinate system crosses zero at the middle of the screen and extends upwards.

## Behaviors for region-bound interactors

Behaviors for region-bound interactors are naturally associated with a region or an object on the screen. Or, to be more precise, with a region or object *in a window* on a screen, because region-bound interactors must always be associated with a window.

The behaviors for region-bound interactors either let the user perform an action on the object/region, such as the gaze activation (clicking), or they provide some sort of monitoring of the user's eye-gaze on the object or region.

### The Activatable behavior

An interactor which has the Activatable behavior represents an action that the user can select and trigger using their eye-gaze. But typically not using their gaze only—because triggering actions entirely using eye-gaze isn't comfortable to most people. The actual triggering is usually performed using another input modality. The default setting in the EyeX Engine is to use the Applications key[3]

[3] The applications key is also known as the context menu key. It looks like this: ▤

to trigger activation. Future releases of the engine may provide additional ways of triggering activation, such as touchpad gestures, or voice commands.

What happens on activation is very much up to the application developer to decide. The activation can be thought of as a mouse click, or a touch tap, or the pressing of a button. Common usages include selecting an item from a menu, executing a command (for example, launching an application), navigating to a web page, flipping pages, firing the lasers, and so on.

**Activation step-by-step**

Activation is a multi-step process: first, before pressing down the activation key, when the user's eye-gaze falls on an activatable interactor, the interactor receives a *tentative focus* event – but only if it has declared interest in those events. Only one interactor may have the tentative focus at any given time.

Be aware that tentative focus might not always be available, even if you request it for your interactors. The engine may choose to disable this function, so that it may run the eye tracker at a lower frame rate, in order to reduce the power consumption when running on a limited power budget.

Pressing down the activation key takes us to the next stage, where interactors get the *activation focus*. Only one interactor may have the activation focus at a given time, and if one interactor has the activation focus, then no interactor may have a tentative focus. The EyeX Engine enforces this rule across all applications, so that several gaze enabled applications can run in windows next to each other without confusing the user with multiple focuses/highlights.

Lastly, releasing the activation key triggers the activation and sends an *activated* event to the interactor that has the activation focus, if any. It also clears the activation focus.

**Design and visual feedback**

The way you design your application can have a huge effect on the usefulness of the activatable behavior. Here are some guidelines to help you make the best use of this interaction pattern:

- Give the user something to focus on: a visual hotspot. This can be as simple as the caption on a button. Sometimes there are several visual hotspots on an interactor, for example, an icon and some text. That's fine too.
- Make sure that the visual hotspots of different interactors are sufficiently separated. For example, add more spacing around the visual elements, and/or make them larger. Note that spacing can be more effective than size.
- Be careful with any visual feedback given; it can be helpful but it can also be distracting.

### The Gaze-aware behavior

An interactor with the Gaze-aware behavior represents a region or object on the screen that is sensitive to the user's eye-gaze. Possible uses of the behavior include widgets that expand on gaze, game characters that act differently when being watched, and other usages where the user interface adapts to what the user is looking at, or implicitly, is paying attention to.

The EyeX Engine raises one event when the user's gaze point enters the bounds of the interactor, and another event when it leaves. If the Gaze-aware interactor has child interactors that also have the Gaze-aware behavior, the gaze point will be considered to be within the parent interactor as long as it is within an unbroken hierarchy of Gaze-aware child interactors. This applies even if the gaze point isn't within the bounds of the parent.

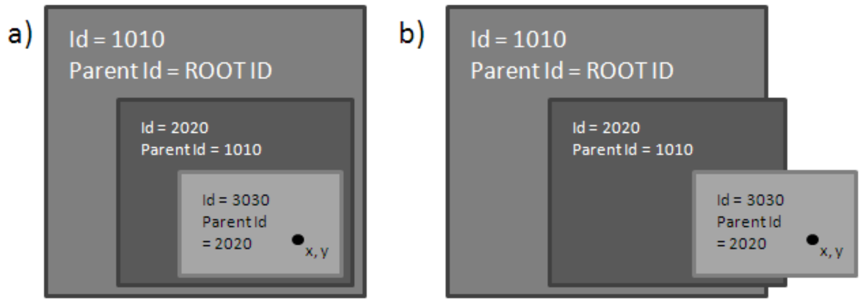


**Figure 17 Nested Gaze-aware interactors: The gaze point at (x, y) is considered to be within the bounds of the parent interactors, no matter if it is a) geometrically within or b) geometrically outside the parent interactors' bounds. Moving the gaze point between child interactors does not trigger any additional events for the parent interactor.**

Note that the fact that the user is looking at something doesn't necessarily mean that she is paying attention to it, and also that this behavior is quite sensitive and can easily be triggered by noise and/or rapid eye movements. A common way of dealing with this uncertainty is to add some inertia to the interaction: make sure that the gaze point stays on the interactor for a while until the response is triggered, and don't release the trigger until the gaze point has been off for a while.

For a simple way to add inertia, there is a built-in delay parameter that can be set on a gaze-aware interactor to specify a delay between when the user's gaze point enters the interactor bounds and when the event is raised.

## Behaviors for global interactors (Data streams)

The behaviors for global interactors can be thought of as data streams that you can subscribe to, by creating a global interactor with the desired behavior.

Each data stream delivers one kind of data, for example the user's gaze point, and often comes in several variants that differ for example in the choice of filtering.

### The Gaze point data behavior

The Gaze point data behavior provides the user's gaze point on the screen as a data stream. The unfiltered data stream produces a new data point whenever the engine receives a valid eye-gaze data point from the eye tracker. No statements are made regarding the frame rate; it is what it is.

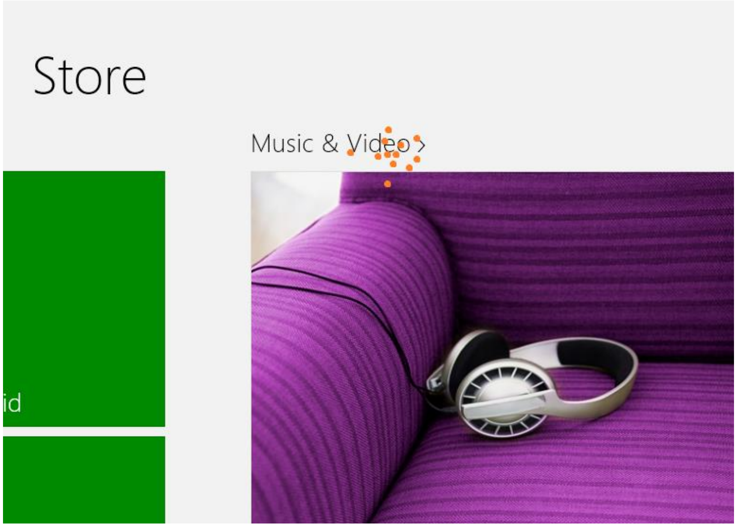


Figure 18 The gaze point is an inherently noisy signal. The orange dots on this screenshot represent the user's gaze point during a fraction of a second. Filtering makes the point cloud shrink towards its center, but also respond slower to rapid eye movements.

The gaze point is given as a single point. If the user has chosen to track a specific eye, then it's the gaze point from that eye. Otherwise the point is taken to be the average from both eyes.

The gaze point is given in physical pixels. If you haven't already done so, take a look at the section called *What you must know about pixels* below for an explanation of what this means.

Because the gaze point is an intrinsically noisy signal, the Gaze point data behavior provides a selection of filters that can be used to stabilize the signal. As usual when it comes to filtering, there is a trade-off between stability and responsiveness, so there cannot be a single filter that is the best choice for all applications. The choice of filters are:

- Unfiltered: no filtering performed by the engine. (Except for the removal of invalid data points and the averaging of the gaze points from both eyes.)
- Lightly filtered: an adaptive filter which is weighted based on both the age of the data points and the velocity of the eye movements. This filter is designed to remove noise while at the same time being responsive to quick eye movements.

*Note: We expect that more filters will be added in later releases of the engine.*

## The Eye position data behavior

The Eye position data behavior provides the user's eye positions in three-dimensional space as a data stream. This data stream can be used, for example, to control the camera perspective in a 3D game.

This data stream produces a new value whenever the engine receives a valid sample from the eye tracker, and no statements are made about the frame rate, just as for the Gaze point data behavior. The eye positions are given for the left and right eyes individually. See the section *3D Coordinate system* for a description of the coordinate system used.

The Eye position data behavior does not offer any filtering options at this time.

### The Fixation data behavior

The Fixation data behavior provides information about when the user is fixating her eyes at a single location. This data stream can be used to get an understanding of where the user's attention is. In most cases, when a person is fixating at something for a long time, this means that the person's brain is processing the information at the point of fixation. If you want to know more about fixations, the Internet is your friend.

To get information about the length of each fixation, the Fixation data behavior provides **start time** and **end time** for each fixation, in addition to the **x and y point** of each individual gaze point within the fixations.

When setting up the fixation data behavior, these fixation data modes are available:

- **Sensitive**, will result in many fixations, sometimes very close and in quick succession.
- **Slow**, will result in fairly stable fixations but may leave somewhat late.

*Note: We expect that more fixation data modes will be added in later releases of the engine.*

## What you must know about pixels

Points on the screen are always given in **physical pixels** in the EyeX Engine API. Unfortunately, this isn't as simple as it sounds. But in order to explain why, we need some background on how Windows handles multiple display monitors, and why a pixel in your application isn't always the same as a pixel on the screen.

### Client and Screen coordinates

The coordinate system most commonly used by developers is the *client coordinate system*, which is relative to the top left corner of a window. The window can be your application's top level window, or it can be a child window such as a button. Each window has its own client coordinate system, which is used when laying out its contents.

There is also a coordinate system that relates to the pixels on the screen. That is, a system that is fixed relative to the screen and doesn't move around with a window. This coordinate system is called *screen coordinates* in Windows.

Mapping between screen coordinates and client coordinates is performed using the `ClientToScreen` and `ScreenToClient` functions (or the `MapWindowsPoints` function if your application supports right-to-left mirroring). This is standard procedure.

This means that—

- If you received, for example, the user's gaze point from the EyeX Engine, and you want to get its position relative to your application's top level window, then you should use the `ScreenToClient` function to map the coordinates to the client coordinate system of your window.
- When preparing a snapshot for the EyeX Engine that includes region-bound interactors corresponding to user interface elements, and you know the bounds of those user interface

elements in client coordinates, then you should use the `ClientToScreen` function to map them to screen coordinates.

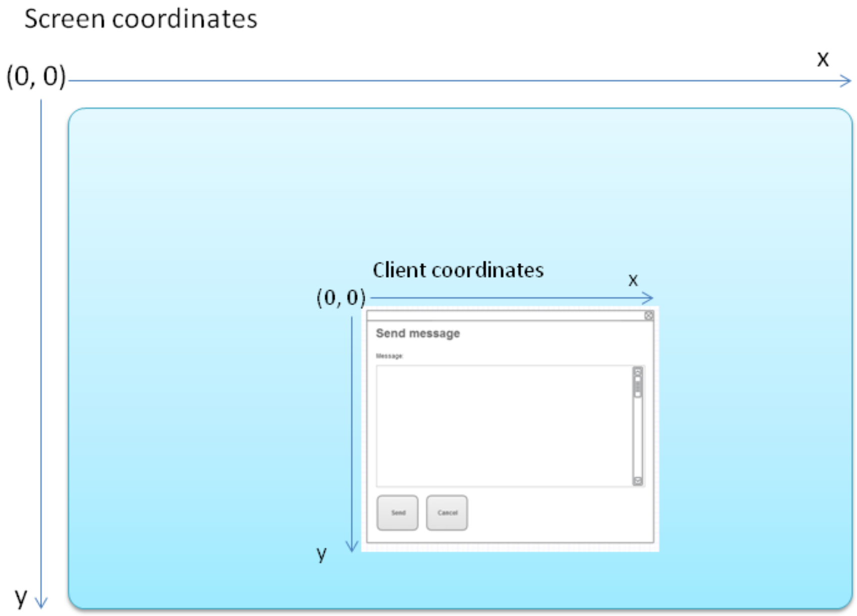


Figure 19 Screen vs client coordinates

## Multiple display monitors

In a system with multiple display monitors there is still a single screen coordinate system that spans all of the monitors. This is referred to as the *virtual screen*. Pixel coordinates on the virtual screen can be negative because the origin (0, 0) is always on the primary monitor. So if you place another monitor to the left of the primary, then it will have negative x coordinates.

If you are using multiple screens, you can place the eye tracker on any screen you want. Once you have set up the EyeX Engine to use a particular screen, it will make sure that the eye tracker coordinates are mapped properly.

## DPI scaling and DPI awareness

The **DPI scaling**[4] feature, also known as DPI virtualization, was first introduced with Windows Vista. It enables the user to set the screen DPI to a value larger than 100%, making everything appear larger on screen. This can be useful with very large monitors, with high-dpi monitors, or for users who have impaired eyesight.

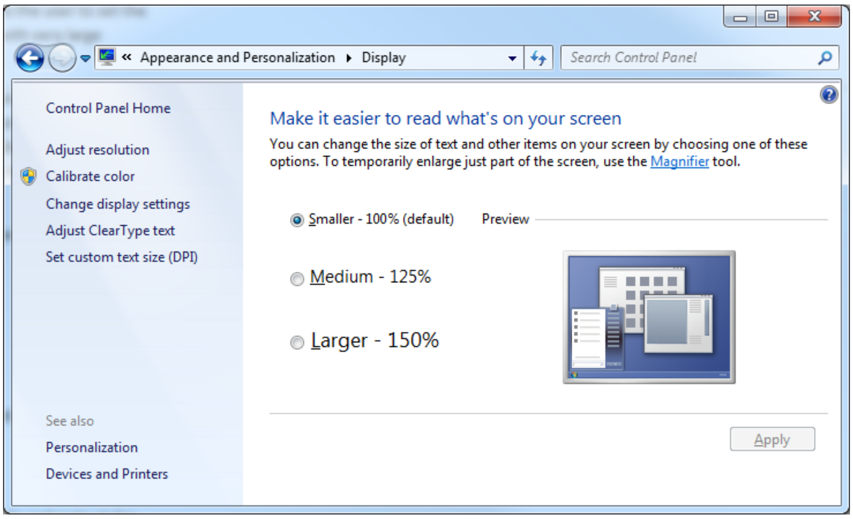
Applications may indicate to Windows whether they take care of the scaling themselves or not, that is, if they are **DPI aware** or not. If they don't declare anything, then Windows will assume that the application does not handle scaling, and will scale the window automatically if the DPI setting is above 100%. Windows performs the scaling by rendering the application's window to an intermediate buffer instead of to the screen, and then drawing a magnified screen image from the buffer.

[4] DPI is an abbreviation for Dots Per Inch, a unit often used when stating the resolution of a screen or a printer.

Windows also has some clever tricks to protect the application from having to know anything about the scaling being performed. Unfortunately, these clever tricks break the transformation between client coordinates and screen coordinates, so that the coordinates reported by the application to the EyeX Engine will be wrong. **Therefore all EyeX client applications should be DPI aware.**

An application which is DPI aware will always be able to respond correctly to the EyeX Engine's queries and events, and as a side effect you also get a better looking user interface without scaling artifacts.

Note that some GUI frameworks, such as the Windows Presentation Foundation, always declare DPI awareness, so you might not have to do it yourself. If you are uncertain if this is the case, it is easily tested: set your monitor DPI setting to "Larger" and run your application full-screen. Any offsets should be easily noticed.



Make it easier to read what's on your screen

You can change the size of text and other items on your screen by choosing one of these options. To temporarily enlarge just part of the screen, use the Magnifier tool.

● Smaller - 100% (default)

○ Medium - 125%

○ Larger - 150%

Figure 20 The Display settings page in the Control Panel. This is where the user can change the DPI setting.

Windows 8.1 takes the concept of DPI awareness and scaling even further, by introducing a per-monitor DPI setting. This is not yet fully supported.

For more information about screen coordinates, multi-monitor setups, and DPI awareness, see

- Window Layout and Mirroring on MSDN
- Multiple Display Monitors on MSDN
- Writing High-DPI Win32 Applications on MSDN

# Using the C API

## Compiling and linking with the C API

The Tobii EyeX Engine C API is made available through a dynamic-link library that your application must be linked with, as well as a set of C header files that describe the API using C syntax.

You will only need to include a single header file—the one called EyeX.h—in your C or C++ program. This include file will in turn include the other header files as needed. All header files for the C API can be found in the include/eyex directory.

The dynamic-link library is available in both 32-bit and 64-bit format and can be found in the lib/x86 and the lib/x64 subdirectories, respectively. The dll must also be copied to the directory where your application's executable file resides, otherwise Windows won't be able to find it at runtime. The code samples use an MSBuild script to copy the correct version to the output directory as part of the linking step, but copying the file manually or by other means works just as well.

## Working with interaction objects

One of the most common data types in the C API is called `TX_HANDLE`. It represents some kind of interaction object: an interactor, a snapshot, an event, etc. These are things you absolutely need to know about `TX_HANDLE`s:

- Interaction objects are always associated with a context, and they are reference counted.
- An empty handle is represented by TX_EMPTY_HANDLE.
- You are responsible for releasing *any* `TX_HANDLE`s that the API hands you, using the `txReleaseObject` function. It doesn't matter how you got the handle; if you called a function called `txCreateSomething`, or if one of your callback functions was invoked with a `TX_HANDLE` as a parameter, you still have to release the object.
- When you delete a context, the client library will report any objects that you forgot to release to the log. You should keep an eye on those reports, since resource leaks are a Bad Thing that can cause your application to run gradually slower over time.
- During development it can be quite helpful to be able to peek inside the interaction objects, for example, to see the contents of events that you receive. There is a function called `txDebugObject` that lets you do exactly that; take a look at the samples to see how it can be used. And be sure not to use it in production builds.

## Setting up a context

The first thing the application needs to do, to be able to start using the EyeX client library, is to initialize the library using the `txInitializeEyeX` function, and then create an interaction context using the `txCreateContext` function. The context handle is the fundamental point of access to do anything in the library. You need it in order to:

- create a snapshot and the interactors in it,
- register event and query handlers,
- establish a connection to the engine.

The application therefore typically creates the context during initialization, holds on to the context handle through the life span of the application, and deletes the context on shutdown.

Initially, the context's connection to the EyeX Engine is disabled, meaning that there is no communication with the engine. Before enabling the connection, the application uses the context handle to set up the client side of the client–engine interaction. Usually this means registering the message handlers for events, queries and connection state changes. The application could also prepare for data streaming by creating a global interactor snapshot which can then be committed whenever the connection to the engine is established. (It isn't possible to commit a snapshot when disconnected from the engine.)

In some advanced cases the application might also wish to set up a custom allocator and/or threading model. This can be done when the client library is initialized.

### Registering handlers

The application needs to register handlers for all types of information from the EyeX Engine it wants to subscribe to.

Handlers for connection state changes, queries, events and messages are registered in the form of callback functions using `txRegisterConnectionStateChangedHandler`, `txRegisterQueryHandler`, `txRegisterEventHandler` and `txRegisterMessageHandler` respectively. The callback functions will be invoked from worker threads.

## The connection state

When all is set up, the application enables the context's connection to the EyeX Engine by calling the `txEnableConnection` function. Enabling a connection means allowing a connection to be established and kept alive until it is disabled, or until the context is destroyed.

When the context's connection has been enabled, its state will change to one of the following:

- `TX_CONNECTIONSTATE_CONNECTED`
  A connection was successfully established to the EyeX Engine.
- `TX_CONNECTIONSTATE_TRYINGTOCONNECT`
  The first connection attempt timed out and now repeated tries will be made until a connection is successfully established.
- `TX_CONNECTIONSTATE_SERVERVERSIONTOOLOW/`
  `TX_CONNECTIONSTATE_SERVERVERSIONTOOHIGH`
  The EyeX client API and the EyeX Engine versions are incompatible. No more attempts to connect to the EyeX Engine will be made, and there is no way of establishing a working connection without upgrading or downgrading to compatible versions.

If an established connection goes down, the connection state is changed to `TX_CONNECTIONSTATE_TRYINGTOCONNECT`. When a connection is re-established, the state is changed back to `TX_CONNECTIONSTATE_CONNECTED` again. A successfully enabled connection will be in either of these two states until it is disabled by the application.

Whenever the connection state changes, the registered connection state changed handler is called with information on what the state was changed to.

## Responding to queries

The registered query handler will receive callbacks with queries from the EyeX Engine, asking the application to supply information about the area of the screen where the user is currently looking. The application can then handle the query step by step:

1. Extract the query bounds from the query
2. Create a snapshot
3. Add interactors that intersect with the query bounds to the snapshot
4. Commit the snapshot to the EyeX Engine

### Extracting the query bounds

Extraction of the query bounds from the query is done in two steps. First `txGetQueryBounds` is used to get a handle to the query bounds property. Then the values for x, y, width and height can be retrieved using the `txGetRectangularBoundsData` function.

### Creating a snapshot

In order to create the snapshot, the application has to decide which interactors to create and add to the snapshot.

First of all, a snapshot object needs to be created. When creating a snapshot as a response to a query a convenient function to use is `txCreateSnapshotForQuery`. This way a snapshot is created with the same bounds and windows id as the query. Another useful alternative is `txCreateSnapshotWithQueryBounds` that uses the same bounds as the query. If, for some reason the application needs to create a snapshot with different bounds, the `txCreateSnapshot` function can be used in combination with `txCreateSnapshotBounds`.

When adding an interactor to a snapshot, the application has to make sure the window ID of the interactor has also been added to the snapshot. If `txCreateSnapshotForQuery` has not been used, window IDs are added to snapshots using the function `txAddSnapshotWindowId.`

The window ID must be the window handle ("HWND") of the top-level window containing the interactor, formatted in a character string as a decimal number. The C function `itoa` is convenient for this—just remember to use 10 for the base.

### Adding the interactors

The word interactor has so far been used interchangeably to mean either the conceptual interactor—a specific region on the screen possible to do eye interaction with, or, the actual interactor object that is created and added to a snapshot. In this section the distinction is important, so, in this section, *interactor* refers to the conceptual interactor, *interactor bounds* refers to the region on the screen bounding the interactor, and *interactor object* refers to the actual object to be created.

In order to decide which interactor objects to create, the application has to find all interactors which have interactor bounds that intersect with the query bounds. (That is, are at least partially within the query bounds). Note that the query bounds are always in screen coordinates, so, if the application keeps its interactor bounds information in client coordinates, these will have to be re-mapped before comparison.

To create a valid interactor object, the following is required: an interactor ID, a parent ID, a window ID, and bounds. In addition to this, one or more behaviors can be created and added to the interactor, and a z value can be set. See the section called Interactor bounds and nested interactors for more information about z values.

For every intersecting interactor, a corresponding interactor object is created and added to the snapshot. This is done in a number of steps:

The interactor object is created using the function `txCreateInteractor`, passing in an interactor ID that is unique within the context, the parent interactor ID, and the window ID. If the interactor is the child of another interactor, then its parent ID should be set to the interactor ID of its parent. Otherwise, the parent ID should be set to `TX_LITERAL_ROOTID`.

Last but not least, all the interactor's behaviors have to be created and added to the interactor object. For example, for an interactor that has the activatable behavior, first an activatable behavior options struct is created and populated with the necessary information, and then the function `txCreateActivatableBehavior` is called to add the behavior to the interactor object.

When all interactor objects have been added to the snapshot, it is time to commit.

### Committing the snapshot

The snapshot is committed to the EyeX Engine using the function `txCommitSnapshotAsync`.

One of the arguments to this function is a callback function that is called with the result of the commit when the snapshot has been received and validated by the EyeX Engine. From the result handle, a `TX_SNAPSHOTRESULTCODE` can be extracted using the `txGetAsyncResultCode` function, indicating if the snapshot validation went well or if the snapshot was malformed.

This callback is mostly useful during development and of limited value in production builds. It is possible to pass in a null pointer if you do not wish to receive the callback.

## Handling events

Now is the time to use those interactor IDs that you chose so carefully, because the interactor IDs provide the link between the interactor objects that you provided in the snapshots, and the events that the engine sends to you. Use the `txGetEventInteractorId` function to extract the interactor ID from an event.

The typical way of handling an event is to get all its behaviors using the `txGetEventBehaviors` function, iterating through the behaviors one by one, and checking the behavior type and parameters as you go using the `txGetBehaviorType` function. This is your only choice if you have an interactor with multiple behaviors of the same type but with different parameters, for example, an interactor with multiple "Gaze point data" behaviors that differ only in the choice of filtering.

If your application uses only one or a few behaviors, then it can be more convenient to retrieve them one by one from the events, using the `txGetEventBehavior` function; if the call succeeds, you have a handle to the behavior of the specified type, and if it doesn't you can move on to the next behavior type.

The content of a behavior can be extracted using behavior specific functions. For example, for the activatable behavior the useful ones are: `txGetActivatableEventType` and `txGetActivationFocusChangedEventParams`.

## Getting state information and handling state changes

If the context is connected, it is possible to retrieve state information synchronously or asynchronously by using the `txGetState` or `txGetStateAsync` functions respectively. To get the correct state, a path needs to be provided. See a list of available paths in the StatePaths constant list. If a correct path is provided, a handle to a StateBag object is returned. To extract state values from the state bag, use the txGetStateValueAsInteger, GetStateValueAsReal, GetStateValueAsString, txGetStateValueAsRectangle, txGetStateValueAsSize2 or txGetStateValueAsVector2 depending on the type of the state value. The EyeX Engine API also has functions to set state values in a similar manner, but this is not recommended.

To be notified of state changes, client applications can set up callback functions using txRegisterStateChangedHandler. In the callback function, the corresponding state bag and state values can be extracted as above. It is also possible to register a state observer using txRegisterStateObserver and get message about state changes as messages that can be subscribed to using txRegisterMessageHandler, but this is a bit more complicated. The client application can (and should) stop listening for state changes when not needed by using txUnregisterStateChangedHandler or txUnregisterStateObserver respectively.

Note that the state paths are hierarchical, so if a client application for example has set up a state changed handler for the TX_STATEPATH_EYETRACKING state path, it will be notified also when sub-states change. In this case sub-states are states related to eye tracking, such as the eye tracker connection state and the screen size of the screen where the eye tracker is mounted. See the MinimalStatusNotifications sample in the SDK package to learn more about how to use states.

## Tearing down a context

When you have finished using a context, use the txShutdownContext function to free up all the resources that the client library has allocated on behalf of the context. This function can also perform a check for leaked resources, that is, interaction objects that have not been released using txReleaseObject—highly recommended for debug builds. Resource leaks are reported to the log.

The function disconnects from the engine and waits for any callback functions to return before freeing up the resources. The calling thread is blocked until the context has been properly cleaned up. If txShutdownContext has completed without errors, you can run txReleaseContext to release the handle to the context.

## Redistributing an EyeX client application

The installer for your application must include the client library dll file and install it along with your executable file. Note that you may *not* install the dll in a system directory, because that could potentially cause version incompatibilities with other EyeX client applications.

The Tobii EyeX SDK license agreement gives you the permission to redistribute the client library dll with your application, free of charge, in most cases. The exceptions include high risk use applications, applications that might inflict on a person’s privacy, and certain other niche applications. Please see the license agreement for more details; it is available in the SDK package and it can also be downloaded from the Tobii Developer Zone.

The client library depends on the Microsoft Visual C run-time libraries, version 110, and will not work unless these libraries are installed on the computer. The run-time libraries can be downloaded free of charge from Microsoft. You can also include them as a merge module in your installer.

# Using the C++ API

The C++ API is a header-only wrapper around the C API that offers the same functionality in a different format: there are classes for the interaction objects, as well as for some other key concepts.

The C++ header files can be found in the include/eyex-cpp directory in the SDK package.