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"THE FUTURE IS NOW"



Distributed Interactive Simulation (DIS) 101: The Basics

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 @IITSEC  NTSAToday



Note that this tutorial is essential to core design of current Modeling and Simulation architectures. It complements I/ITSEC tutorials on Test and Training Enabling Architecture (TENA) and High Level Architecture (HLA).

Intended Audience. Practitioners interested in networking, simulation interoperability and shared virtual environments using open standards.

Abstract. The Distributed Interactive Simulation (DIS) protocol is a well-established IEEE standard for packet-level exchange of state information between entities in military simulations. DIS facilitates simulation interoperability through a consistent over-the-wire format for information, widely agreed upon constant enumeration values, and community-consensus semantics. Anyone can obtain the IEEE-1278 standard and implement their own compliant, interoperable, DIS application. A large variety of tools and codebases simplify this effort, and enable multi-architecture integration of simulations using the DIS stand baseline. DIS focus begins with real-time, physics-based, entity-scale simulations, providing state update and interaction mechanisms which can scale to large virtual environments. This tutorial is a "DIS 101" introduction for software implementers and an introduction to the DIS philosophy for simulation systems integrators. Examples are provided using the open-source Open-DIS library for DIS v7 and Enumerations support, available in multiple programming languages. Ongoing work is included in unit testing of DIS streams, and Web-based implementations using X3D Graphics, as well as Compressed DIS and DISv8 development.

Grateful acknowledgement: this tutorial was originally developed by Don McGregor NPS.

Learning Objectives

The learner will be able to...

- Identify what standards are used by distributed simulations for military use.
- Identify what types of communication protocols are used for various networks.
- Identify what aspects need to be standardized, and what aspects can be customized, to support diverse simulations with differing models and goals.
- Identify how DIS techniques for dead reckoning (DR), visual smoothing and distributed collision detection can reduce network traffic.
- Learn how to apply new capabilities expected for Compressed DIS and DISv8.



Discuss how connecting all manner of simulations, namely Live Virtual Constructive LVC, is the necessary path for connecting to Command and Control (C2) systems. Establishing such connections between traditionally separate domains is central to conference theme,

- “The Future is Now“

Note that, for example, common tutorial topic “What coordinate systems are used?” is also central to requirements for connecting C2 and M+S.

Slide 2 and last slide are identical.

Topics

- What is distributed simulation? Scaling from isolated networks to the Web.
- Military modeling & simulation, distributed simulation standards, interoperability
- Underlying TCP/IP network requirements common to all distributed simulations
- DIS: goals, design principles, basic structure, Entity State PDUs explained
- DIS: distributed identification of all participants, Entity Types and Entity IDs
- DIS: tracks and Coordinate Systems, real time clocks, packet PDUS, code APIs
- DIS: collisions, shooting, Dead Reckoning, Smoothing, visual synchronization
- DIS and Open-DIS: DIS standard development, ongoing implementation efforts
- Resources and References for further activity, including latest software builds



Communicate that this is a broad and deep topic. Much information is available. Ace card for participants: DIS “just works” across many systems, is much tested and strives to match/represent real-world activities. So experience in each domain being simulated is useful.

Distributed Simulation Terms

- A *distributed simulation* runs on multiple cooperating hosts on the network.
- *State information* describes the position, orientation, and other information about an entity at a point in time.
- *Live, Virtual, Constructive* (LVC) simulation involves different hosts doing different aspects of simulation in one cooperative system.
 - Live: Real people, real systems
 - Virtual: Real people, simulated systems (human in loop)
 - Constructive: simulated people, simulated systems (AI controlled)



Emphasize that terminological clarity is always important when modeling cross-domain interactions.

Live, Virtual, Constructive (LVC) Example

- Automatic Identification System (AIS) is a standard for transmitting the current position of commercial ships in the real world; ships have a transmitter and receiver on board and send information in a standard format. This is a **live** component (real system, real people).
- Ship simulators portray a simulated virtual view of navigation from the perspective of a ship's bridge, perhaps in a "cave" environment with wall-sized screens. This is a **virtual** component (real people, simulated system).
- We can also inject simulated, computer-generated ships controlled by AI into the simulation. This is a **constructive** component (simulated system controlled by simulated people).
- As M+S LVC connects with C2 for warfighters, ever-greater synergies emerge.



Stress final point, encourage participants to consider LVC in their individual domains of interest.

Live, Virtual, Constructive (LVC) Example, Illustrated

Virtual: bridge simulator



Live: AIS feed



Single
Shared LVC
Environment

Participants may be
local or distributed



Constructive: computer-
generated ship traffic,
controlled by AI agents



This diagram is not showing “one way to do things,” rather many alternative variations are possible depending on scenarios of interest.

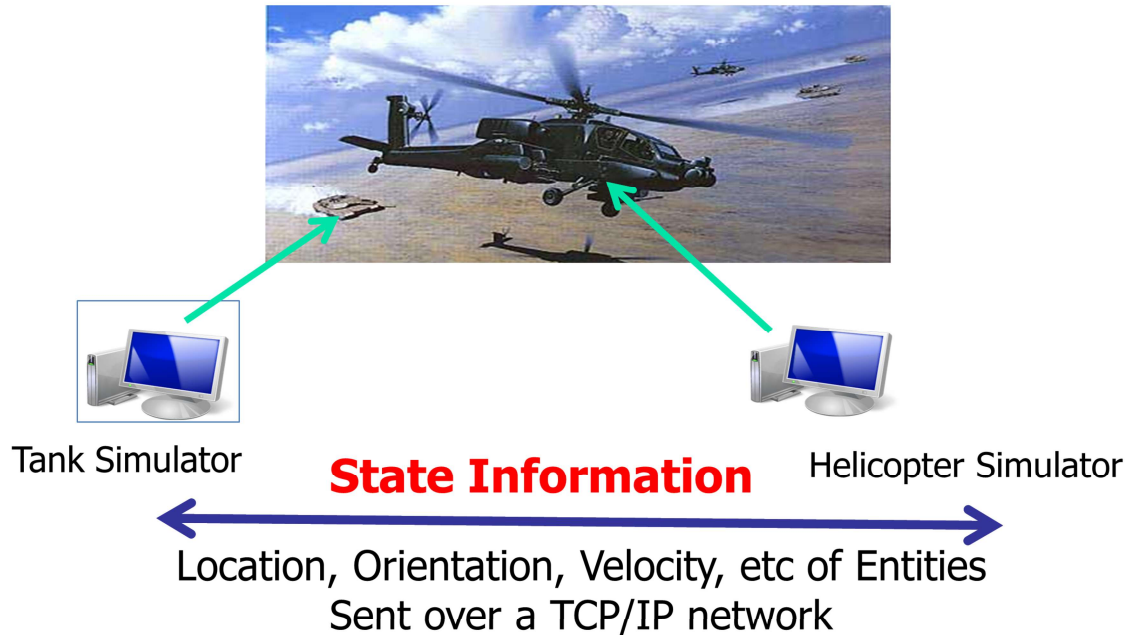
What Do We Want to Do?

- DIS has been running and evolving since early 1990s, remains widely used in many applications.
- People who want to learn about Distributed Interactive Simulation (DIS) usually are in the “virtual” or “constructive” domains, though it can also be used in the live domain.
 - They want to simulate ships, tanks or other entities in 3D world, controlled by humans or AI.
- We need to exchange *state information* between hosts on the network about entities in the world.
 - To view someone else in the simulation, we need to know their position, orientation, and other state information, and this information needs to be sent to us by them.
- Typically entities are controlled by different hosts that are connected via a network. The state information is usually exchanged over the TCP/IP protocol.



Shared state is the essence of a distributed virtual environment. If participants can't communicate well, then they can't interact well.

State Information in Distributed Simulations



The tank & helicopter in the simulation are controlled by different hosts. The simulation running the tank needs to know about the helicopter's position, and the helicopter needs to know about the tank's position

We have to come to all sorts of agreements to exchange information. It's harder than it looks!

We want the information to be in a standard format, because we don't want to be locked into one vendor

What's So Hard About That?

- The format of state update messages needs to be *exactly* specified.
 - What coordinate system should you use? You need one that works well for ground and air systems, and can handle curvature of the earth issues.
 - Text or binary format messages?
 - The order in which the fields appear?
- Network issues: what happens if a message is dropped?
- Scalability issues: how can we get a reasonable number of entities to participate?
- Latency: can we keep the message delay reasonable?
- Do all participants have a consistent, coherent operational picture?



Convey that all of this complexity must be handled sensibly and sharably, which is design basis of DIS.

Distributed Simulation Standards

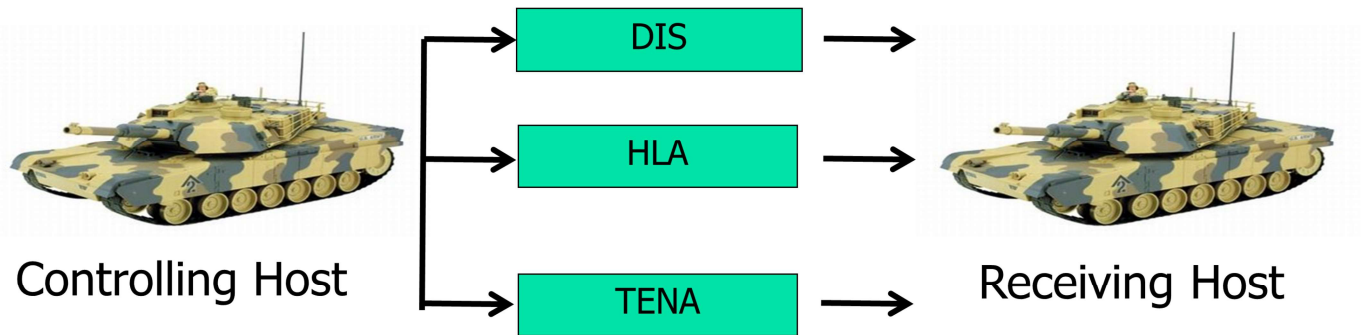
- There are many ways to exchange the state information, but we want a *standard* way so we can interoperate with simulations from many vendors rather than being locked in to one. We don't want to use only one vendor's proprietary method, for which we will pay dearly.
- In the case of defense modeling and simulation, the “big three” are
 - TENA: Test and Training Enabling Architecture
 - HLA: High Level Architecture
 - DIS: Distributed Interactive Simulation
- TENA and HLA borrow many semantic concepts from DIS. Understanding DIS has many carry-over benefits when working with other standards.



Stable interoperability is essential for long-term use, re-use, sharing and advancing progress.

State Information Exchange Standards

The controlling host sends the state information update via one of the standards to other hosts



State Information Updates



TENA

- Used on ranges; often the “L” in Live-Virtual-Constructive simulations.
- Designed for real time and embedded systems, real sensor systems, etc.
- In effect it is thinly disguised CORBA distributed objects with multiple new features to help it work in a simulation environment.
- Can gateway it to other standards, such as DIS or HLA.
- See <http://tena-sda.org>



Encourage participation in all three tutorials, they are complementary

High Level Architecture (HLA)

- HLA is very general and intended to cover most defense modeling domains including training, analysis, and engineering in addition to virtual worlds.
- Participants communicate via an agreed-upon *Federation Object Model* (FOM) and an API associated with a *Run-Time Infrastructure* (RTI).
- Specification is maintained by SISO (<http://sisostds.org>), is IEEE standard 1516 and has implementations by
 - MAK (<http://www.mak.com>),
 - Pitch (<http://www.pitch.se>),
 - Portico (older version) (<http://porticoproject.org>) and others.
- <http://www.pitch.se/hlatutorial> is a good introduction to HLA.



Encourage participation in all three tutorials, they are complementary

Distributed Interactive Simulation (DIS)

- DIS was the first standard to tackle these problems in a systematic way.
- Originated in the SIMNET project in the 80's. DARPA supported converting the SIMNET research into a standard; SISO developed the standard and took it to IEEE for approval.
- Anyone can get standard from IEEE, implement it, and participate in simulation.
- Development of standard continues; updated DIS standard version 7 is the latest approved version. SISO maintains DIS, presents it to IEEE for approval.
- Substantial commercial support, open source implementations, many home grown implementations of portions of the standard.



Encourage participation in all three tutorials, they are complementary

Distributed Interactive Simulation (DIS) functionality

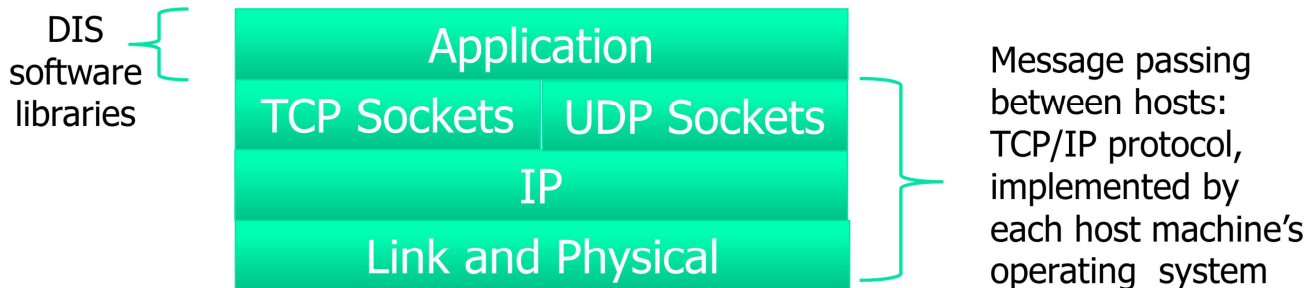
- What does DIS support?
 - A standardized way to exchange messages about entities in a virtual world
 - Common semantics for coordinate systems and other information, such as how to describe and specify entities
 - Common practices to ensure interoperability



Essentials. All the detail flows from these design principles. Meaningful results are not otherwise possible.

Networking: the Protocol Stack

- DIS defines the format of the messages, but doesn't specify how to get the messages from one host to another. Almost always this is done via TCP/IP network protocol.
- Knowing network basics helps you be a better simulation designer/user!



TCP/IP is the underlying substrate for almost all network communications. Web servers, streaming video, email and almost everything else you use on the internet all rely on TCP/IP. Users typically implement things at the “application layer” at the top of the stack. This is where DIS lives

Somewhat confusingly, the DIS protocol is considered part of the “application layer” in addition to what users think of as the “application”, the visual simulation

The lower layers of the stack are responsible for delivering messages. We can usually ignore this part; it's all handled by operating system vendors

We interact with the TCP/IP stack via either the User Datagram Protocol (UDP) or Transmission Control Protocol (TCP) APIs.

UDP messages are like postcards: they contain a fairly small amount of data, and we need to address them to a destination

We can send them to one host (based on IP number): called *unicast*

We can send them to all hosts on a local network: called *broadcast*

We can send them to those hosts, on the local network or not, that are interested in the message: called *multicast*

DIS messages are contained inside of UDP packets and can use any one of these addressing schemes. Broadcast is very common. Multicast is better.

TCP/IP and UDP

- TCP sockets have higher latency, higher *jitter* (variation in latency), and doesn't scale to large numbers of hosts as well.
- UDP sockets have lower latency, lower jitter, scales to large numbers of participants better, but are unreliable.
- DIS typically uses UDP.
- Hold on—UDP is *unreliable*? What's up with that?
 - Individual UDP messages may be dropped by the network; there's no guarantee that each UDP message will be delivered. This tradeoff achieves lower latency and jitter, which in turn brings better scalability.
 - Not as big a deal as it might seem. If we get position updates from entity every 1/30th of a second, does it matter if we drop one? Better information is coming along shortly, so why resend dropped messages?



In some ways TCP/UDP are yin/yang of networking. Helping participants understand this point helps them comprehend many other DIS design decisions.

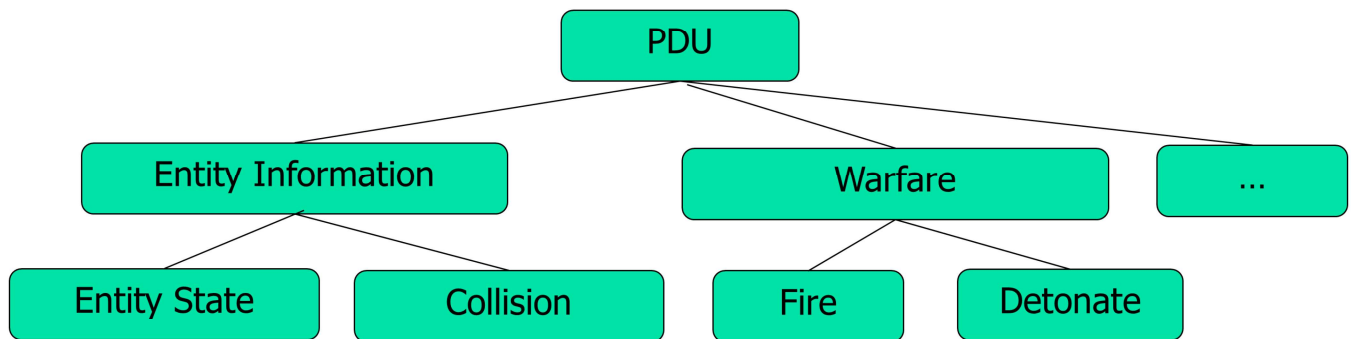
DIS Messages

- We know **what** we want to do: send a message that tells another host what the state of an entity is.
- We know **how** we do this: send the message via TCP/IP, typically in a UDP message over broadcast or multicast.
- What is **actual format** of the messages? This is specified by the DIS standard.
 - There are dozens of possible messages to send, relating to everything from logistics to electronic warfare to radio communications.
 - Each message type is called a “Protocol Data Unit” (PDU).



PDU's are messages. So are email, SMS text, 2-way web-browser interactions, and even object-oriented method invocations.

DIS Messages



Several dozen different message types (called Protocol Data Units, or PDUs) to describe entity movement, collisions, combat, radio communications, logistics, and many more. The Entity State PDU is the most widely used.



The world is a big place, many years of work by M+S community have established a rich vocabulary of messages supporting modeling and information sharing that reflects the real world.

PDU Families are Diverse



PDU Families

- Entity information/interaction
 - Warfare
 - Logistics
 - Simulation Management
 - Distributed Emission Regeneration
 - Radio Communications
 - Entity Management
 - Minefield
 - Synthetic Environment
 - Simulation Management with Reliability
 - Live Entity
 - Non-Real Time protocol
 - Information Operations
- Color Key
 - 1995
 - 1998
 - 201X

Credit: from SISO slideset

IEEE 1278 Distributed
Interactive Simulation (DIS)

by Mark McCall and Bob
Murray, 26 May 2010.

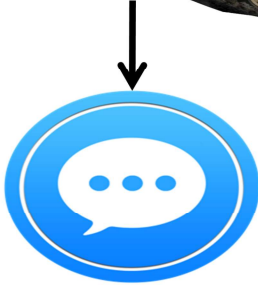
Many people have used and
extended DIS Protocol so
you can likely find what your
system needs to do.



Ask participants if they have knowledge of any of these domains.

DIS Messages: Entity State PDU

- We use ESPDU when we want to inform other hosts of the position of an entity we control—the most common PDU



Entity sends ESPDU with

- Unique ID
- Position (xyz) in standard coordinate system
- Orientation
- What type of vehicle it is
- More....



ESPDU is workhorse PDU, and also affects how other PDUs are interpreted.

Site, Application, Entity ID: a Unique Identifier

- Before telling entities “hey you there, do that” we need a way to differentiate between entities.
- The entity ID is a unique identifier for each simulation object in the world. In DIS this is accomplished via a triplet of three numbers: *Site*, *Application*, and *Entity* ID numbers.
- This triplet of three numbers taken together must be unique for each entity.



DIS: Entity IDs

- Example: before the simulation starts we agree, simulation-wide, on the following arbitrary numbers. Here are simple possibilities:

Site	Number
China Lake	42
Norfolk	17
Orlando	23

Application	Number
YoYoDyne M1A2 Simulator	112
ACME UCAV Simulator	417
JCATS	512



Entity IDs



Tank Simulator
EID: (42, 112, 18)
EID: (42, 112, 19)

**YoYoDyne simulator (112) at
China Lake (42) controls two
distinct tanks, 18 and 19**



Helicopter
EID: (17, 417, 18)

**ACME (417) simulator at
Norfolk (17) controls a
Helicopter (entity 18)**



Aha moment: triples designate “who” sent a PDU and
can identify any participant uniquely.

DIS: Entity Type

- We may need some other information. What if we want to draw this entity? We need to know what kind of entity this is—a tank, a helicopter, a ship?
- This is done via a field called the *Entity Type*, which in turn depends on a SISO document called the “Enumeration and Bit Encoded Values” (EBV).
- The EBV document is a long listing of standardized record values that lets us identify military hardware.



Designates “what” kind of thing this entity is.

Entity Type

```
{  
  Kind: 1 (entity)  
  Domain: 1 (Land)  
  Country: 225 (US)  
  Category: 1 (Tank)  
  Subcategory: 1 (M1)  
  Specific: 6 (M1A2)  
}
```



Whenever a DIS message has an entity type record with the above settings we know it's referring to an M1A2 tank. What the numbers are doesn't matter, as long as *all* participants agree on what they mean. SISO maintains the master list of arbitrary numbers, called the EBV document.



Subcategories flesh out the details and variations corresponding to each entity type.

Entity Type From EBV Document

<u>Kind</u>	<u>Domain</u>	<u>Country</u>	<u>Cat</u>	<u>Scat</u>	<u>Specific</u>
1	1	225			
				11	M125 81-mm mortar carrier
				1	M125A1
				2	M125A2
				12	Cadillac Gage V-600 Armored Car
				13	Cadillac Gage LAV Assault Gun LAV-105
				15	LAV-105
				16	Chrysler MAC-1 armored car
				17	Cadillac Gage Commando Scout
				18	Cadillac Gage Commando V-300
				1	V-300 w/ TOW
				2	V-300 w/ 81-mm mortar
				3	V-300 ambulance



Note this community has met for years. EBV values available in Word, XML and derivative forms.

Entity Type

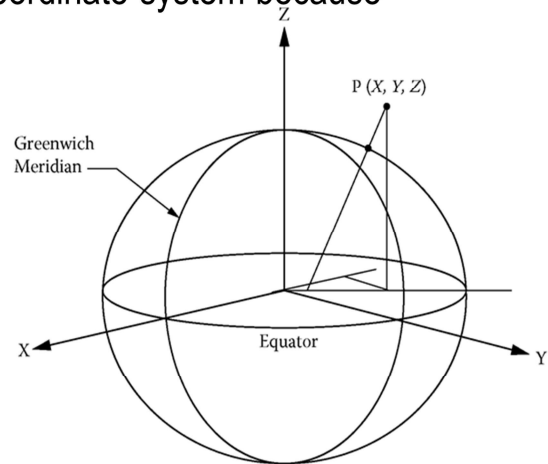
- The EBV document has gone through many versions as new hardware has been added. An important checkpoint for consistency: all participants in the simulation *should* agree on the current version of EBV document being used.
- In reality this can sometimes be hard; some simulations have not been updated to reflect new EBV documents, and sometimes those implementing a simulation simply make up numbers, and *no* simulation implements all entities in the EBV.
- You may need a gateway such as Joint Simulation Bus (JBUS) to act as a “shim” connection between simulations and change entity type values to match what is expected. The gateway can rewrite the entity type values in the PDUs to force them to match expectations.
- The EBV enumerations are also often used in HLA RPR-FOM and in TENA.



Note that EBV for Entity Type goes to great pains to maintain backwards compatibility, so almost everything stays stable over time.

Entity State PDU: Position

- What does it mean if we say an entity is at (x, y, z) ? This has no meaning without a coordinate system. We need to agree on one, and where the origin is.
- DIS chose to use a Cartesian, geocentric coordinate system because
It's easy to convert from that to other coordinate systems, such as geodetic (latitude, longitude, altitude) or military Systems such as MGRS.



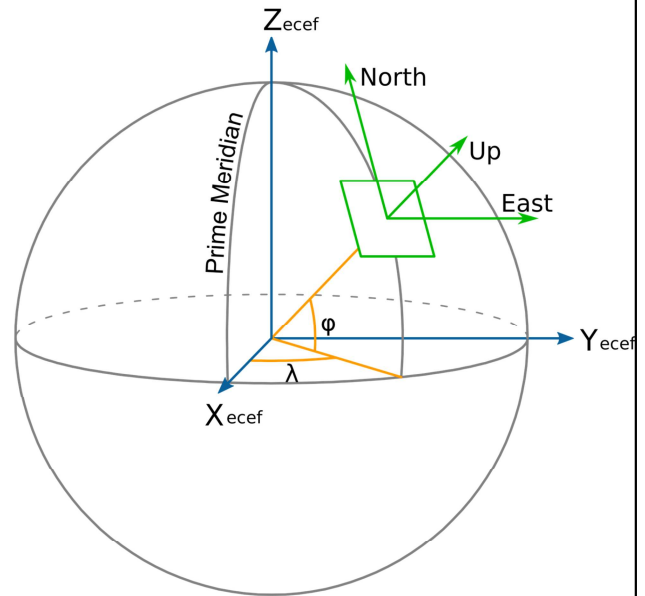
If you want to specify the location of an entity in DIS, you have to specify it in terms of how far from the center of the earth it is. You should also agree on the shape of the earth (eg WGS-84) and terrain.

Using geocentric coordinates may seem strange, but DIS has to account for curvature of the earth issues if the simulation demands it. The geospatial people have done the math to convert geocentric coordinates to latitude, longitude, altitude, MGRS, or other coordinate systems. The geocentric coordinate system is often used in TENA and HLA

SEDRIS has provided an open source framework for dealing with these issues in their Spatial Reference Model (<http://www.sedris.org/hdr1trpl.htm>)

DIS: Coordinate Systems

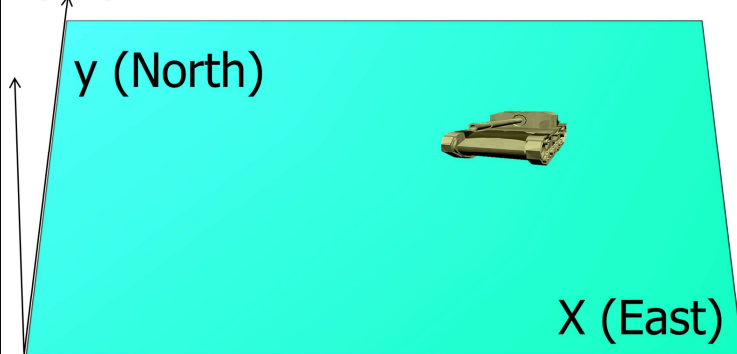
- Very often simulations set up a local, flat-plane coordinate system at a point tangent to a point on the earth's surface, using that for local physics movement. When ESPDU is actually sent, local coordinates are changed back to the global coordinate system. The SEDRIS SRM package can do all the math.
- Nobody will ever agree on which way the local coordinate system axes should point for all simulations.



Utility methods for conversions are how codebases comply and cooperate.

Coordinate Systems

A local Cartesian coordinate system origin is set at {lat, lon, alt}. The simulation does all calculations and movement in this coordinate system, because it's convenient. Before sending entity information out in a DIS ESPDU, convert from local to geocentric (DIS) coordinates:



Entity position can be expressed in:

Local: (10, 10, 4)

Geodetic: 43.21001 N, 78.12012W, 124

UTM: Zone 44N, 266061E, 4788172N, 124M

DIS: 958506.1, 455637.2, 4344627.4

We have enough information to convert from one coordinate system to another, if local coordinate system origin known.



(Ensure participants understand these simple concepts.)

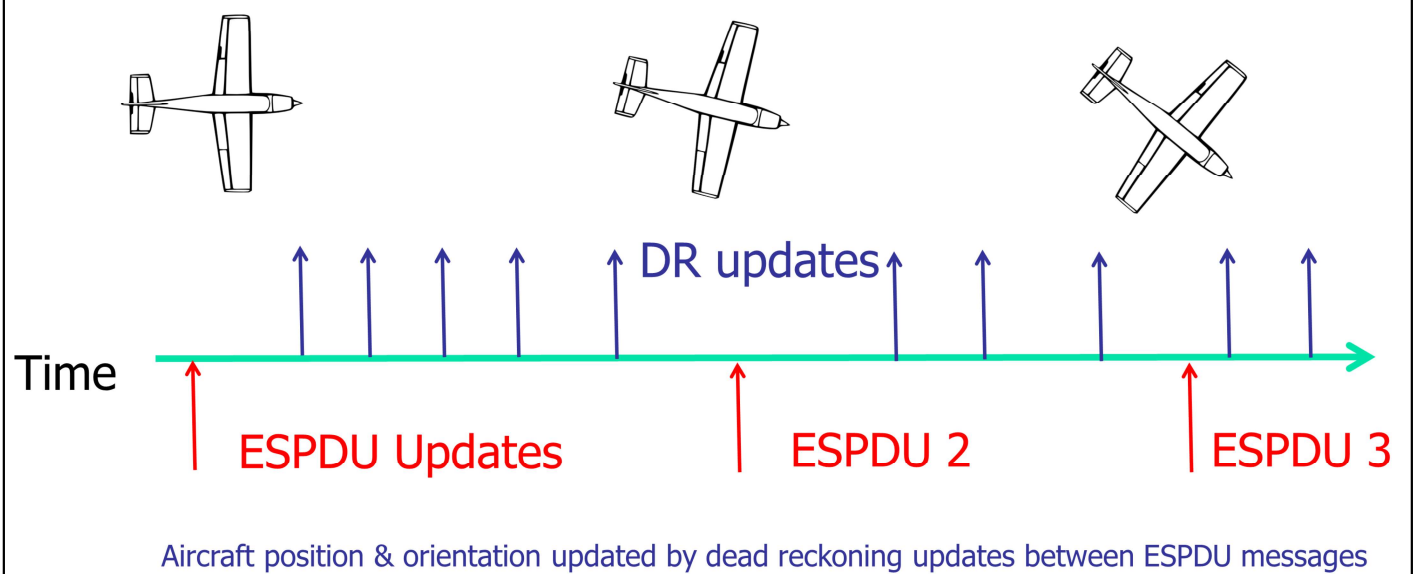
DIS: Dead Reckoning (DR) Algorithms

- If we're running a visual simulation, how often do we need to send ESPDUs?
- If running at frame rate, maybe about every $1/30^{\text{th}}$ of a second.
 - If we have 500 entities in a simulation, this works out to 15,000 UDP messages per second. If you're doing other computation on host, this will tax your CPU and network.
- Do we *really* need to send that fast? If we know how fast and in what direction an entity is moving, we can "dead reckon" in between receiving each ESPDU and then interpolate position to draw our entity there.
 - Sure, we're lying to the user. Got a problem with that? If our DR is wrong, we just correct our position stealthily when we get better info on the next packet. The user won't know the difference, probably.
 - Due to latency all simulation participants are a little out of sync anyway.



This is applying relatively simple math to everyday physics. This is conceptual similar to how people fly, sail and drive.

DIS: Dead Reckoning between ESPDU Snapshots



High-order handwaving! Walk through a maneuver, describe what happens from each participant's perspective.

DIS: Dead Reckoning

- What DR algorithm is best? (... wait for it...)
- It depends! In some situations we might want to include acceleration or angular velocity, but not in others. The ESPDU sender specifies what DR algorithm to use.
- The sender can also perform its own DR to determine what the recipients are seeing. If the sender decides the clients are probably wrong in their guess about where the entity is, it can issue another ESPDU with better location information.



George Box: “All models are wrong, some are useful.”

Dead Reckoning (DR), Smoothing, Synchronization

- Dead Reckoning (DR) is projection of entity location based on last received timestamp, position and vector-based velocities/accelerations.
 - Enables recipients to more accurately estimate entity state in-between PDU updates.
 - Enables senders to more accurately estimate when to send more-frequent updates.
- Smoothing is a recipient-presentation technique for handling dropped packets.
 - Avoid sudden jerky jumps in motion, instead interpolate from prior estimate to new state.
 - No need to improperly distract user with corrective actions when recovery is satisfactory.
- Synchronization among multiple players is a blend of capabilities.
 - Networking monitoring and management, simulation management, logging, etc.
 - Measurable metric: is a “fair fight” taking place among distributed participants?



Hitting the “sweet spot” of where physics, math, networking, modeling, simulation, perception and reality align acceptably.

DIS: keeping it real, with less throughput required

- Dead Reckoning (DR) algorithms use projected trajectory information (such as linear or rotational velocities and accelerations) to compute how often network updates need to be sent. Helpful for quiet and intensely active intervals.
- Visual smoothing techniques hide when packets are dropped or arrive late. Entity display smoothly interpolates to the correct location and direction, avoiding distracting jumps that do not correctly represent behavior anyway.
- Having each individual entity honorably compute whether collisions occurred takes advantage of highest fidelity information with least computation, avoiding expensive time delays and greater inaccuracies of server-based adjudications.



No single optimization is possible. This is a tradeoff so that DIS can meet the shared expectations of participants.

DIS: Learning About the World and Heartbeat

- If we run a DIS simulation, how do we learn about all other entities in the world?
 - One design possibility is to use a master server. Instead, the designers chose for DIS to be peer-to-peer; there is no central server, and hosts talk to one another directly.
- In DIS essentially all we have to do is listen for ESPDUs. New-entity ESPDUs contain what we need to know: entity type, location, velocity, orientation. This is simple and avoids a single point of failure, making configuration easier.
 - There are also Simulation Management PDUs for announcing arrival, removal, etc.
- To make this work, every entity must periodically send a time-stamped ESPDU even if its state hasn't changed. This is called a *heartbeat*. Usually entities must send an ESPDU at least once every five seconds.



Discovery of new entities, confirmation of known entities, learning of lost entities.

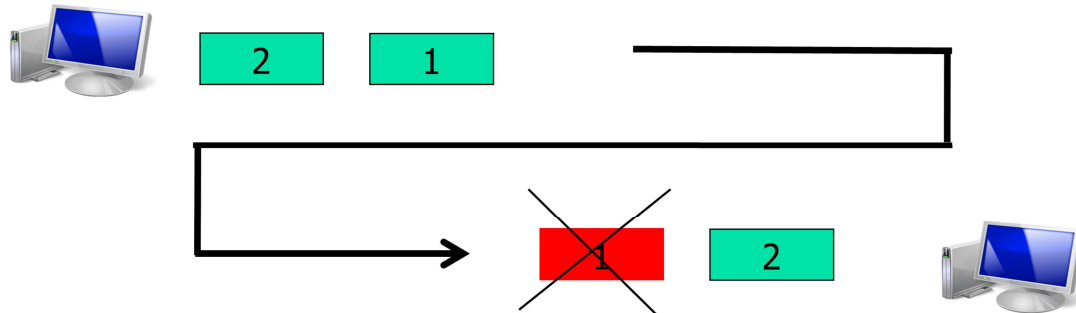
DIS: Timestamp

- One of the oddities of UDP is that UDP packets may be *duplicated* during TCP/IP routing; we send a single packet, but two might arrive nevertheless.
- UDP packets may also arrive *out of order*. We send packets in order A, B, C, but they arrive in order C, A, B
 - This creates problems for position updates! How to handle?
- DIS includes a *timestamp* field to detect these kinds of problems:
 - The field typically represents time since the top of the hour (as common practice).
 - If the next packet we receive has a timestamp before the last packet we processed, then we can discard it; it's old information that has been obviated by new data.
 - Time coordination between hosts is useful but not required.



Accurate shared time is a great benefit that helps DIS accurately model interactions occurring across the network.

DIS: Timestamp



Host A sends 1 and then 2. Host B receives 2, and then 1. We should discard 1, because we know it's older than 2, due to its older timestamp.



OMG the network isn't perfect?? That is correct... this is an example of how we cope.

Note how DIS design turns a potential weakness into a robustness feature.

DIS: Entity State PDU

- So far we've looked at an ESPDU, which contains
 - Entity ID
 - Entity Type
 - Position, orientation, velocity, etc.
 - Specifies a DR algorithm for the receiver to use
 - Timestamp
- We've also seen that we need to agree upon a coordinate system, and agree on the enumerations that describe things like entity type.



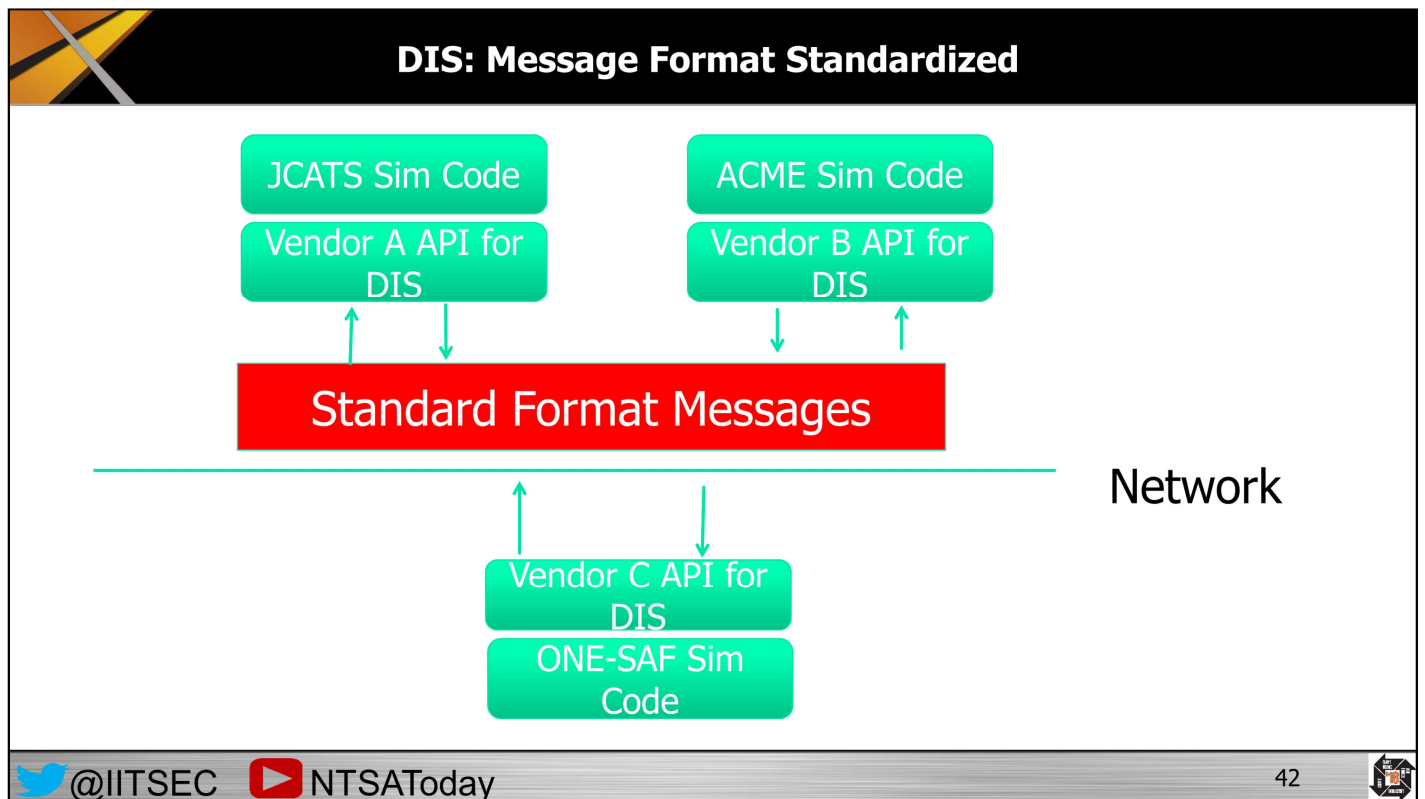
But wait there's more... a lot more.

DIS: no approved Application Programming Interface (API) per se

- DIS doesn't have an API. This seems strange to people coming from HLA or TENA, but reflects common practice in networking protocols.
 - The standardized part is the format of the messages on the wire. The standard is silent about how to create or receive those messages.
 - Different DIS vendors have different APIs, *but all produce the same format messages*. This is in contrast to HLA, which has a standard API, but is *silent about the format of messages on the wire*. As a result, different HLA RTI vendors usually use different message formats for exchanging information.
 - TENA standardizes the API, and there is a single approved implementation of the RTI equivalent; this sidesteps the wire standard problem because there is only one approved equivalent of the RTI.

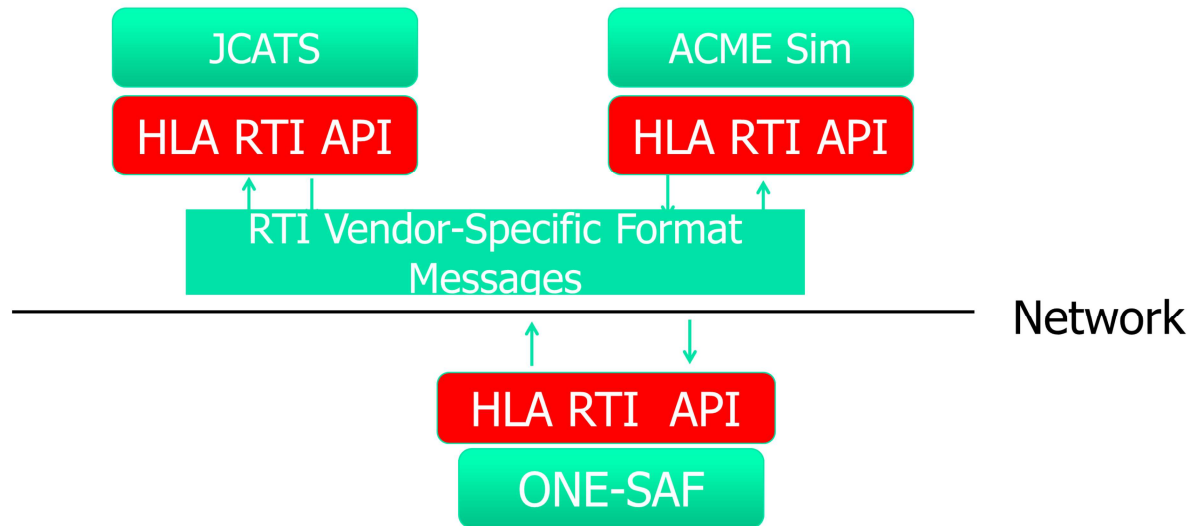


Theme to convey: vive la difference.



Can we all just get along? Yes, with commonly understood messages.

HLA: API Standardized



While the API is standard, implementations of HLA RTI API from different vendors are allowed to produce messages in different formats.



Can we all just get along? Yes, with commonly accessed federated object models.

DIS: API

- The implications of this are that while HLA has a standardized API, RTIs from different vendors can't typically talk directly to each other. This makes changing vendors easy, but makes getting RTIs from different vendors talking to each other hard--you need to use a gateway.
- DIS in contrast makes changing vendors hard (since it involves changing the API your simulation code uses) but talking between vendors easy (since all the messages on the wire are in the same format)
 - The lack of an API can help when using a variety programming languages, such as Objective-C, C#, Python, and JavaScript. Since there's no official API, just make one up that fits your application's programming language. As long as they produce standard messages on the wire, the API creating packets doesn't affect anyone else.



Programmers need some kind of API to create and read PDUs. You may use any from a variety of software libraries (for example Open-DIS) but your PDU messaging mileage won't vary.

DIS: PDU Format

- Remember, all this information is being sent in binary format in (typically) a UDP packet.
- The *exact* format that an ESPDU must have on the wire is specified in the DIS standard. This includes byte order.
- For example, the EntityID field starts 12 bytes into the ESPDU message, is in the order (site, application, entity), and each field entry is 16 bits long, in network byte order, and unsigned.



Attention to detail is necessary for the simulation plumbing to work properly. Pipes + water == network sockets + PDU messages.

DIS: ESPDU Format

Table 134—Entity State PDU

Field size (bits)	Entity State PDU fields	
96	PDU Header	Protocol Version—8-bit enumeration
		Exercise ID—8-bit unsigned integer
		PDU Type—8-bit enumeration = 1
		Protocol Family—8-bit enumeration = 1
		Timestamp—32-bit unsigned integer
		Length—16-bit unsigned integer
		PDU Status—8-bit record
		Padding—8 bits unused
48	Entity ID	Site Number—16-bit unsigned integer
		Application Number—16-bit unsigned integer
		Entity Number—16-bit unsigned integer



Theme to convey: be not afraid, the IEEE DIS specification explains everything well. Proof point is decades of interoperability by diverse participants.

DIS: Looking at ESPDUs

- What do ESPDUs look like? We can examine them on the network with a free tool called Wireshark, which can decode DIS packets
 - <http://www.wireshark.org>
- Remember, it's the format of the messages on the wire that count. The DIS standard specifies the exact format of binary messages, and any tool that produces or consumes those messages is fine with DIS. *How you create them (or consume them) is none of DIS's business.*



We are moving from theory to practice.

Wireshark: Capture Packets

en0 [Wireshark 1.6.0 (SVN Rev 37592 from /trunk-1.6)]

File Edit View Go **Capture** Analyze Statistics Telephony Tools Internals Help

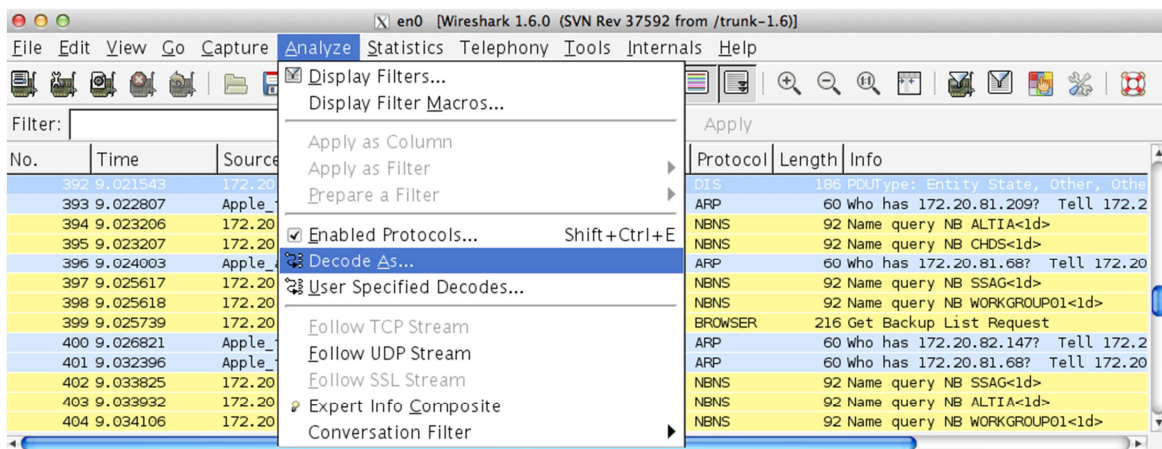
Filter: Expression... Clear Apply

No.	Time	Source	Destination	Protocol	Length	Info
121	2.613981		4.0.0.13	PIMv2	68	Hello
122	2.614227		4.0.0.13	PIMv2	68	Hello
123	2.614477	brocade:90:29:00	Broadcast	ARP	60	Who has 172.20.81.33? Tell 172.20.81.33
124	2.655632	Intel_3e:ee:aa	Broadcast	ARP	60	Gratuitous ARP for 192.168.30.32 (192.168.30.32)
125	2.692191	Dell_60:e0:01	Broadcast	ARP	60	Who has 172.20.80.107? Tell 172.20.80.107

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Describe wireshark's immense generality, availability, capability. Viva open source!

Wireshark: Decode Packets as DIS



Wireshark does DIS too.

Wireshark: Examine DIS Packets

No.	Source	Destination	Protocol	Length	Info
50717	172.20.82.149	239.1.2.3	DIS	186	PDUType: Entity State, Other, Other
50718	172.20.82.149	239.1.2.3	DIS	186	PDUType: Entity State, Other, Other
50719	172.20.82.149	239.1.2.3	DIS	202	PDUType: Set Data
50720	172.20.82.149	239.1.2.3	DIS	202	PDUType: Set Data
50721	172.20.82.149	239.1.2.3	DIS	186	PDUType: Entity State, Other, Other
50722	172.20.82.149	239.1.2.3	DIS	202	PDUType: Set Data
50723	172.20.80.3	239.255.255.250	IGMP	60	V2 Membership Query / Join group 23
50724	172.20.82.149	239.255.255.250	SSDP	175	M-SEARCH * HTTP/1.1

Frame 546: 186 bytes on wire (1488 bits), 186 bytes captured (1488 bits) on interface 0
 Ethernet II, Src: Apple_a9:5c:13 (70:cd:60:a9:5c:13), Dst: IPv4mcast_01:02:03 (01:00:5e:01:02:03)
 Internet Protocol Version 4, Src: 172.20.82.149 (172.20.82.149), Dst: 239.1.2.3 (239.1.2.3)
 User Datagram Protocol, Src Port: 62040 (62040), Dst Port: 62040 (62040)
 Distributed Interactive Simulation
 Header
 Entity State PDU
 Entity ID
 Entity ID Site: 17
 Entity ID Application: 127
 Entity ID Entity: 8
 Force ID = 0
 Number of Articulation Parameters: 0
 Entity Type
 Alternative Entity Type
 Entity Linear Velocity
 Entity Location
 X = 1000.000000
 Y = 0.000000
 Z = 1000.000000
 Entity Orientation
 Entity Appearance
 Dead Reckoning Parameters (40 bytes)
 Entity Marking (12 bytes)
 Capabilities = 0



Drill down to any/every level of detail lets everyone know what is really happening/working (and also enables debugging occasional mysteries).

DIS: Implementations

- Format
 - We know what information we want to send: entity type, entity ID, position, orientation, etc.
 - We know what coordinate system we want to use.
 - We know where to find arbitrary, agreed-upon enumeration identifier values—the EBV document.
 - We know some PDU types: entity state PDU, etc.
- How do we get the information into the format we want on the wire?
- This is where DIS implementations come in.



Review checkpoint. We've covered a lot – everyone on board?

DIS: Implementations

- Where can you get a DIS implementation?
 - Write your own (cough cough)
 - Buy one. There are several commercial implementations and many have excellent support.
 - Use an open source version—"free as in free puppy" (also includes freedom to fix)
 - Open-DIS (<https://github.com/open-dis> - formerly <http://open-dis.sourceforge.net>)
 - Java, C++, C#, Objective-C, JavaScript, Python
 - KDIS (<http://sourceforge.net/projects/kdis>)
 - C++
 - Aquarius (<http://sourceforge.net/projects/aquariusedispdu>)
 - C++
 - JDIS (<http://sourceforge.net/projects/jdis>)
 - Java



Have fun out there. Emphasize that Open-DIS strives for exact compliance, and errors (actual or perceived) can be fixed by the community.

Note current work to establish a DIS unit-test suite to confirm repeatability by software applications and API libraries.

DIS: Sending

- Remember, DIS has no official API. Every implementation is different. This example will use the Open-DIS API codebase. Implementation available at <https://github.com/open-dis>
- Source code now at <https://gitlab.nps.edu/Savage/NetworkedGraphicsMV3500>
- The example contains supporting libraries for other things. Can ignore those.
- All code is BSD open-source license; nonviral, use any way you see fit.



DIS: Send ESPDUs in Java

```
public void sendEspdus()
{
    try
    {
        EntityStatePdu espdu = new EntityStatePdu();

        // Set the entity ID, the unique identifier for an entity in the world
        espdu.getEntityID().setSite(CHINA_LAKE);
        espdu.getEntityID().setApplication(NPS);
        espdu.getEntityID().setSite(1);

        // Set this up as a Russian BMP-1
        EntityType type = espdu.getEntityType();
        type.setEntityKind((short)1); // vehicle
        type.setDomain((short)1); // land
        type.setCountry(222); // Commie russians
        type.setCategory((short)2); // AFV
        type.setSubcategory((short)1); // BMP
        type.setSpec((short)1); // basic BMP

        // Set position
        espdu.getEntityLocation().setX(1000.0);
        espdu.getEntityLocation().setY(2000.0);
        espdu.getEntityLocation().setZ(3000.0);

        for(int idx = 0; idx < 100; idx++)
        {
            byte data[] = espdu.marshalWithDisAbsoluteTimestamp();
            DatagramPacket packet = new DatagramPacket(data, data.length, destinationAddress, port );
            socket.send(packet);
            Thread.sleep(1000);
        }
    }
    catch(Exception e)
    {
        System.out.println(e);
    }
}
```



Typical code excerpt for sending, uses Open-DIS

DIS: Send PDUs in Javascript

Can use HTML5 Browser geolocation and Javascript to send DIS from a web page

```
// Set location. We get an object with properties x, y, and z back
// from conversion.
var disCoordinates = conversion.getXYZfromLatLonAltDegrees(latLonAlt);
espdu.entityLocation.x = disCoordinates.x;
espdu.entityLocation.y = disCoordinates.y;
espdu.entityLocation.z = disCoordinates.z;

espdu.marking.setMarking("Browser");

var dataBuffer = new ArrayBuffer(1000); // typically 144 bytes, make it big
var outputStream = new dis.OutputStream(dataBuffer);
espdu.encodeToBinaryDIS(outputStream);

// Trim to fit
var trimmedData = dataBuffer.slice(0, outputStream.currentPosition);
websocket.send(trimmedData);
```



Typical code excerpt for sending to a web browser, uses Open-DIS

DIS: Receive PDUs in Java

```
public void receivePdu()
{
    try
    {
        PduFactory pduFactory = new PduFactory();
        while(true)
        {
            byte[] buffer = new byte[1500];
            DatagramPacket packet = new DatagramPacket(buffer, buffer.length);
            socket.receive(packet);
            Pdu aPdu = pduFactory.createPdu(packet.getData());
            int pduType = aPdu.getPduType();
            switch(pduType)
            {
                case 0:
                    System.out.println("Unrecognized PDU type");
                    break;

                case 1:
                    System.out.println("Got Entity State Pdu");
                    break;

                case 2:
                    System.out.println("Got Fire PDU");
                    break;

                default:
                    System.out.println("got some type of PDU");
                    break;
            }
        }
    }
}
```



Typical code excerpt for receiving, uses Open-DIS

DIS Sending and Receiving PDUs

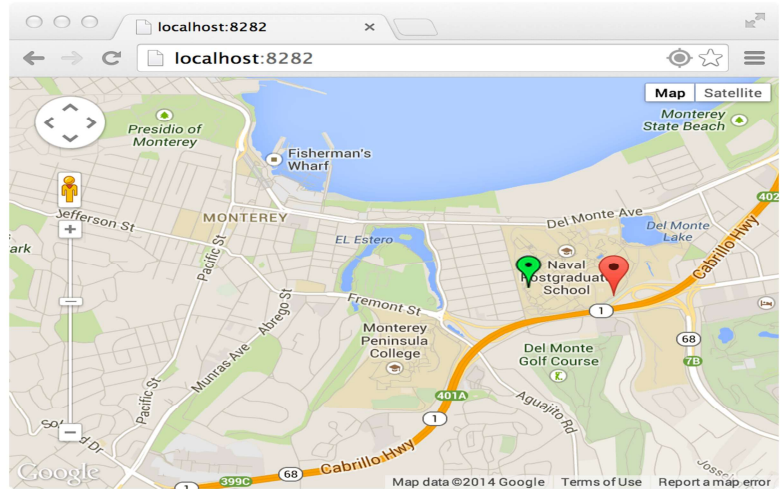
- There are similar idioms for other languages such as C++, Objective-C (iOS/macOS), Javascript, Python, C# (Windows phone, Unity 3D)
- Note that this requires that you do a bit of socket programming, which TENA and HLA hide from you. Socket programming isn't *that* bad...



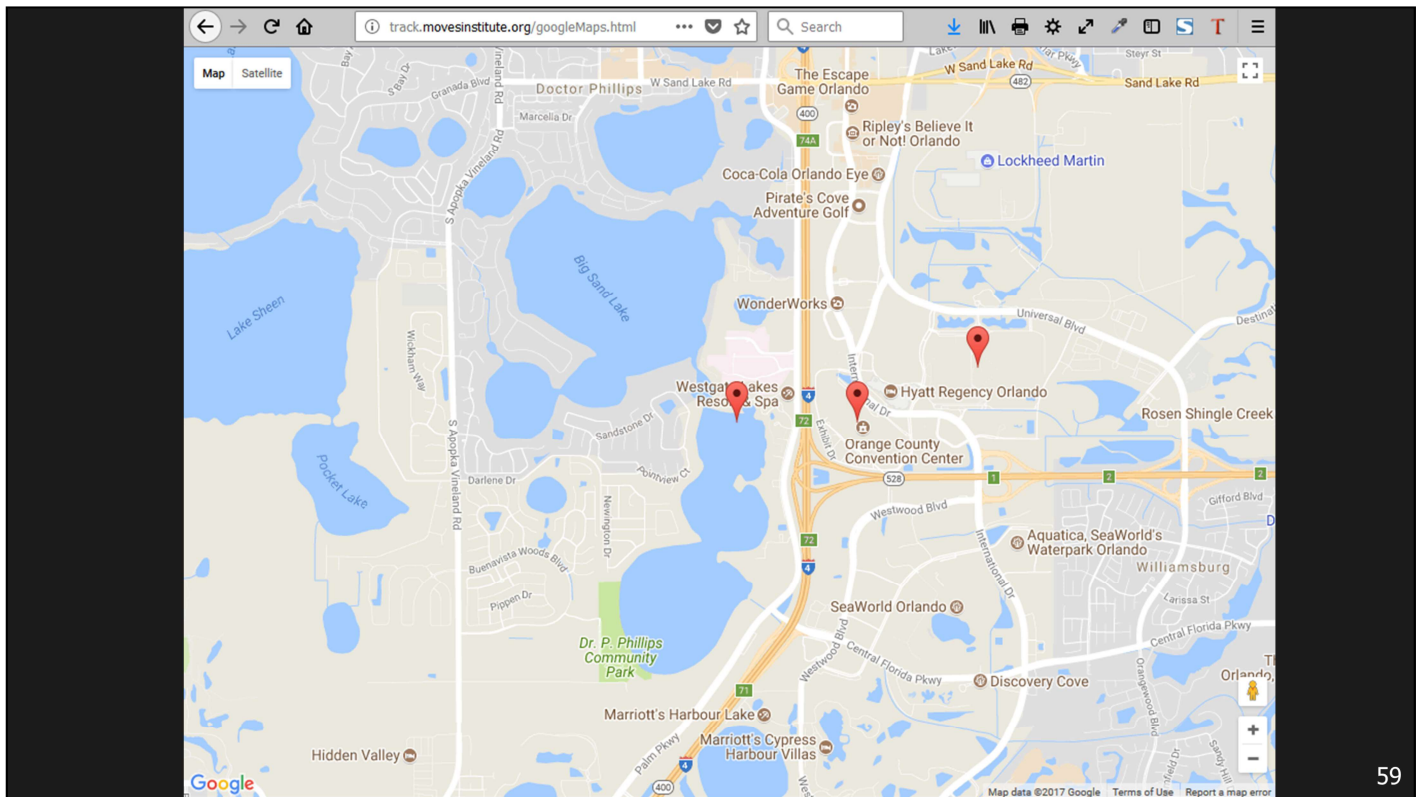
Virtue of programming: you only have to get it right once!

Visualizing DIS Data via Online Map using DISWebGateway

- [DISWebGateway](http://localhost:8282) running at
- <http://track.movesinstitute.org>
 - Java sender & receiver for DIS
 - Can receive native DIS from existing DIS applications
 - Web-based map that shows DIS entity locations

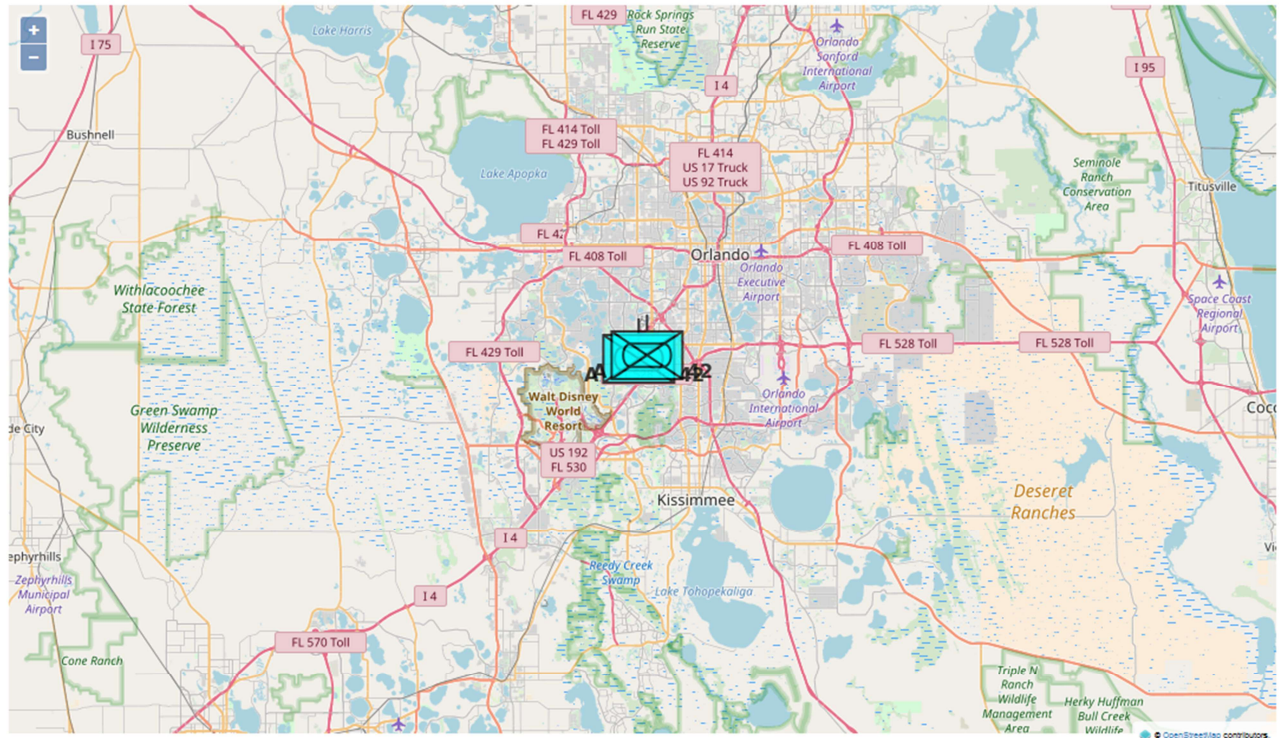


Exemplar demo. Server is being moved, will be ready for IITSEC (being updated for 2 classes at MOVES).



A script moves entities around a GoogleMaps display by animating KML placemarks with DIS.

Open Street Map/Open Layers 3 implementation of binary DIS to the web browser



60

A script moves entities around an OpenStreetMaps display by animating KML placemarks with DIS.

Constructive Simulation DIS Entity

This web page sends Entity State PDUs with the values below. Fill out the form, and click "Submit." The page will send ESDPUs with those values to the web server over a websocket, and the server will transmit them on the local network.

The Javascript in the web page will send the ESDPUs with the frequency indicated (in milliseconds).

Entity Type Information; Russian T-72 by Default

Kind: 1
Domain: 1
Country: 222
Category: 1
Subcategory: 2
Specific: 1
Extra: 1

Entity ID site and application

Site: 48
Application: 23

Location

Latitude (Decimal degrees): 28.425
Longitude: -81.47
Altitude (meters): 10
28.425

Marking Marking: MyEntity

Send Frequency

Send Frequency (ms): 5000

61

An HTML web-page form is used to create and send DIS ESPDU stream, source-code script uses Open-DIS JavaScript library with HTML.

DIS: Shoot at Something

- We've been sending ESPDU messages back and forth, but there are dozens of other sorts of messages. What if we want to shoot at someone? What does this involve?
- We can use a Fire PDU, which contains
 - The entity ID of the shooter
 - The entity ID of the target (if known)
 - The type of munition being fired, fuse, quantity, etc. This is very similar to the entity type
 - Enough information to compute the path of the munition (if desired)



We are now moving from sending/receiving to interacting.

DIS: Shoot at Something, then...

- The Detonation PDU usually follows a Fire PDU. It contains
 - Location of detonation, shooter entity ID, target entity ID
 - Fuse, munition type, and so on
- When a Detonation PDU is received simulations assess and report damage to their own entities, not to others.
 - This means simulations are on the “honor system” for determining their own damage; thus James T. Kirk can beat the unwinnable Kobayashi Maru scenario.
 - Here is a harsh adjective to describe cheating in distributed scenarios: **boring**.
 - For military simulations we are much more interested in strengths, vulnerabilities and possibilities that may occur in the real world. Thus cheating is also critically unhelpful.
 - Trusted participants using trusted software suites also reduces the risk of cheating.



Shared state for collision dynamics is fundamental to many many virtual environment interactions: driving, shooting, sensing, tracking, etc. etc. etc.

DIS Shooting



Fire! I'm entity (17, 23, 42), shooting at entity (123, 7, 12) with a HEAT round from (x, y, z)



Explosion! There's an detonation of a HEAT round at (x', y', z').



All entities now assess the damage to themselves by the Detonation at (x', y', z')



Walk through an interaction.

DIS: Arbitrary Data

- You can also exchange arbitrary data between DIS simulation participants with the DataQuery and Data PDUs.
 - Participant sends a DataQuery PDU addressed to another participant
 - That participant responds with a Data PDU
- The data itself is sent as “fixed variable datums” or “variable data datums”. Therefore it’s up to you to specify the exact format of these



A protocol is a handshake, carefully choreographed.

DIS: Other messages

- There are many other messages that can be used in DIS
 - Electronic warfare
 - Logistics
 - Directed energy weapons
 - Voice/Intercom
 - Collisions
 - Simulation management
 - Data exchange
- It's a big topic! Many different “conversations” can occur among entities.
- But the basics are: a standard format for exchanging state information.



Lots more can be said!

DIS and Other Standards: HLA, TENA

- How can DIS interoperate with HLA or TENA?
- HLA Real-time Platform Reference Federation Object Model (RPR-FOM)
 - Intentionally matches DIS, same entity types, same entity IDs and coordinate system, etc.
 - HLA object model mapping makes transition from DIS to HLA easy and consistent
 - Several gateways to translate between DIS and RPR-FOM. JBUS, AMIE, others
 - Guidance, Rationale and Interoperability Modalities (GRIM) for RPR-FOM standard provides further rules and usage information.
 - <https://www.sisostds.org/productspublications/standards/sisostandards.aspx>
- TENA has generalized gateway functionality that can map TENA events to DIS and vice versa. It generally uses the same coordinate system, entity types, etc.



There is a large community of practitioners and programmers out there.

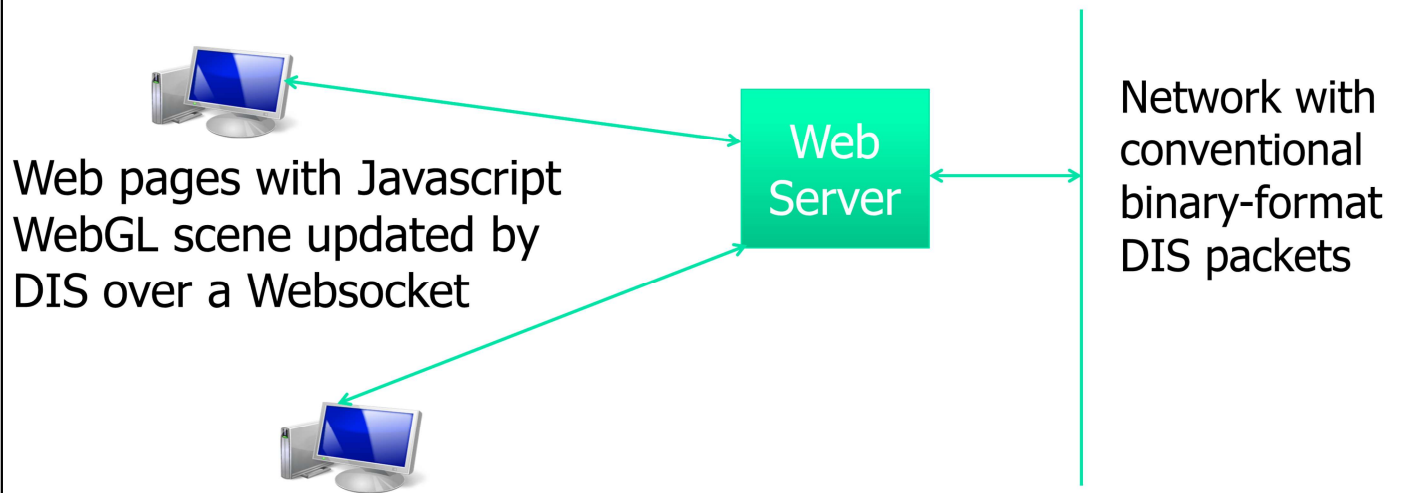
DIS Research Topic: DIS in the Web Page

- Websockets are a standard from IETF and W3C. The idea is to provide a direct Javascript-based TCP socket into a web page without having to use AJAX polling techniques. Widespread browser support.
- JavaScript is a widely used language for dynamic web content.
 - WebGL is JavaScript binding for OpenGL which allows us to use accelerated 3D graphics inside the web page.
 - WebGL can be the substrate for higher level graphics standards such as Extensible 3D Graphics Standard (X3D).
- Put all three together and you can implement a networked virtual environment in a web page.



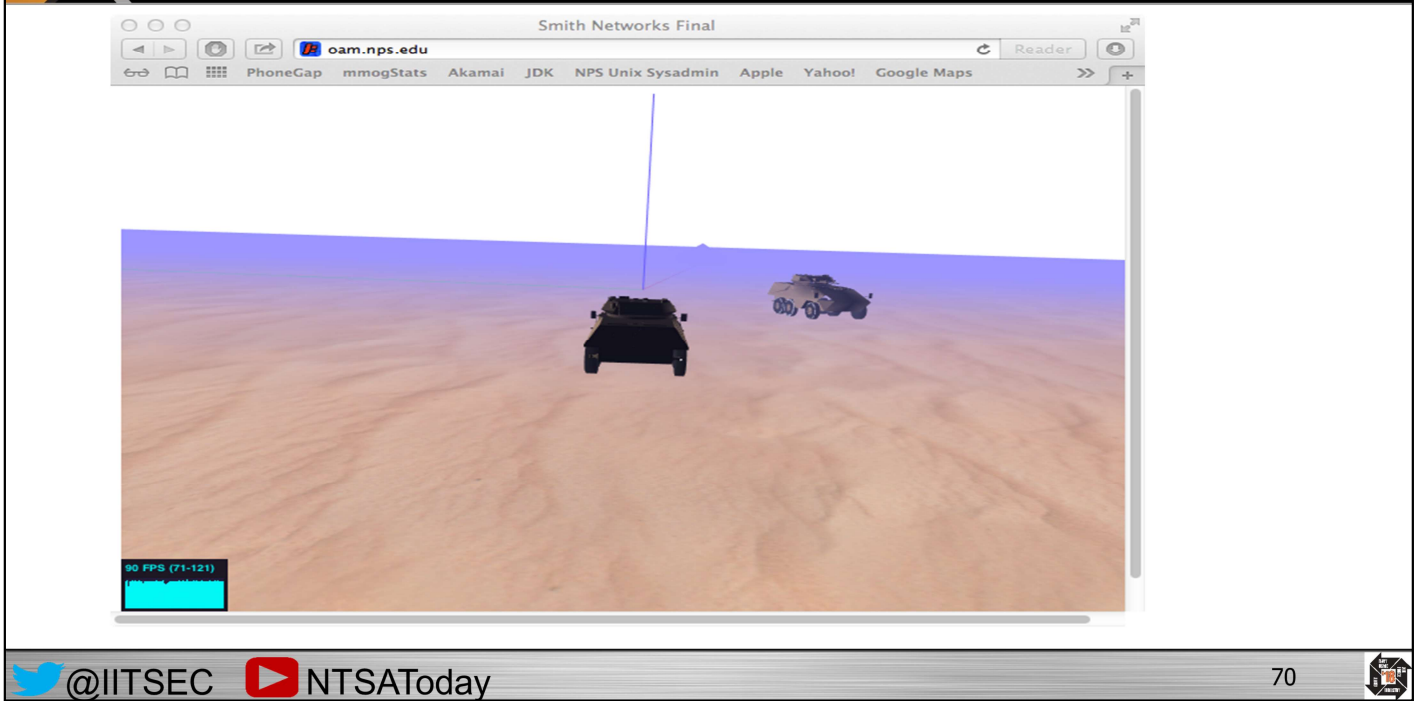
Lots of work, slowly steadily progressing. Web technology provides the greatest possible footprint, either on big internet or private military networks.

DIS Research Topic: 3D in the Web Page



For example: it has to be simple to be repeatable and reusable.

DIS Research Topic: 3D in the Web Page



Demo. Server may change, details will be confirmed at IITSEC.

Applied Research using WebLVC

- Excellent combinations of WebGL/X3D, WebSockets, and fast JavaScript in the web browser have emerged in recent years.
 - [Open-DIS](#) library can send DIS PDUs directly into a web browser.
- SISO WebLVC Product Development Group (PDG)
 - <https://www.sisostds.org/StandardsActivities/DevelopmentGroups/WebLVCPDG.aspx>
- One of many examples: Virtual World Framework
 - <http://virtualworldframework.com> and https://en.wikipedia.org/wiki/Virtual_world_framework
- Active research topic... but no wide-scale “Ready Player One” arenas for DIS, yet



There is no one single way to do it! There are many ways... and more work to do. Participants have an important role to play.

DIS Tutorial Summary

- DIS applications exchange state information among distributed set of players.
- Defines syntax and semantics for a series of binary-formatted messages, with each packet's bytes, data representation and functionality exactly defined.
- Different software APIs can implement the same “over the wire” data standard.
- Applications focused on large-scale, high-fidelity, virtual / constructive simulations.
- Common concepts: entity types, entity IDs, heartbeats, coordinate systems.



Are we clear? Remembering key points remaining constant among many details.

Resources and References

- SISO: <http://sisostds.org>
- SISO DIS Protocol Support Group:
<https://www.sisostds.org/StandardsActivities/SupportGroups.aspx>
- Open-DIS: <https://github.com/open-dis>
- SEDRIS SRM: <http://sedris.org>
- Kdis: <http://kdis.sourceforge.net>
- Wireshark: <http://wireshark.org>
- WebGL: <http://www.khronos.org/webgl>
- X3D Graphics: <http://www.web3d.org/x3d/what-x3d> and <http://x3dgraphics.com/slidesets>
- WebLVC: <https://www.sisostds.org/StandardsActivities/DevelopmentGroups.aspx>
- WebSockets: <http://tools.ietf.org/html/rfc6455> , <http://www.w3.org/TR/websockets>

Tutorial and other examples can be found at
<https://gitlab.nps.edu/Savage/NetworkedGraphicsMV3500>



More references available online. This takes study and... we learn most of all from practice. Questions welcome, the community learns together.

TODO: lots of work in progress!

Much work is ongoing in DIS at NPS. Several areas of improved focus were realized during the SISO Simulation Interoperability Workshop (SIW) held in Orlando Florida February 2020. The following work is planned for this year:

- Improved Java enumerations (over 22,000 values) regularly autogenerated,
- Improved OpenDIS7 library with full coverage of all 72 PDUs and growing set of examples,
- Thesis work to support unit testing of simulations via DIS streams and LVC connectivity including Extensible 3D Graphics (X3D) Standard,
- Planned work in Compressed DIS (C-DIS) encoding and DIS version 8 development.

We look forward to steady tutorial and library improvements throughout the year.



Learning Objectives

The learner will be able to...

- Identify what standards are used by distributed simulations for military use.
- Identify what types of communication protocols are used for various networks.
- Identify what aspects need to be standardized, and what aspects can be customized, to support diverse simulations with differing models and goals.
- Identify how DIS techniques for dead reckoning (DR), visual smoothing and distributed collision detection can reduce network traffic.
- Learn how to apply new capabilities expected for Compressed DIS and DISv8.



Discuss how connecting all manner of simulations, namely Live Virtual Constructive LVC, is the necessary path for connecting to Command and Control (C2) systems. Establishing such connections between traditionally separate domains is central to conference theme,

- “The Future is Now“

Note that, for example, common tutorial topic “What coordinate systems are used?” is also central to requirements for connecting C2 and M+S.

Slide 2 and last slide are identical.