Extensibility Architecture for 3D Virtual Worlds

What if you could edit a visually appealing and highly interactive virtual world just like you edit traditional files? Change them locally, save multiple versions, then publish them on the net as shared environments where anyone can log in? Cut-and-paste scene data from the Web or add your own custom data and functionality using familiar scripting languages? You can already do all of this using the open source realXtend platform.

Introduction

Over the past several years, the realXtend project has developed a freely available open source virtual world platform that lets anyone create their own applications using it's platform as a base. RealXtend began as a collaboration of several small companies that coordinated in developing a common technology base that they then applied in different application fields including virtual worlds, video games and educational applications.

Like several other 3D virtual world platforms, the realXtend project has take a client-server approach. A browser-like client called a viewer renders content enabling end users to see and manipulate a 3D window into a virtual world where the content itself is stored and shared on a (typically remote) server. The realXtend project has developed an open source viewer called Naali, the Finnish word for the arctic fox, referring to the Finnish origins of the project and also a reference to the open source Firefox web browser because it aims for similar wide-spread availability as a browser for virtual worlds. The Naali viewer can connect to Second Life (SL), Open Simulator, or realXtend's own Tundra server. It can run on Windows, Linux, Mac and some mobile platforms.

One goal of the realXtend project has been to build entirely on open standards and open source software to remove the roadblock of proprietary software and pave the way for 3D virtual worlds to become widely used. To this end, Naali and Tundra make use of HTTP, COLLADA, XMPP and open source software such as OGRE 3D, Qt, OpenSimulator, and Blender. An immediate benefit can be seen in that realXtend supports 3d geometry in the typical polygon mesh format so existing material such as game characters and architectural models can be used by exporting them from e.g. 3ds Max, Maya and Blender. RealXtend has had this capability since the beginning in late 2007, whereas Second Life (a widely used but proprietary 3D virtual world) has been limited to an own special representation using prims (primitive graphical objects) and finally brought mesh support to public beta in late 2010. The tool allows reuse of existing models and scripts from libraries on the web. Any model asset in realXtend can be included in a scene via a URL reference, and the Naali graphical user interface supports drag-and-drop of 3D models from web pages like Google 3D Warehouse to the 3D virtual world scene. In realXtend, a virtual world can be snapped together from existing components like Lego bricks, and instantly viewed.

Another goal of realXtend is flexible editing of virtual worlds -- editing can be done locally, and the creation published later. This is in contrast to Second Life where all edits and additions happen on remote servers -- the client application being no more than an interface to server side functionality. Naali/Tundra can run completely standalone, without the complexity of setting up a separate server for local editing as with Opensimulator [opensim-on-a-stick]. This is similar to how a HTML web page can be authored locally by just editing the HTML, CSS and Javascript sources, before publishing them simply by copying the files over to a web server. Tundra can similarly open scenes from local files to show the 3d view, which greatly streamlines the creation work as for example changes to the images used as textures on the 3d objects show immediately in the final form without any uploads to a virtual world system.

A final architectural goal of our project is extensibility - the ability to dynamically add or remove functionality to a virtual world platform to meet the needs of specific applications. Our extensibility architecture is the focus of the rest of this paper.

Extensible Scene Architecture

Independent of any particular virtual world viewer and server implementation, we can define an extensible scene model. A scene is defined by the entities it has -- there is nothing hardcoded about them at the platform level. This differs essentially from the current OpenSimulator paradigm when using the SL protocol where the model is largely predefined and hardcoded into the platform: so, in SL, there is always a certain kind of terrain, a sky with a sun, and each client connection gets an avatar to which the controls are mapped [VWRAP]. We argue that there is no need to embed assumptions about the features of the world in the base platform and protocols.

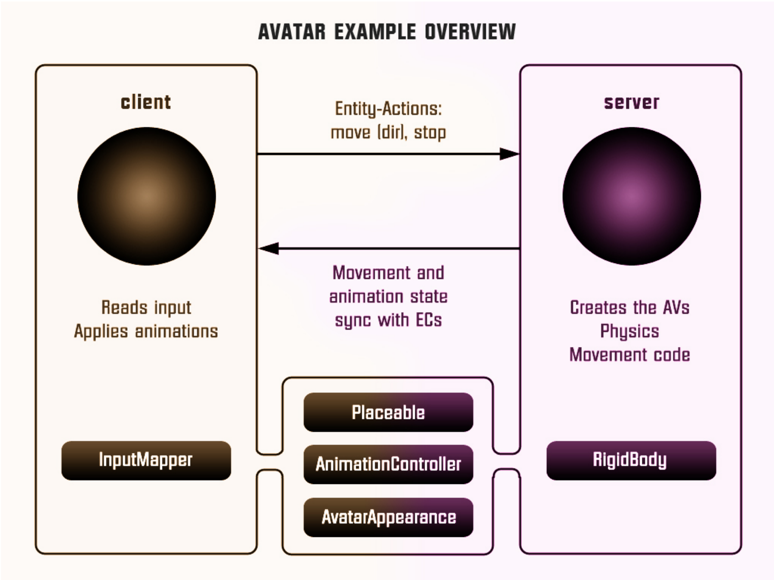
Our Naali viewer uses an Entity-Component-Action (ECA) model as a basis to construct extensible scenes. The model was adapted from contemporary game engine architectures [ec-links]. Entities are unique identities, with no data or typing. They aggregate components, which can be of any type and store arbitrary data. Applications built using Naali can add their own components to have the data they need for their own functionality. The code that handles the data exists in preinstalled custom modules or in scripts loaded at runtime as a part of the application data. To get a matching server counterpart where the scene is entirely built with Entity-Components, we have added a server module to the Naali codebase and a new protocol without application level assumptions. This whole we call the Tundra SDK, and it consist of both viewer and server executables.

The Tundra platform provides basic functionality for all ECAs: persistence, network synchronization among all the participants via a server and a user interface for manipulating components and their attributes (and eventually will support security). In addition, Tundra introduces a new concept called “entity actions,” a simple form of remote procedure call. The ECA architecture is demonstrated in two examples later in this article.

To demonstrate the feasibility of this generic scene modeling approach, we are using Tundra to develop a growing collection of example scenes in a directory available on GitHub [tundra-scenes]. Below, we present two of them to illustrate how the ECA model works in practice. In the first example, we implement a SL-like avatar using a set of pre-existing generic ECAs and specific JavaScript code that run both on the server and the clients. The second example is a presentation application that lets a presenter control the view for the others as the presentation proceeds.

Avatars are not part of the platform

Avatars are graphical representations of the user within the virtual world. It may seem at first that the concept of an avatar is integral to 3D virtual worlds. Second Life’s avatar protocol is hardcoded into the platform. Yet, many virtual worlds, simulation platforms, and games do not have a single character as the locus of control: for instance, map applications or astronomical simulations are about efficient navigation and time control of the whole space, not about moving one’s presence around. Game genres like real time strategy games feature controlling several units, similar to board games like chess. Thus, we argue instead that avatars should not exist as part of the base platform because many simulations do not require them. Of course, a generic platform must still allow the implementation of avatar add-in functionality. Below we describe a proof of concept implementation of avatars as add-ins using the realXtend ECA model. The full source code is available at [tundra-avatar].



The architecture of the avatar example uses a client (brown), a server (purple), arrows representing network messages, and filled boxes representing ECAs on the client, server or shared by both.

Avatar functionality is split in two parts: The first part governs the visual appearance and related functionality to modify the looks and clothing, and the use of animations for communication. The second part models insures that every user connection is given a single entity as the point of focus and control. The default inputs from arrow keys and the mouse are mapped to move and rotate the avatar. In this discussion, while we cover the basics of avatar appearance, the focus is on the latter control functionality.

The server-side functionality to give every new client connection a designated avatar is implemented in a JavaScript (avatarapplication.js, see code below). Upon a new connection, this script creates a new Avatar entity and these components: EC_Mesh for the visible 3D model and an associated skeleton for animations; EC_Placeable for the entity to be positioned in the 3D scene; EC_AnimationController to change and synchronize the animation states; and EC_Script to implement the functionality of a single avatar. Different parts of the same script are executed on the client, where it adds two additional components: a new camera which follows the avatar and a keybinding to toggle between camera modes.

```
function serverHandleUserConnected(connectionID, userconnection) {
    var avatarEntity = scene.CreateEntity(scene.NextFreeId(),
                       ["EC_Script", "EC_Placeable", "EC_AnimationController"]);
    avatarEntity.Name = "Avatar" + connectionID;
    avatarEntity.Description = userconnection.GetProperty("username");
    avatarEntity.script.ref = "simpleavatar.js";

    // Set random starting position for avatar
    var transform = avatarEntity.placeable.transform;
    transform.pos.x = (Math.random() - 0.5) * avatar_area_size + avatar_area_x;
    transform.pos.y = (Math.random() - 0.5) * avatar_area_size + avatar_area_y;
    transform.pos.z = avatar_area_z;
    avatarEntity.placeable.transform = transform;
}
```

A second script for an individual avatar (simpleavatar.js) adds additional components: AvatarAppearance for the customizable looks, RigidBody for physics; and, on the client side, an InputMapper for user input. Entity actions are used to make the avatar move according to the user controls. These actions are commands that can be invoked on an entity, and executed either locally in the same client or remotely on the server, or on all connected peers. For example, the local code sends the action "Move(forward)" to be executed on the server when the up-arrow is pressed on the client. The built-in EC_InputMapper component provides triggering actions based on input, so the avatar code only needs to register the mappings it wants. The server maintains a velocity vector for the avatar and applies physics for it. Using ECA attributes, the resulting position in the transform attribute of the component Placeable is automatically synchronized with the generic mechanism so the avatar moves on all clients. The server also sets the animation state to either "Stand" or "Walk" based on whether the avatar is moving. All participants run common animation update code to play back the walk animation while moving, calculating the correct speed from the velocity data from the physics on the server. The following code shows the common code for updating animations that is executed both on the client and the server:

```
function commonUpdateAnimation(frametime) {
    var animcontroller = me.animationcontroller;
    var animname = animcontroller.animationState;
    if (animname != "")
        animcontroller.EnableExclusiveAnimation(animname, true, 0.25, 0.25, false);
    // If walk animation is playing, adjust speed according to the rigidbody velocity
    if (animcontroller.IsAnimationActive("Walk")) {
        // Note: on client the rigidbody does not exist,
        // so the velocity is only a replicated attribute
        var vel = me.rigidbody.linearVelocity;
        var walkspeed = Math.sqrt(vel.x * vel.x + vel.y * vel.y) * walk_anim_speed;
        animcontroller.SetAnimationSpeed("Walk", walkspeed);
    }
}
```

These two parts are enough to implement basic avatar functionality using the ECA model. This proof of concept implementation totals in 369 lines of JavaScript code in two files. The visual appearance comes from a pre-existing AvatarAppearance component, which reads an xml description with references to the base meshes used and individual morphing values set by the user in an editor. Implemented in C++, it uses the realXtend avatar model from an earlier realXtend prototype which did not have the ECA model, but is re-used in this demo as is. A more generic and customizable appearance system could be implemented with the ECAs, but that is outside the scope of the demo and description here.

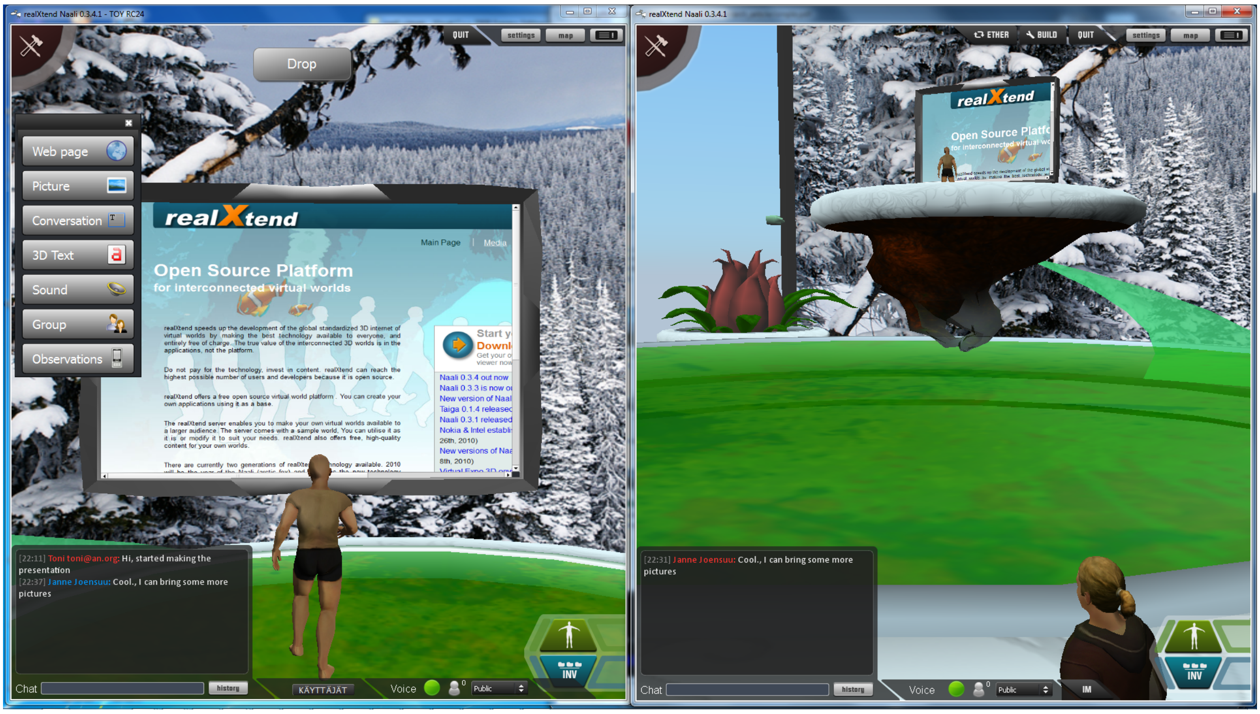
It is worth noting that the division of work between the clients and the server described here is not the only one possible. We use the same code to run both the server and the clients, making it simple to reconfigure what is executed where. This model of clients sending commands only and the server doing all the movement is identical to how the Second Life protocol works. It is suitable when trust and physics are centralized on a server. A drawback is that user control responsiveness can suffer from network lag. In the future, we plan to include the physics module in the client as well as the server to allow movement code to run locally as well.

With the ability to run custom code also in the client, it is easy to extend avatar related functionality. For example, in one project for schools, we added the capability for avatars to carry objects around as a simple means for 3D scene editing. Another possibility is to further augment the client with more data that is synchronized for animations, for instance, the full skeleton for motion capture or machine vision based mapping of the real body to the avatar pose. In our open source Chesapeak bay watershed demo scene there are minigames with customized game character controls, for example flying as an osprey with the ability to dive to catch fish. These were implemented by using the human avatar functionality as a starting point, and modifying it according to the different animal characteristics.

A Collaborative Presentation Tool

To demonstrate an entirely different use of the ECA framework, we consider an application that, in its simplest form, implements collaborative presentations where one user controls sequencing through a collection (of web pages or PowerPoint slides) while other viewers watch. The presentation tool gives the presenter the means to control the position in the prepared material, for example to select the currently visible slide in a slideshow. In a local setting where everyone is in the same physical space, it is simply about choosing what to show via the overhead projector. In a remote distributed setting, there must be some system to get a shared view over the network, and that is the use case in this example.

A shared, collaborative view of a set of 2D web pages could be implemented without realXtend technology by using regular web browsers with HTML, Javascript and some backend server logic. Our goal here is to illustrate the use of the ECA model and automatic attribute synchronization for developing custom functionality. In a minimal implementation of shared collaborative presentations, we can use ECA without using avatars or geography. Alternatively, because it is easy to do, we could add those components back in to build shared presentations like the one in Figure 2 where different avatars see the presentation from different view points. [We could go further and consider a situation where we added multiple views for the presentation, like slide view and outline view, or where we animate the presentation content or where we add voice and text chat components used for communicating with other viewers or to add annotations to the presentation -- but for simplicity's sake, we will keep our application simple.]



Two Naali clients stand nearby and view the presentation stage of the TOY system, an open source learning environment for the Future School of Finland project. The one on the left just added a web page to the stage, and is currently carrying the object.

No matter how the presentation view is made, the presenter typically needs the same controls. In Second Life, avatar controls are fixed and, to control a presentation, one might need to create a presentation sequence object with mouse click controls to press virtual buttons. Because realXtend's ECA model can support an EC_InputMapper component in the presenter's viewer, avatar controls can be customized for the presentation without introducing an intermediary object or without the server or other viewers needing to know anything about control of the presentation. Alternatively, sharing the presentation control functionality and the data among the participants would enable useful features for the audience. An outline view could highlight the current position. Participants could follow the presentation in an outline viewer or could browse the material freely in an additional view next to the one the presenter controls.

Regarding the implementation in realXtend ECA, the simplest way to get a shared, synchronized view of the presentation slides is to use a static camera which shows a single webpage view. It then suffices for the server to change the current page on that object for everyone to see it. We could do implement in ECA with a 2D widget, but let's use a 3D scene to illustrate the extensibility.

So, we add a new entity called Presentation. For showing web pages, we need a few basic components: EC_Placeable to have something in the scene; EC_Mesh to have geometry (e.g. a plane) on which to show the slides; and WebView to render HTML from URLs. Let's add two additional components for our custom functionality: a EC_DynamicComponent for custom data, and an EC_Script to implement the user interface presentation controls. As data, we need two attributes: a list of URLs and an index number for the current position. This custom data becomes part of the scene data and is automatically stored and synchronized among the participants. The EC_Script component is a reference to Javascript or Python code which implements the logic.

To handle the user input, we have two options: either handle input events and modify the state correspondingly directly in the client code, or send remote actions like in the avatar example. Let's use remote actions again so we can use the server as a broker for security, and to get a similar design to compare with the avatar example. So client side code maps right-arrow and spacebar keys to “SetPresentationPos(index+1)” etc. The server can then check if the caller has permissions to do that action, for example in presentation mode, only the designated presenter is allowed to change the shared view. Then if the presentation material is left in the scene for later use, control can be freed for anyone. The index attribute is synchronized for all participants so the outline GUI can update accordingly. To add an outline view, we could can add a 2D panel with thumbnails of all the slides and highlight the current one. For free browsing, clicking on a thumbnail can open a new window with that slide, while the main presentation view remains.

Thus, we have a simple, complete presentation application implemented on top of a generic ECA model virtual world platform architecture.

Related work

Simulations have long demonstrated that avatars and geography are not always required -- the open source Celestia universe simulator (http://www.shatters.net/celestia) let’s users view 100,000 stars but does not have any hardcoded land or sky. Nor are we the first to propose a generic component model for virtual world base architectures. For example, the NPSNET-V system is a minimal microkernel on which arbitrary code can be added at runtime using the the Java virtual machine [NPSNET-V]. A contemporary example is the meru architecture from the Sirikata project, where a space server only knows the locations of the objects. Separate object hosts, either running on the same server or any client / peer, can run arbitrary code to implement the objects in the federated world [sirikata-scaling]. Messaging is used exclusively for all object interactions [sirikata-scripting]. The idea with the Entity-Component mechanism in Naali is, instead, to lessen the need to invent particular protocols for all networked application behavior when, for many simple cases, using automatically synchronized attributes suffices. In preliminary talks with some Sirikata developers, we concluded that they aimed to keep the base level clean from high level functionality, but that capabilities like attribute synchronization would be desirable in application level support scripts.

The Naali EC model borrows the idea of using aggregation and not inheritance from the game engine literature, specifically a gaming oriented virtual world platform called Syntensity [syntensity]. Like with Tundra, Syntensity can run the same JavaScript code both on the server and clients [syntensity]. In Syntensity, you compose entities by declaring what state variables they have. The data is then automatically synchronized among all participants. The Naali implementation is inspired by Syntensity. The difference is that in Syntensity the entities exists on the scripting level only, and basic functionality like object movements is hardcoded in the Sauerbraten/Cube2 first person shooter platform. In Naali, all higher level functionality is now implemented with the ECs, so the same tools work for e.g. graphical editing, persistence and network sync identically for all data.

The document-oriented approach of having representing worlds externally as files has precedents in 3D file format standards like VRML, X3D and COLLADA. Unlike those, the realXtend files do not directly include 3D geometry, but describe a scene using URL references to external assets, for example meshes in the COLLADA format. Essentially, these files describing scenes are a mechanism for application-specific custom data, which is automatically synchronized over the net. They have script references that implement the functionality of the applications, similar to the way HTML documents contain JavaScript references. This is not specified in the file format; instead, it is how the bundled Script component works.

Status of the realXtend implementations

There are currently two generations of realXtend technology available. An original viewer (GPL license) still had more features, while the newer Naali viewer (built-from scratch viewer available under the Apache 2 license) is the more modular and extensible platform. Taiga (which combines OpenSimulator and the realXtend add-on for it) is a continuation and refinement of the original server project (BSD license). Latest addition to the new generation, Tundra, completes the Naali codebase with server functionality built purely with ECs and support for running the same code both on server and clients, resulting in a powerful toolkit for networked application development.

Regarding the status of the Naali viewer, it is maturing and has already been deployed to customers by some of the development companies. It is a straightforward modular C++ application with optional Python and JavaScript support. The Qt object metadata system is utilized to expose the C++ internals automatically. This covers all modules including the renderer and user interface as well as all the ECs. The QtScript library provides this for Javascript support, and PythonQt does the same for Python. There is also a QtLua so Lua support can be added. Thanks to the Ogre3D graphics engine, Naali runs both on e.g. the N900 mobile phone with OpenGL ES, and on powerful PCs with multiple video outputs with the built-in CAVE rendering support. There is also an experimental WebNaali client, written in Javascript to run in a web browser, doing the EC synchronization over WebSockets and rendering with WebGL.

Regarding the status of the generic EC architecture, this is implemented in Naali and hence is in use throughout in the Tundra SDK which complements the original Naali codebase with a server module [tundraproject]. This configuration enables Naali to run standalone for local content authoring or for single user applications, but it can also be used as a server instead of using OpenSimulator. With Tundra, LLUDP is not used; instead, all basic functionality is achieved with the generic EC synchronization. For the transport, we use a new protocol called kNet which can run on top of either UDP or TCP [knet]. kNet is similar to eNet but performed better in tests with regards to flow control. The Tundra server lacks many basic features of the more advanced OpenSimulator, like running untrusted user authored scripts and combining multiple regions to form a large grid. However, Tundra is already useful for local authoring and deploying applications with custom functionality. And it serves as an example of how a generic EC approach to virtual worlds functionality can be simple yet practical.

The generic EC architecture was proposed to the OpenSimulator core and accepted as the plan of record in December 2009 [adam-ecplan]. The implementation of EC for OpenSimulator is still in the early stage. However, EC can be utilized with the Naali client communicating with the OpenSimulator servers running the realXtend addon (modrex) in a limited fashion, as these servers still assume the hardcoded SL model, but developers using Naali can still add additional arbitrary client side functionality and have the data automatically stored and synchronized over the net via OpenSimulator.

The realXtend platform does not yet solve all problems related to virtual world architectures. Naali does not currently address scaling at all, nor is federated content from several possible untrusted sources supported. We started by having providing power at the small scale to provide the ability to easily make rich interactive applications. Another important missing element in our current EC synchronization architecture is security, e.g., a permission system. An initial implementation is planned to cover the basic capabilities, similar to how Syntensity already has attributes that can only change only if the server allows. In the future, we look forward to continuing collaboration with e.g. the OpenSimulator and Sirikata communities to address the trust and scalability issues. OpenSimulator is already used to host large grids by numerous people, and the architecture in Sirikata seems promising for the long run [sirikata-scaling] [sirikata-scaling2]. Also Intel research has recently demonstrated how multiple servers can be used to host a single scene for thousands of interacting users, using Opensimulator [intel-distributedscene]. We will see whether that design can be either easily be ported to the Tundra server or better utilized for realXtend as is by using OpenSimulator.

Conclusion

In this paper, we described the realXtend project and focused especially on its Entity-Component architecture which provides a general extensibility mechanism for building 3D virtual worlds. The Tundra SDK, which is built entirely using the EC model, is a true platform that does not get in the way of the application developer; they can create anything from a medical simulator for teachers, to action packed networked games - and always with a custom interface that exactly fits the application's purpose. Seemingly fundamental elements of virtual worlds (like support for avatars) can instead be treated as an add-in functionality, so the overall architecture can make less commitment and thereby accommodate a wider range of kinds of virtual worlds. We demonstrated how this generic approach to virtual world architectures can be simple and practical, yet powerful and truly extensible. We hope this is taken into consideration both in future Opensimulator development and upcoming standardization processes, for example if the IETF VWRAP or IEEE Metaverse standardization efforts choose to address in-world scene functionality. We will continue to develop the realXtend platform and applications on top of it. Anyone is free to use it for their needs, and motivated developers are invited to participate in the effort which is mainly coordinated on-line.

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