

Repeatable Unit Testing of Distributed Interactive Simulation (DIS) Protocol Behavior Streams using Web Standards

“A Stream is a Stream”

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Problem Statement

- It is hard for simulation systems to interconnect, especially with partner nations and C2 systems
- Utilizing open-source Web Technology is a valuable resource that can help numerous systems regardless of data classification
- Partnerships with NATO partners are needed to improve shared understanding of mutual goals and challenges
- M&S is not relevant to active warfighting unless we can achieve interoperability between Live, Virtual and Constructive (LVC) simulations, robot telemetry, and Command and Control (C2)

Thesis Motivation: Basic Premises

- A stream is a stream, at rest in a file or in motion over the network
 - Playback recorded manipulation of a model using PDUs
 - Stream manipulation of models using OpenDIS7 library
- Multiple open-source codebases available, initially Java with more languages to follow (JavaScript, Python, XML, JSON, etc.)
- X3D Graphics standard allows dynamic 3D in any Web browser
 - Record remote animation of a model using PDUs
 - Distill concise first-order linear interpolators from streams

Research Questions

- Stability of IEEE DIS specs and capabilities of MOVES LVC Lab offer excellent new opportunities for broad interoperation
 - Open-source codebase by Mike Bailey offers entire vocabulary
 - Curt Blais dissertation work on Rich Semantic Track (RST)
 - How can these best be adapted and applied?
- How to promote DIS behavior streams as first-class media type?
 - Coherent data streams for collaboration, simulation, telemetry
 - Unit testing of recorded streams for adaptable repeatability
 - Establish archivable annotated records of simulation activity

What is IEEE DIS Protocol?

- Distributed Interactive Simulation (DIS) is an [Institute of Electrical and Electronics Engineers \(IEEE\)](#) standard for conducting real-time platform-level wargaming across multiple host computers and is used worldwide, especially by military organizations and other agencies.
- Wikipedia: [Distributed Interactive Simulation \(DIS\)](#)
- Simulation Interoperability Standards Organization ([SISO](#)): "Simulation Interoperability and Reuse through Standards"
- SISO [DIS / RPR FOM Product Support Group \(PSG\)](#)



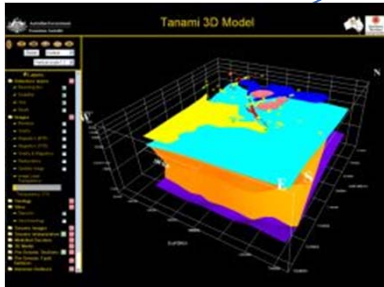
What is X3D4 Graphics?

Extensible 3D (X3D) Graphics is the royalty-free open standard for publishing, viewing, printing and archiving interactive 3D models using Web technology.

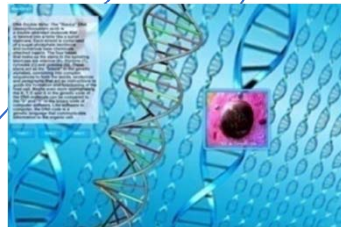
X3D Anywhere



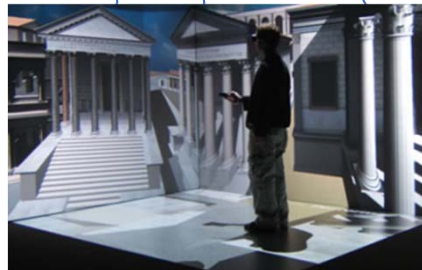
Geo Visualization



Education



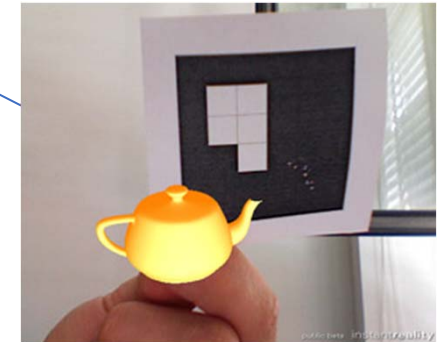
Cultural Heritage



Gaming



Augmented Reality



update: [X3D4](#)

Virtual Worlds



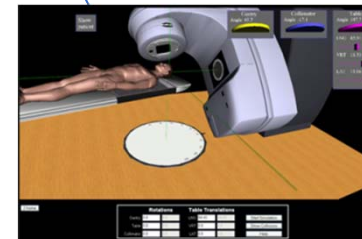
Mirror Worlds



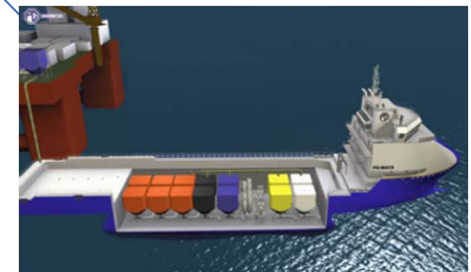
E-commerce



Medical

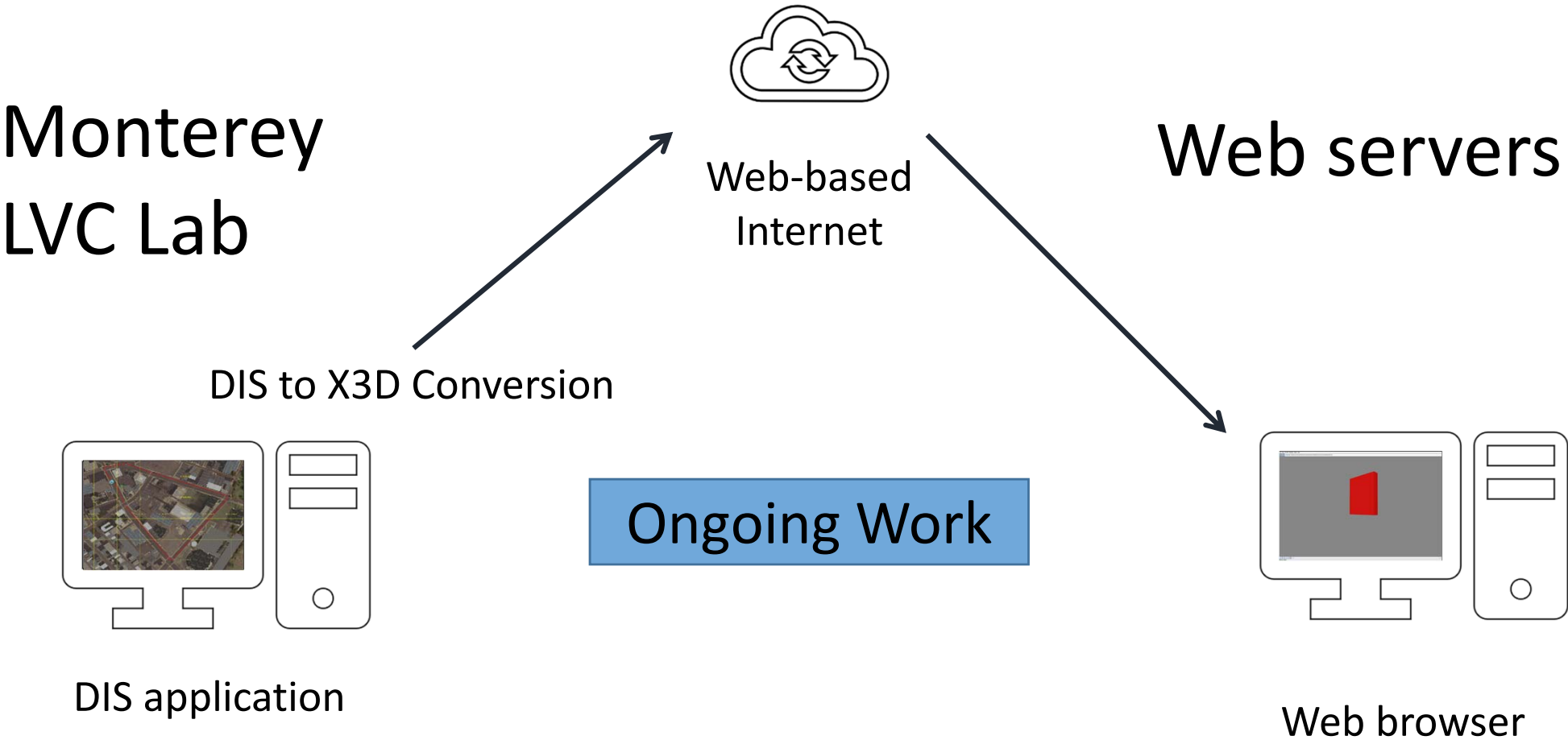


Enterprise

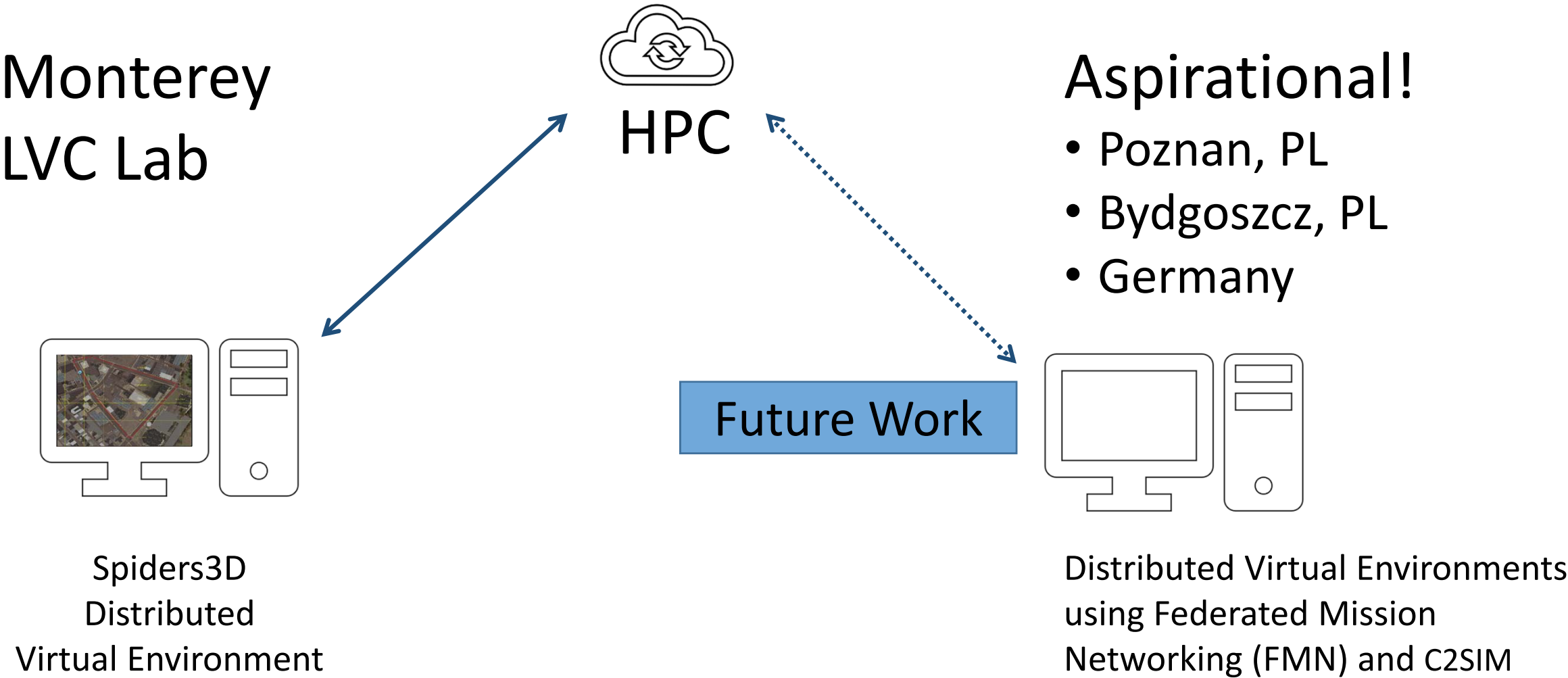


www.web3d.org/case-studies

Use Case: Record in LVC Lab / Playback in X3D

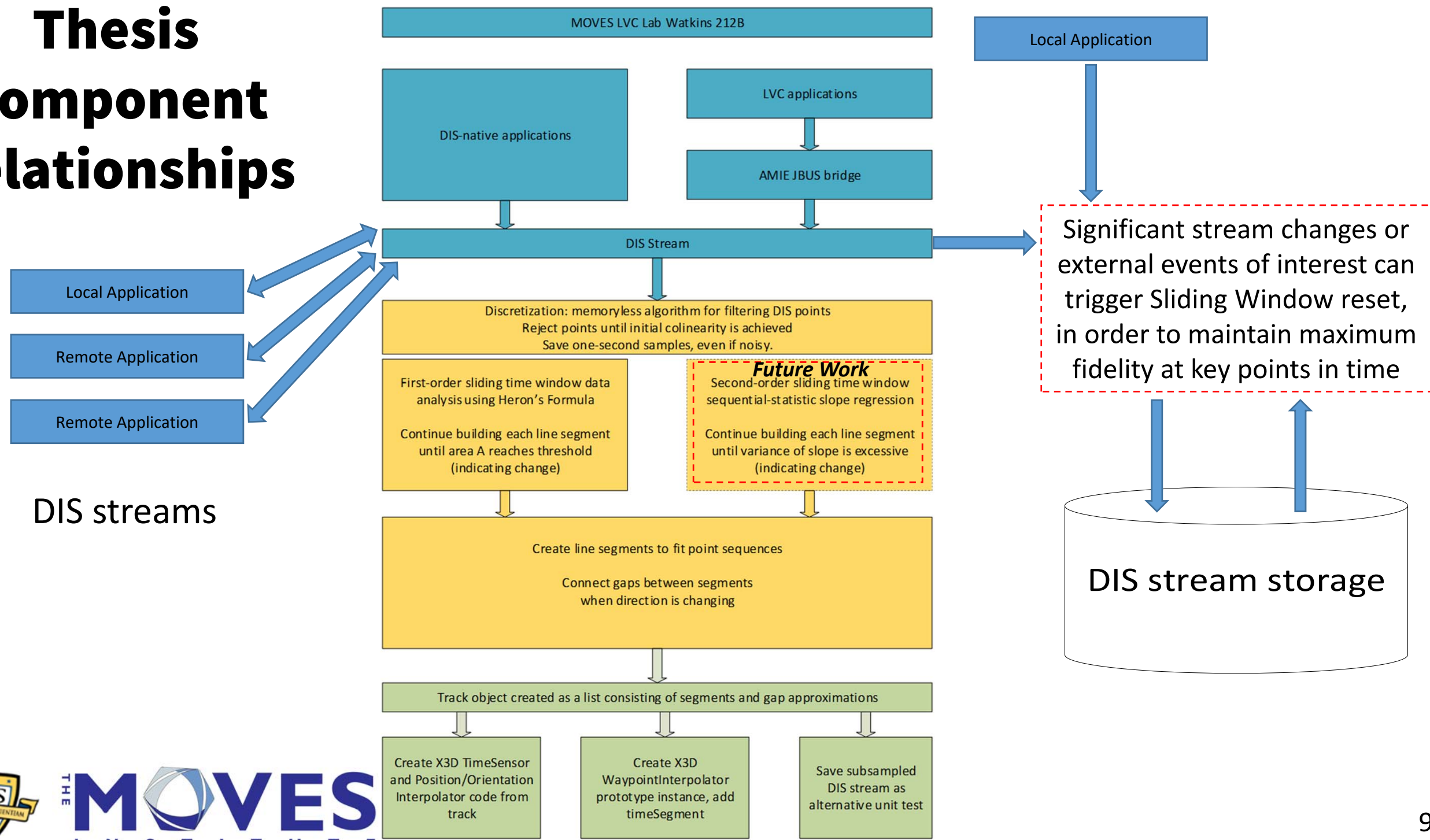


Use Case: Long-Haul DIS for Collaboration



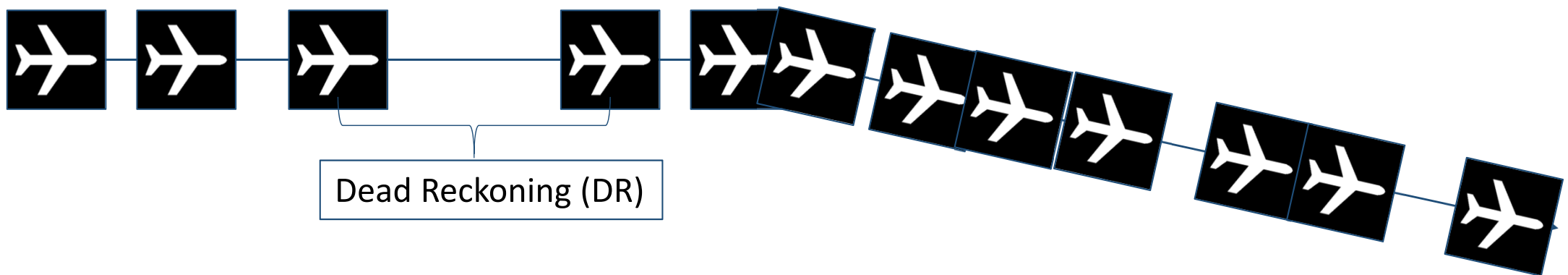
Thesis

Component Relationships

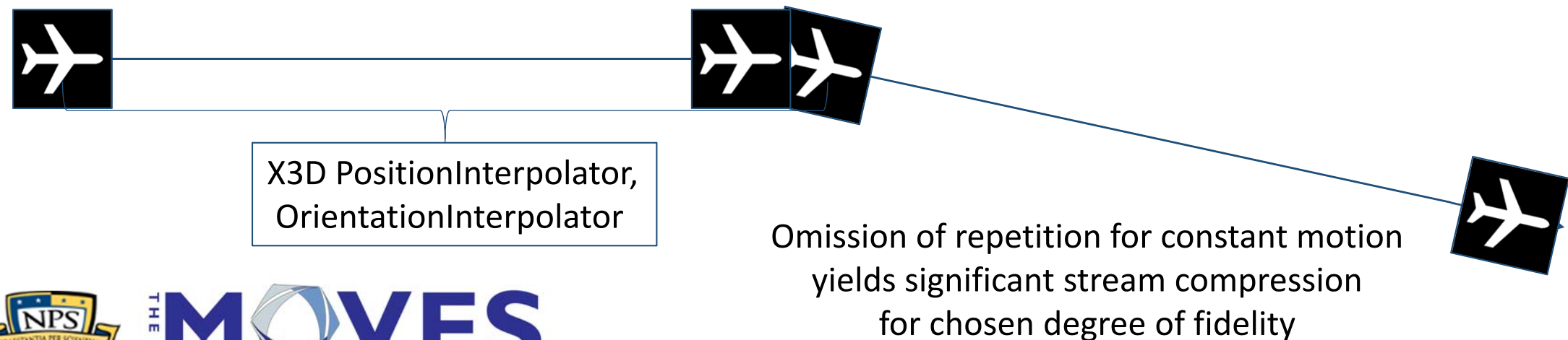


Test Scenario for Playback Compression

Raw DIS PDU Data from Simulation or Live Streaming:

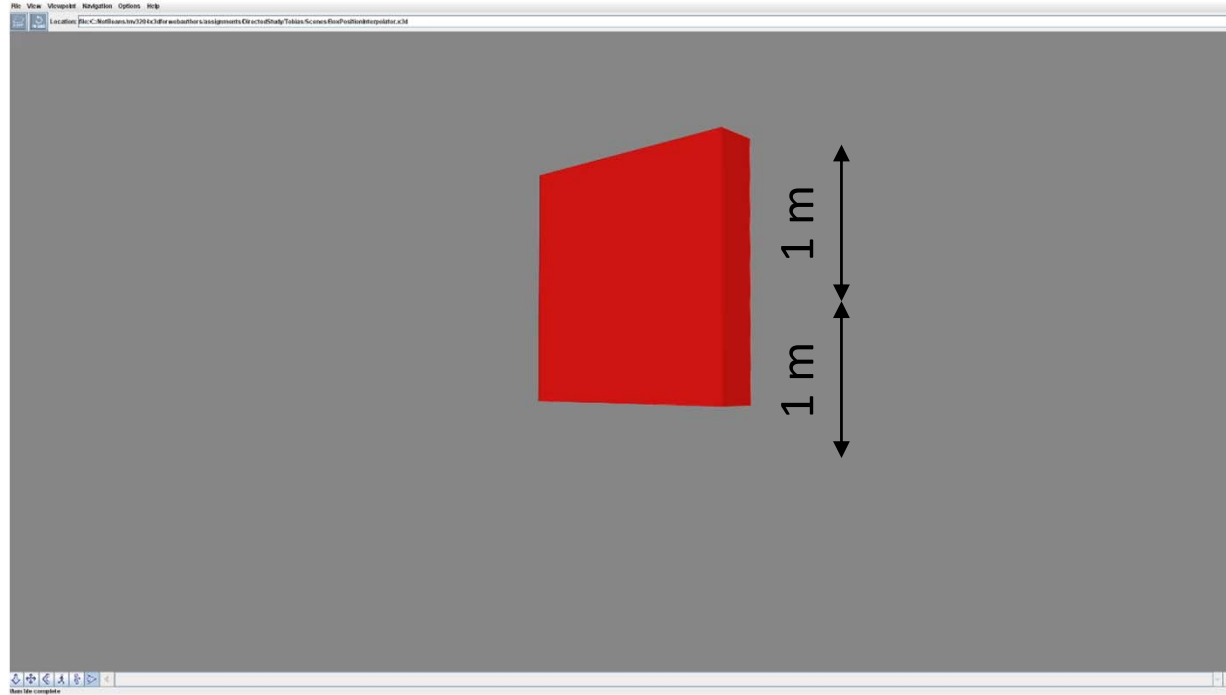


Sliding Window Interpolator for X3D Animation Playback:



Completed research implementation:

Generating X3D PositionInterpolator from DIS Stream (Example)



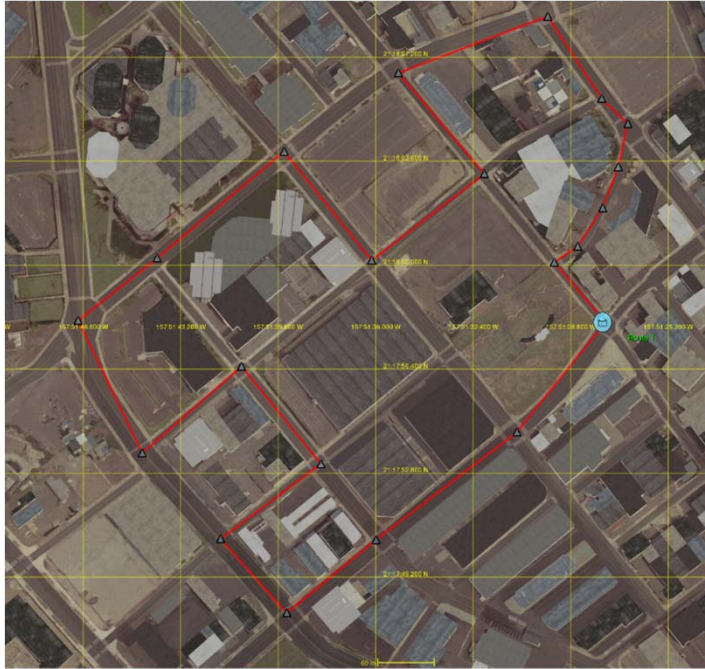
```
<TimeSensor DEF='BoxTimeInterval' cycleInterval='1' loop = 'true'/>
```

```
<PositionInterpolator DEF='Entity' key = '0.0 0.25 0.5 0.75 1.0 ' keyValue = '0 0 0  0 1 0  0 2 0  0 1 0  0 0 0' />
```

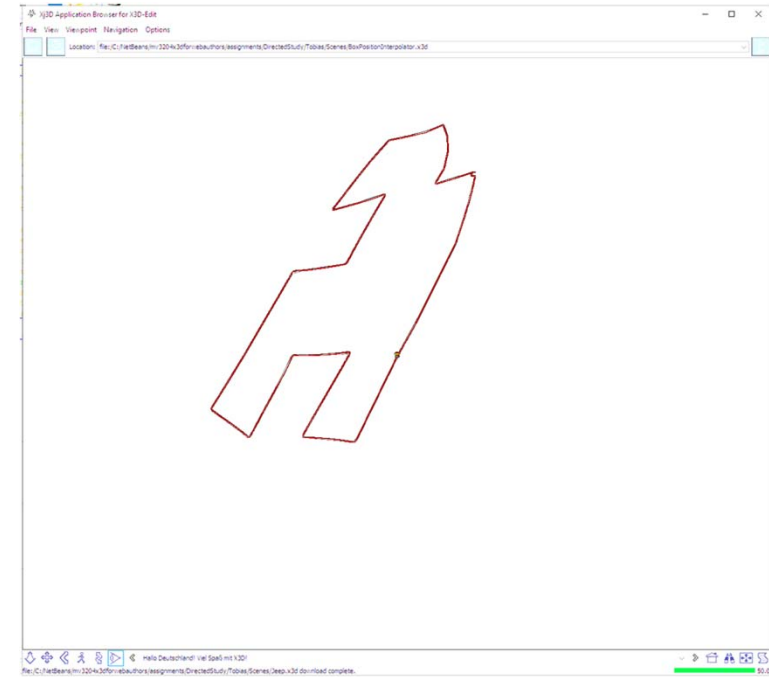
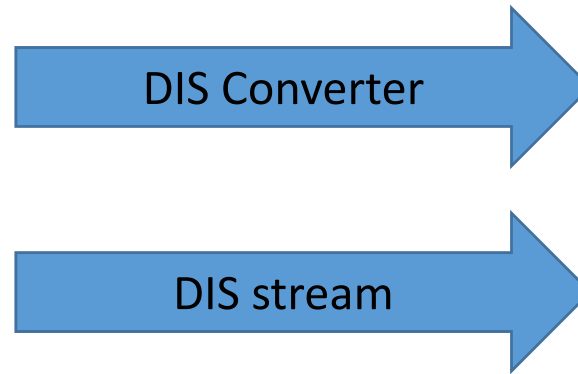
(Similarly for OrientationInterpolator)

Autogenerate X3D Code:

- Generating PositionInterpolator and OrientationInterpolator from DIS Stream



VR Forces



Xj3D

X3D TimeSensor and X3D PositionInterpolator are distilled from raw DIS streams and saved as XML.

Looking ahead: can we build libraries of recorded behaviors for playback?

Goal: Physics-Based Compression (kinematics)

```
<TimeSensor DEF='PduStreamClock' cycleInterval='114.735954' loop = 'true'/>
<PositionInterpolator DEF='Entity' key = '0 0.024 0.025 0.026 0.027 0.028 0.029 0.03 0.031 0.032 0.033 0.034 0.035 0.036 0.038 0.039 0.041 0.041 0.043 0.043 0.044 0.046 0.046 0.048 0.049 0.05 0.051 0.052 0.053
0.055 0.056 0.058 0.059 0.063 0.067 0.071 0.077 0.078 0.084 0.086 0.092 0.102 0.105 0.116 0.118 0.12 0.13 0.167 0.172 0.19 0.19 0.255 0.32 0.346 0.385 0.39 0.435 0.452 0.454 0.456 0.468 0.475 0.517 0.518 0.52
0.522 0.522 0.523 0.525 0.525 0.527 0.528 0.528 0.53 0.53 0.533 0.534 0.535 0.536 0.537 0.538 0.539 0.54 0.541 0.542 0.544 0.545 0.546 0.547 0.548 0.549 0.558 0.564 0.569 0.578 0.62 0.625 0.641 0.642 0.657
0.673 0.673 0.713 0.713 0.714 0.735 0.735 0.751 0.751 0.767 0.767 0.782 0.782 0.814 0.844 0.844 0.867 0.896 0.903 0.905 0.912 0.925 0.927 0.931 0.932 0.946 0.949 0.954 0.974 0.975 0.992 0.993 0.996 0.997
0.998 0.999 1 '
keyValue = '0 0 0 0.007 0.003 0.018 0.014 0.005 0.038 0.038 0.014 0.103 0.054 0.019 0.146 0.097 0.029 0.257 0.123 0.034 0.323 0.187 0.04 0.481 0.225 0.041 0.57 0.267 0.039 0.668 0.363 0.025 0.882 0.418
0.012 1 0.542 -0.031 1.252 0.611 -0.062 1.388 0.851 -0.204 1.82 0.941 -0.271 1.971 1.137 -0.438 2.278 1.243 -0.54 2.432 1.469 -0.785 2.734 1.589 -0.93 2.88 1.712 -1.091 3.021 1.968 -1.459 3.278 2.099 -
1.667 3.391 2.414 -2.229 3.606 2.497 -2.394 3.647 2.643 -2.703 3.702 2.766 -2.984 3.728 2.867 -3.231 3.732 2.948 -3.445 3.723 3.063 -3.772 3.685 3.137 -3.996 3.645 3.278 -4.473 3.518 3.321 -4.638 3.461
3.595 -5.773 3.014 3.916 -7.104 2.49 4.219 -8.345 4.958 -11.234 0.839 5.114 -11.855 0.592 5.967 -15.285 -0.773 6.135 -15.975 -1.046 7.162 -20.299 -2.74 9.53 -28.241 -5.855 9.703 -30.95 -6.92 11.988 -
40.467 -10.664 12.316 -41.831 -11.199 12.712 -43.66 -11.831 -12.721 -45.49 -12.517 -47.32 -13.189 -49.15 -13.861 -50.98 -14.573 -52.80 -15.295 -54.63 -16.017 -56.46 -16.739 -58.29 -17.461 -60.12 -18.183 -61.95 -18.905 -63.78 -19.627 -65.61 -20.351 -67.44 -21.075 -69.27 -21.523 -71.10 -22.071 -72.93 -22.569 -74.76 -23.067 -76.59 -23.565 -78.42 -24.063 -80.25 -24.561 -82.08 -25.059 -83.71 -25.557 -85.34 -26.055 -86.97 -26.553 -88.60 -27.051 -90.23 -27.549 -91.86 -28.047 -93.49 -28.545 -95.12 -29.043 -96.75 -29.541 -98.38 -30.039 -100.01 -30.537 -101.64 -31.035 -103.27 -31.533 -104.90 -32.031 -106.53 -32.529 -108.16 -33.027 -109.79 -33.525 -111.42 -34.023 -113.05 -34.521 -114.68 -35.019 -116.31 -35.517 -117.94 -36.015 -119.57 -36.513 -121.20 -37.011 -122.83 -37.509 -124.46 -38.007 -126.09 -38.505 -127.72 -39.003 -129.35 -39.501 -130.98 -40.000 -132.61 -40.498 -134.24 -40.996 -135.87 -41.494 -137.50 -41.992 -139.13 -42.490 -140.76 -42.988 -142.39 -43.486 -144.02 -43.984 -145.65 -44.482 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-252.500 -838.15 -253.000 -840.00 -253.500 -841.63 -254.000 -843.26 -254.500 -844.89 -255.000 -846.52 -255.500 -848.15 -256.000 -850.00 -256.500 -851.63 -257.000 -853.26 -257.500 -854.89 -258.000 -856.52 -258.500 -858.15 -259.000 -860.00 -259.500 -861.63 -260.000 -863.26 -260.500 -864.89 -261.000 -866.52 -261.500 -868.15 -262.000 -870.00 -262.500 -871.63 -263.000 -873.26 -263.500 -874.89 -264.000 -876.52 -264.500 -878.15 -265.000 -880.00 -265.500 -881.63 -266.000 -883.26 -266.500 -884.89 -267.000 -886.52 -267.500 -888.15 -268.000 -890.00 -268.500 -891.63 -269.000 -893.26 -269.500 -894.89 -270.000 -896.52 -270.500 -898.15 -271.000 -900.00 -271.500 -901.63 -272.000 -903.26 -272.500 -904.89 -273.000 -906.52 -273.500 -908.15 -274.000 -910.00 -274.500 -911.63 -275.000 -913.26 -275.500 -914.89 -276.000 -916.52 -276.500 -918.15 -277.000 -920.00 -277.500 -921.63 -278.000 -923.26 -278.500 -924.89 -279.000 -926.52 -279.500 -928.15 -280.000 -930.00 -280.500 -931.63 -281.000 -933.26 -281.500 -934.89 -282.000 -936.52 -282.500 -938.15 -283.000 -940.00 -283.500 -941.63 -284.000 -943.26 -284.500 -944.89 -285.000 -946.52 -285.500 -948.15 -286.000 -950.00 -286.500 -951.63 -287.000 -953.26 -287.500 -954.89 -288.000 -956.52 -288.500 -958.15 -289.000 -960.00 -289.500 -961.63 -290.000 -963.26 -290.500 -964.89 -291.000 -966.52 -291.500 -968.15 -292.000 -970.00 -292.500 -971.63 -293.000 -973.26 -293.500 -974.89 -294.000 -976.52 -294.500 -978.15 -295.000 -980.00 -295.500 -981.63 -296.000 -983.26 -296.500 -984.89 -297.000 -986.52 -297.500 -988.15 -298.000 -990.00 -298.500 -991.63 -299.000 -993.26 -299.500 -994.89 -300.000 -996.52 -300.500 -998.15 -301.000 -1000.00 -301.500 -1001.63 -302.000 -1003.26 -302.500 -1004.89 -303.000 -1006.52 -303.500 -1008.15 -304.000 -1010.00 -304.500 -1011.63 -305.000 -1013.26 -305.500 -1014.89 -306.000 -1016.52 -306.500 -1018.15 -307.000 -1020.00 -307.500 -1021.63 -308.000 -1023.26 -308.500 -1024.89 -309.000 -1026.52 -309.500 -1028.15 -310.000 -1030.00 -310.500 -1031.63 -311.000 -1033.26 -311.500 -1034.89 -312.000 -1036.52 -312.500 -1038.15 -313.000 -1040.00 -313.500 -1041.63 -314.000 -1043.26 -314.500 -1044.89 -315.000 -1046.52 -315.500 -1048.15 -316.000 -1050.00 -316.500 -1051.63 -317.000 -1053.26 -317.500 -1054.89 -318.000 -1056.52 -318.500 -1058.15 -319.000 -1060.00 -319.500 -1061.63 -320.000 -1063.26 -320.500 -1064.89 -321.000 -1066.52 -321.500 -1068.15 -322.000 -1070.00 -322.500 -1071.63 -323.000 -1073.26 -323.500 -1074.89 -324.000 -1076.52 -324.500 -1078.15 -325.000 -1080.00 -325.500 -1081.63 -326.000 -1083.26 -326.500 -1084.89 -327.000 -1086.52 -327.500 -1088.15 -328.000 -1090.00 -328.500 -1091.63 -329.000 -1093.26 -329.500 -1094.89 -330.000 -1096.52 -330.500 -1098.15 -331.000 -1099.00 -331.500 -1100.00 -332.000 -1101.63 -332.500 -1102.89 -333.000 -1104.52 -333.500 -1105.89 -334.000 -1107.52 -334.500 -1108.89 -335.000 -1110.52 -335.500 -1111.89 -336.000 -1113.52 -336.500 -1114.89 -337.000 -1116.52 -337.500 -1117.89 -338.000 -1119.52 -338.500 -1120.89 -339.000 -1122.52 -339.500 -1123.89 -340.000 -1125.52 -340.500 -1126.89 -341.000 -1128.52 -341.500 -1129.89 -342.000 -1131.52 -342.500 -1132.89 -343.000 -1134.52 -343.500 -1135.89 -344.000 -1137.52 -344.500 -1138.89 -345.000 -1140.52 -345.500 -1141.89 -346.000 -1143.52 -346.500 -1144.89 -347.000 -1146.52 -347.500 -1147.89 -348.000 -1149.52 -348.500 -1150.89 -349.000 -1152.52 -349.500 -1153.89 -350.000 -1155.52 -350.500 -1156.89 -351.000 -1158.52 -351.500 -1159.89 -352.000 -1161.52 -352.500 -1162.89 -353.000 -1164.52 -353.500 -1165.89 -354.000 -1167.52 -354.500 -1168.89 -355.000 -1170.52 -355.500 -1171.89 -356.000 -1173.52 -356.500 -1174.89 -357.000 -1176.52 -357.500 -1177.89 -358.000 -1179.52 -358.500 -1180.89 -359.000 -1182.52 -359.500 -1183.89 -360.000 -1185.52 -360.500 -1186.89 -361.000 -1188.52 -361.500 -1189.89 -362.000 -1191.52 -362.500 -1192.89 -363.000 -1194.52 -363.500 -1195.89 -364.000 -1197.52 -364.500 -1198.89 -365.000 -1200.52 -365.500 -1201.89 -366.000 -1203.52 -366.500 -1204.89 -367.000 -1206.52 -367.500 -1207.89 -368.000 -1209.52 -368.500 -1210.89 -369.000 -1212.52 -369.500 -1213.89 -370.000 -1215.52 -370.500 -1216.89 -371
```

Goal: Parsability/Readability with Compression

BASE64:

536 bytes

```
!Begin!Beginning of DIS capture file, Pdusave3.dislog.
AAAAABnRSPQ=,BwAFAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAAB/m8kg=,BwAGAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAACXtWVw=,BwAHAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAACvzmWA=,BwAIAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAADH7KVQ=,BwAJAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAADgffug=,BwAKAwAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAAD5FCqQ=,BwALBQAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
AAAAAERbrfg=,BwAMBQAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA==
!End!End of DIS capture file, Pdusave3.dislog.
```

Suitable for MIME email attachments

Software archives include
round-trip testing with
version-control diffs for
consistency checking

Plain Text:

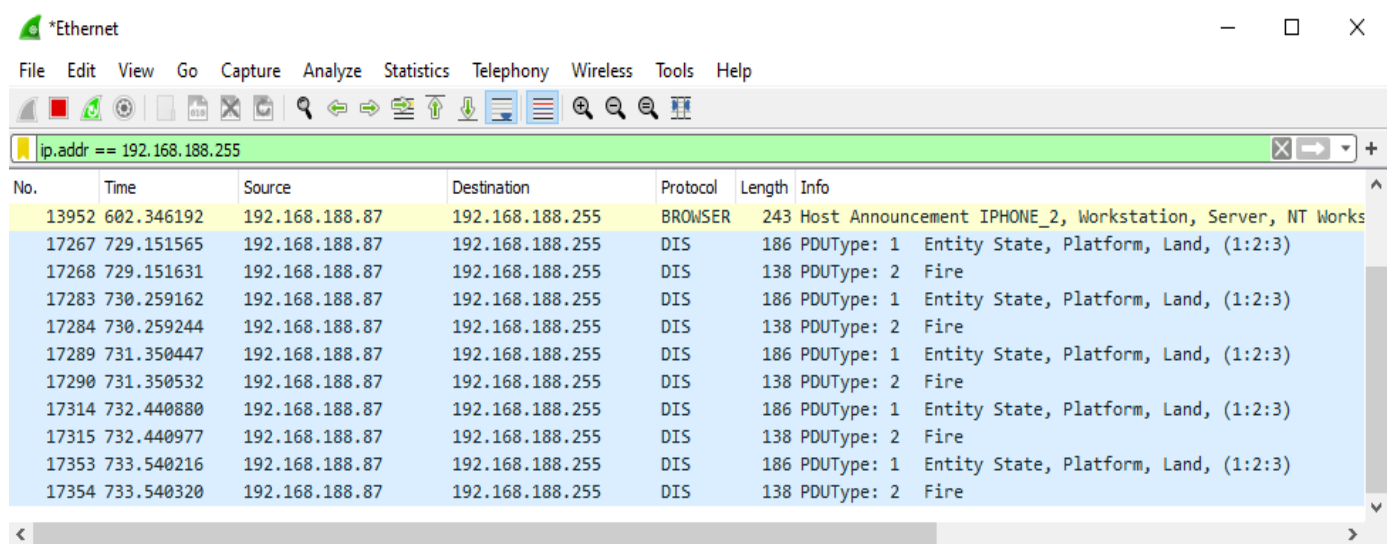
781 bytes

[illegible]

Suitable for
debugging

Future Work: Compressed DIS (C-DIS) Encoding

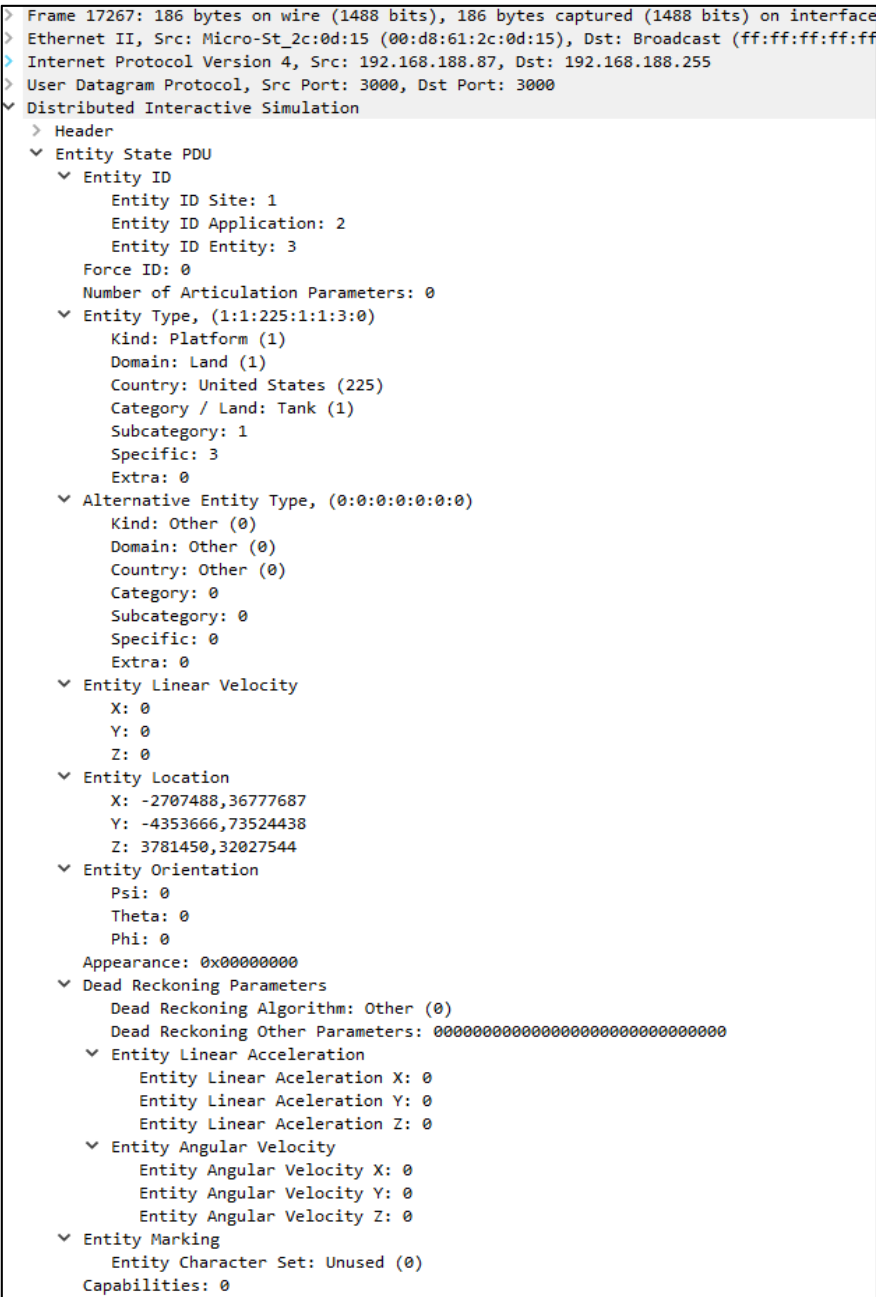
Additional parsing tool: Wireshark ([setup help](#))



No.	Time	Source	Destination	Protocol	Length	Info
13952	602.346192	192.168.188.87	192.168.188.255	BROWSER	243	Host Announcement IPHONE_2, Workstation, Server, NT Works
17267	729.151565	192.168.188.87	192.168.188.255	DIS	186	PDUType: 1 Entity State, Platform, Land, (1:2:3)
17268	729.151631	192.168.188.87	192.168.188.255	DIS	138	PDUType: 2 Fire
17283	730.259162	192.168.188.87	192.168.188.255	DIS	186	PDUType: 1 Entity State, Platform, Land, (1:2:3)
17284	730.259244	192.168.188.87	192.168.188.255	DIS	138	PDUType: 2 Fire
17289	731.350447	192.168.188.87	192.168.188.255	DIS	186	PDUType: 1 Entity State, Platform, Land, (1:2:3)
17290	731.350532	192.168.188.87	192.168.188.255	DIS	138	PDUType: 2 Fire
17314	732.440880	192.168.188.87	192.168.188.255	DIS	186	PDUType: 1 Entity State, Platform, Land, (1:2:3)
17315	732.440977	192.168.188.87	192.168.188.255	DIS	138	PDUType: 2 Fire
17353	733.540216	192.168.188.87	192.168.188.255	DIS	186	PDUType: 1 Entity State, Platform, Land, (1:2:3)
17354	733.540320	192.168.188.87	192.168.188.255	DIS	138	PDUType: 2 Fire

Independent second checks are helpful with widely used open-source protocol decoder and networking-analysis tool

www.wireshark.org ([DIS support](#))



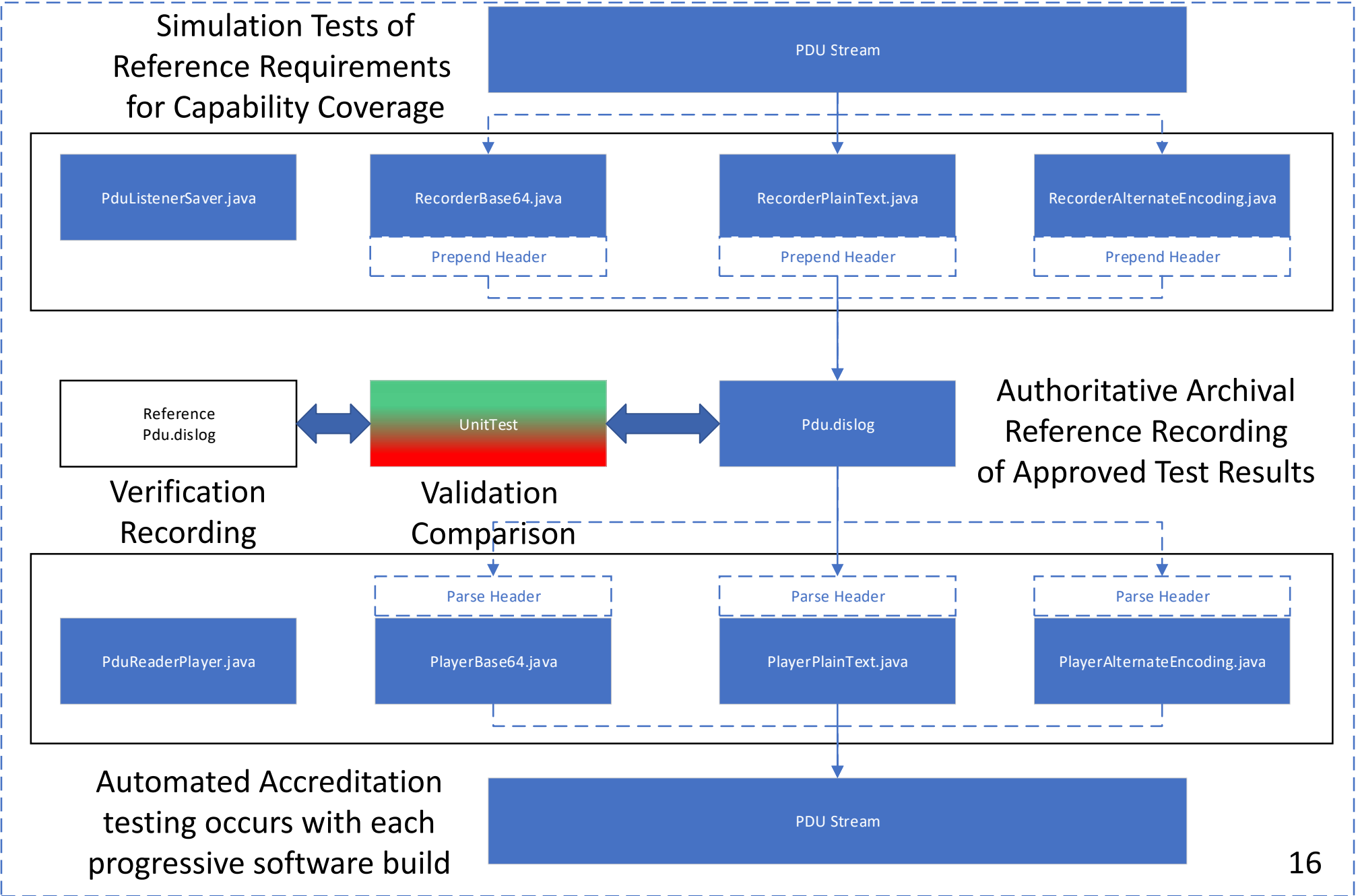
```
> Frame 17267: 186 bytes on wire (1488 bits), 186 bytes captured (1488 bits) on interface
> Ethernet II, Src: Micro-St_2c:0d:15 (00:d8:61:2c:0d:15), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
> Internet Protocol Version 4, Src: 192.168.188.87, Dst: 192.168.188.255
> User Datagram Protocol, Src Port: 3000, Dst Port: 3000
Distributed Interactive Simulation
  > Header
  > Entity State PDU
    > Entity ID
      Entity ID Site: 1
      Entity ID Application: 2
      Entity ID Entity: 3
      Force ID: 0
      Number of Articulation Parameters: 0
    > Entity Type, (1:1:225:1:1:3:0)
      Kind: Platform (1)
      Domain: Land (1)
      Country: United States (225)
      Category / Land: Tank (1)
      Subcategory: 1
      Specific: 3
      Extra: 0
    > Alternative Entity Type, (0:0:0:0:0:0:0)
      Kind: Other (0)
      Domain: Other (0)
      Country: Other (0)
      Category: 0
      Subcategory: 0
      Specific: 0
      Extra: 0
    > Entity Linear Velocity
      X: 0
      Y: 0
      Z: 0
    > Entity Location
      X: -2707488,36777687
      Y: -4353666,73524438
      Z: 3781450,32027544
    > Entity Orientation
      Psi: 0
      Theta: 0
      Phi: 0
      Appearance: 0x00000000
    > Dead Reckoning Parameters
      Dead Reckoning Algorithm: Other (0)
      Dead Reckoning Other Parameters: 00000000000000000000000000000000
    > Entity Linear Acceleration
      Entity Linear Acceleration X: 0
      Entity Linear Acceleration Y: 0
      Entity Linear Acceleration Z: 0
    > Entity Angular Velocity
      Entity Angular Velocity X: 0
      Entity Angular Velocity Y: 0
      Entity Angular Velocity Z: 0
    > Entity Marking
      Entity Character Set: Unused (0)
      Capabilities: 0
```

V V & A Possible via Test Streams

Verification

Validation

Accreditation

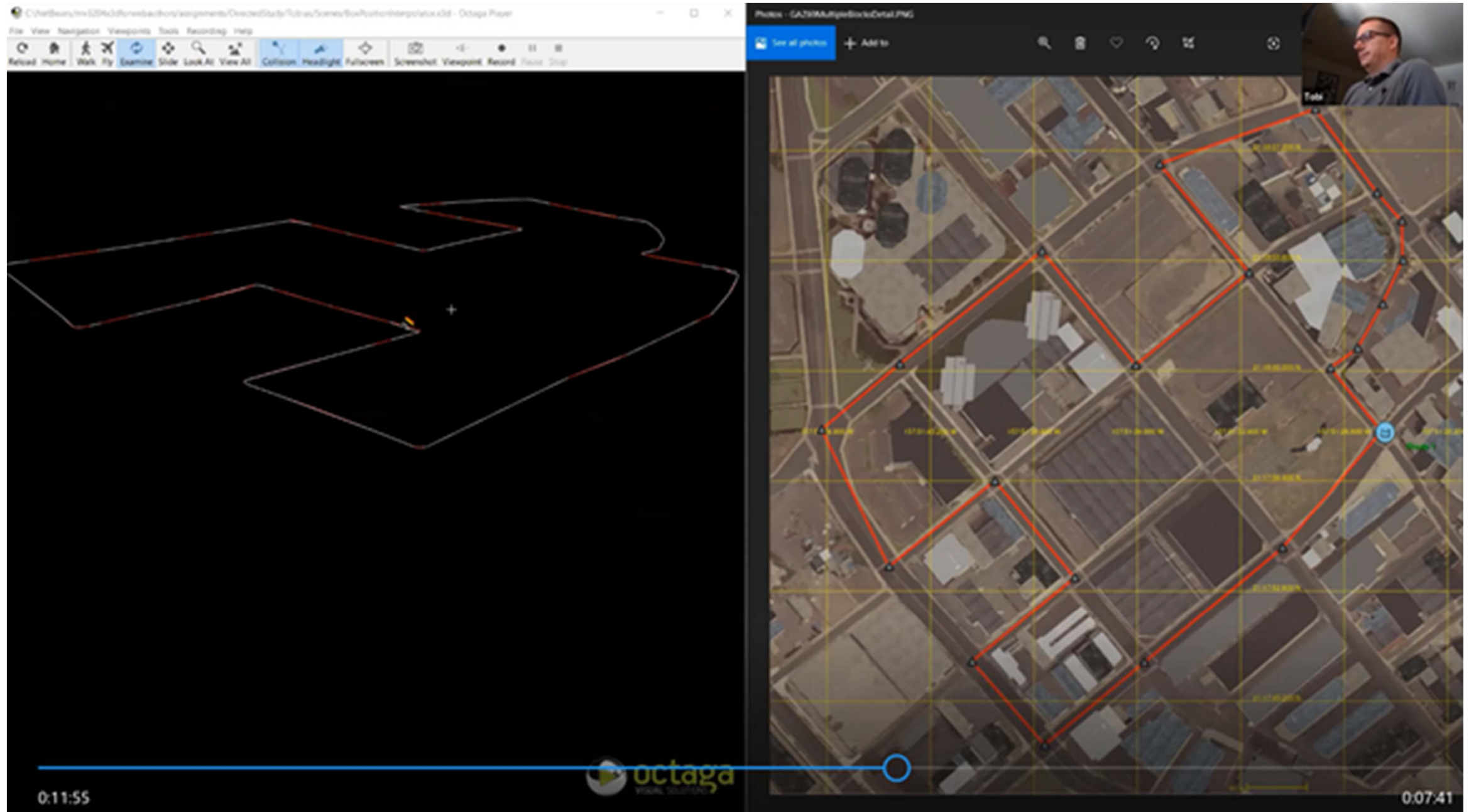


Way Ahead and Future Work

- Further test Java implementation, then create Python, JavaScript
- Expand X3D capture/conversion/replay code for multiple entities
- Further optimization coding of Sliding Window Algorithm
- Assess Spiders3D with JavaScript Virtual Environment Web Server
- Collaborate on distributed LVC models and simulations
 - Take advantage, test campus-wide Multicast capability
 - Test with #Xj3D Java-based X3D browser
 - Explore possible HPC network connection to Germany, Poland
 - Consider NATO C2SIM and CWIX 2021 participation



• *Continue Experimentation and Unit Testing!*



THE **MOVES**
INSTITUTE

Thesis, presentation and video demonstration
online at gitlab.nps.edu

Asset Availability

OpenDIS7 Java

- <https://github.com/open-dis/open-dis7-java>
- <https://github.com/open-dis/open-dis7-source-generator>

Open-source Java codebase with

- Full set of 72 IEEE DIS PDUs,
- 27,000 DIS Enumerations, and
- Complete [DIS7 XML Schema](#)

MOVES MV3500 course Network Simulation

- <https://gitlab.nps.edu/Savage/NetworkedGraphicsMV3500/-/blob/master/README.md> (with [Brennenstuhl thesis assets](#))

Extensible 3D (X3D) Graphics International Standard

- <https://www.web3D.org/what-x3d>

SPIDERS3D Naval Virtual Environment

- <https://gitlab.nps.edu/Savage/Spiders3dPublic/-/blob/master/README.md>

Tobias Brennenstuhl Thesis Availability

REPEATABLE UNIT TESTING OF DISTRIBUTED INTERACTIVE SIMULATION (DIS) PROTOCOL BEHAVIOR STREAMS USING WEB STANDARDS, Tobias Brennenstuhl, Masters Thesis, NPS, June 2020, <https://calhoun.nps.edu/handle/10945/65436>

Abstract. The IEEE Distributed Interactive Simulation (DIS) protocol is used for high-fidelity real-time information sharing among simulations and trainers across the entire international Modeling and Simulation (M&S) community. If archivally saved and replayed, DIS streams have the potential to become a valuable source of Big Data. The availability of archived prerecorded behavior streams for replay, adaptation, and analysis can benefit an immense variety of application areas. The computer science principle “a stream is a stream” indicates that data in motion is equivalent to data at rest. This characteristic can enable powerful capabilities for DIS. This thesis presents prototypes to demonstrate how various forms of repeatability are key to gaining improved benefits from DIS stream analysis. Unit testing of DIS behavior streams allows confirmation of both repeatability and correctness when testing all manner of applications, exercises, simulations, and training sessions. A related use case is automated after-action review (AAR) from recorded DIS streams. This thesis also shows how a DIS stream is converted into autogenerated code that can animate an X3D Graphics model. Many obstacles were overcome during this work, and so various best practices are provided. Of note is that unit testing might even become a contract requirement for incrementally developing and stably maintaining Live Virtual Constructive (LVC) code bases. Recent progress includes autogeneration of all SISO enumerations as Java classes and development of a complete type-safe XML Schema for a DIS-XML encoding as well. This progress provides many opportunities for future work including C-DIS and DISv8 activity.

Questions and contributions always welcome!

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tdnorbra@nps.edu