New File Format for 3D Printing, its extensions and applications

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Abstract

STL has been used as the 'de facto' standard for over 20 years. New file format called AMF was developed in order to overcome numbers of limitations of STL. The author reports his brief interpretations of AMF, applications using the current AMF, and ideas of extensions for next version AMF.

1. Background

In the world of 3D Printing, STL (Stereolithography, Standard Triangulated Language, Standard Tessellation Language), which was originally proposed by 3D systems, has been used as the 'de facto' standard for over 20 years. The original specification is still available:
http://www.fabbers.com/tech/STL_Format

STL is very simple, since a file consists of a list of only facet data. STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. Needless to explain, however, recent progress of 3D Printing machines is going far beyond coverage of STL.

The group called "STL2.0"
(https://groups.google.com/forum/#!aboutgroup/stl2) had started in this context. This is an informal ASTM-driven group for discussion of a new file-format for 3D Printing, which was supposed to replace the de-facto STL standard (Of course, also to keep connecting to STL).

While discussion is still on going, a new file format called AMF (Additive Manufacturing Format) was successfully published out of fruitful discussion, and globally launched with authorizations by ASTM and ISO. Dr. Hod Lipson has been leading the discussion for many years.

2. Basic features of AMF

AMF is a new XML-based standard with native support for curved surface, color, multiple materials, internal meso-structure, constellations, and metadata. It overcame major limitation of STL.

Overview is available at:
https://en.wikipedia.org/wiki/Additive_Manufacturing_File_Forma t
Official Specification of AMF 1.2 is available at:
www . astm.org / Standards / ISOASTM52915.htm

According to the overview on wikipedia, 6 of key considerations are explained:

(1) Technology independence:
The file format must describe an object in a general way such that any machine can build it to the best of its ability. It is resolution and layer-thickness independent, and does not contain information specific to any one manufacturing process or technique. This does not negate the inclusion of properties that only certain advanced machines support (for example, color, multiple materials, etc.), but these are defined in such a way as to avoid exclusivity.

(2) Simplicity:
The file format must be easy to implement and understand. The format should be readable and editable in a simple text viewer, in order to encourage understanding and adoption. No identical information should be stored in multiple places.

(3) Scalability:
The file format should scale well with increase in part complexity and size, and with the improving resolution and accuracy of manufacturing equipment. This includes being able to handle large arrays of identical objects, complex repeated internal features (e.g. meshes), smooth curved surfaces with fine printing resolution, and multiple components arranged in an optimal packing for printing.

(4) Performance:
The file format must enable reasonable duration (interactive time) for read and write operations and reasonable file sizes for a typical large object.

(5) Backwards compatibility:
Any existing STL file should be convertible directly into a valid AMF file without any loss of information and without requiring any additional information. AMF files are also easily convertible back to STL for use on legacy systems, although advanced features will be lost.

(6) Future compatibility:
In order to remain useful in a rapidly changing industry, this file format must be easily extensible while remaining compatible with earlier versions and technologies. This allows new features to be added as advances in technology warrant, while still working flawlessly for simple homogenous geometries on the oldest hardware.

On the premise of current 3D-Printing environment, it is apparent that design process of product includes design considerations on all the aspects of an object- color, material, shape and form. Moreover, AMF can define graded materials. Since this is new notion of an object, this could change designer's common sense, and work as a trigger to explore new designs.

Also, improvements on geometric representations such as sophisticated curved surface is highly welcomed by people who are working with high-accuracies of mechanical parts. Projects on metal printing are very active in some countries. For example in Japan, national project called TRAFAM (Technology Research Association for Future Additive Manufacturing; https://trafam.or.jp/) is trying to develop the novel metal-printing-machine for industry-use. They are planning to adopt AMF.

Finally, if we compare the uniqueness of 3D-Printing with other manufacturing methods, the most important feature is about internal meso-structure. It has been impossible by other manufacturing method such as milling and molding-and-casting. AMF allows us to define internal structures by mathematical functions/equations. That enables us to assign lattices, honeycomb or other infill patterns as intenal meso-structures with reasonable size of data. Fig.1 shows a "gyroid" structure, which was 3D-printed in my laboratory.

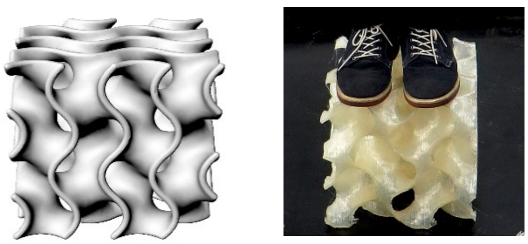

Figure1. 3D-Printed Gyroid Unit

$$\sin x \cos y + \sin y \cos z + \sin z \cos x = 0$$

In AMF, we can use <metadata> tag to define author, software, name, revisions and so on. While data encryption and copyrights are still under discussion, the importance of those information is recognized by industries. 3D-Printing is becoming not only for prototyping, but also for final products.

<metadata type="Author">Hiroya Tanaka</metadata>
<metadata type="Software">VoxCAD</metadata>
<metadata type="Name">Gyroid</metadata>
<metadata type="Revision">2.0</metadata>

3. Application.I – AMF embedded in a physical object

Once a 3D object was printed out from 3D data in AMF (with 3D-printer), after that we wouldn't get AMF from a 3D object itself any more. An object and its data are not coupled, not linked, not referred. But if we'd like to transport, give or sell a 3D printed object, anyway we need 'product information' to ensure, or make a trust. In general, product information can be printed as 2D barcode or QR-Code and attached on the surface of an object. But since 3D Printed parts are often curved and complex, 2D printed tags don't fit to that case.

To solve this problem, we developed RFID-embedding 3D Printer to save AMF data directly into a RFID tag in an object, while printing.

Our previous paper [1] describes our concept and implementations in detail. We use a small RFID tag to write a simple URL and embed it onto an object. Our original android application can read/write URL from RFID in an object, and the URL indicates the address of AMF. So we can derive 3D data, material data, author, name, date and instructions on how to use a product. This also can contribute to traceability.

In the world of RFID/IoT, PML(Physical Markup Language)[2] is already designed for this purpose. Compatibility between PML and <matadata> tags in AMF is required for the further applications.

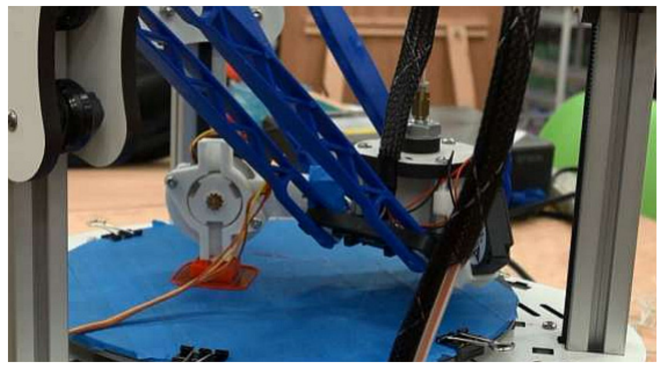

Fig.2 RFID-Embedding 3D Printer:
Video is available at :
https://www.youtube.com/watch?v=Idsc57BB_CQ

4. Application.II – 3D contents for educational use

Another trend in 3D data is the emergence of 'open' 3D data mainly for educational use. The Smithsonian Museum [3] and the British museum [4] have published 3D scanned data of their archived art pieces. NIH [5] and NASA [6] have set up the website for 3D open data. At the current stage, most of open 3D data are still in STL.

For making use of new features of AMF, we developed web-based STL-AMF converter/Editor. It doesn't matter to convert geometry data in STL to it in AMF, it can be processed automatically. After that, our editor enables users (especially young kids) to paint favorite colors on the surface of an object. Also, It enables users (especially teachers and parents) to add additional information onto specific areas.

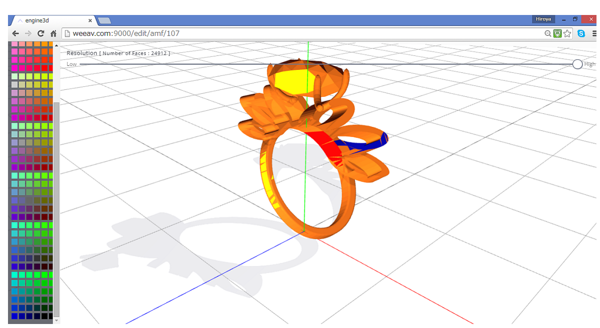

Figure.3 STL-AMF converter/Editor

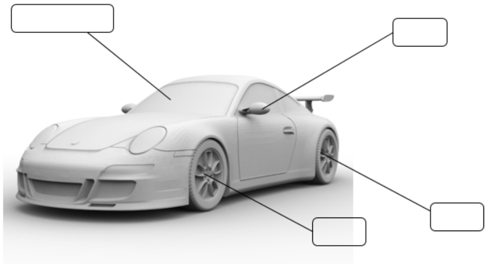

Figure.4 Annotaion tags on a car model

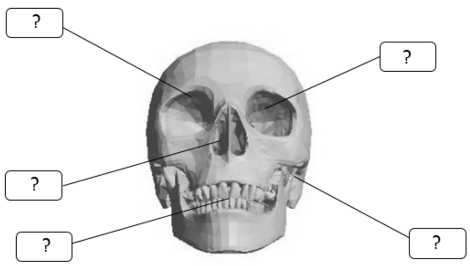

Figure.5 Annotation tags on a skull model.

Web-3D technology is also rapidly growing. HTML5 has lots of new features, today we don't need any plugins to see 3D with javascript. Some of CAD/CAE/CAM software run on the browser, not as a local software. OS-independent approach is welcomed by many people.

Through our method, we would finally get beautiful 3D pictorial contents. Further application out of this approach is 3D-search by annotations. If users add a precise annotation like "eyes" or "body" or "legs", we can retrieve a specific region in a 3D data, and compare several regions with the same annotation.

5. Discussion on Voxels

When users would like to define an internal mesostrucure, not only mathematical equations but also 3D-bitmap pattern is available. By using this method, and combining other methods, we can define a voxel-like structure. However, those types of voxel representation are limited to repetitive structural pattern.

Voxel data derived from medical imaging such as CT and MRI is non-repetitive 3D bitmap (DICOM and OsiriX are standard). And when we consider the easiest modelling method for kids, voxel model is highly recommended. MineCraft is a very popular game to construct 3D voxel models.

Voxel is also suitable for FEA and other simulation methods.
Thus on one hand, voxel is expected for the next version of AMF. But on the other hand, in general, voxel is challenged in both their scalability and their resolution dependency. When it comes to Doxel (Dynamic voxel, 3D bitmap with time dimension), the size of a file would be much greater than simple voxel.

When we look back on the history of data format for 2D, we always have two different thread- raster and vector. While STL and AMF are on the thread of vector format, we still need a new standard for raster (bitmap) for 3D.

	.binvox	.svx	.vxc	.vol
Material	×	○	○	(×)
Color	×	○	○	(○)
Shape definition of voxel	×	×	○	(×)
Linking between voxels	×	×	×	(×)

Table.1 Voxel file format

	VoxCad	Monolith	VCAD	MagicaVoxel
modelling	△	○	(×)	○
simulation	○	○	◎	×
material	○	×	?	×
color	○	○	○	○

Table.2 Voxel modelling software

VoxCAD (.vxc) www.voxcad.com/
binVox (.binvox) http://www.cs.princeton.edu/~min/binvox/
abFab3D (.svx) http://abfab3d.com/
Monolith (.vox) http://www.monolith.zone/features
MagicaVoxel http://3dnchu.com/archives/magicavoxel/
VCAD[8] http://www.riken.jp/vcad/

Table.1 and Table.2 shows our survey on existing voxel file formats and voxel based modelling softwares. Through this survey, we found that voxel is useful for both CAD and CAE, but in the data level, connections between those two are not enough. In general, if we use CAE, we have to define linkages between voxels. However, there are no file format contains linkages with voxels. So now we are trying to design new "linked" voxel format called "fav" (fab voxels).

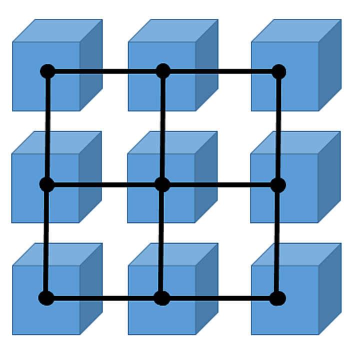

Figure6. the linked voxels model (.fav)

This feature would also contribute to CAM software. In CAM, we have to make a toolpath from an object. If an object is defined as an accumulation of huge numbers of voxels, toolpath can be defined as a set of linkages between one voxel to another. Problem about this approach is about the size of data. In order to overcome this, we are now doing a research on new compression algorithm.

6. Conclusions

There are many 3D formats in the world. On the one hand, CAD community is using CAD model, XVL is a compression of CAD model, NC-STEP is widely used for CAM. Adobe 3DF can transfer a 3D CAD –embedded PDF.

On the other hand, Microsoft consortium was started with a new file format “3MF”, probably being compatible with other 3D VR/AR devices.

3D could be a crossing point between “manufacturing” community and “Digital Contents (AR/VR/Entertainment)” community. But in any case, Web infrastructure is so powerful in this era. I think the most valuable aspect of AMF is that it is based on ‘XML’. We can extend this format, explore new Web-services using AMF, and propose XML-based voxel standard.

References

[1] “RFID 3D Printer Printing Objects that Connote Information”, Ken Fujiyoshi, Chihiro Fukai, Hiroya Tanaka, Jun Murai, and Jin Mitsugi, Keio University, NIP30, 2014.

[2] PML (Physical Markup Language): http://web.mit.edu/mecheng/pml/overview.htm

[3] The Smithonian Museum : 3d.si.edu

[4] British museum: https://sketchfab.com/britishmuseum?utm_source=oembed&utm_medium=embed&utm_campaign=9246efe1279543a784a08be62e6b96a8

[5] NIH: http://3dprint.nih.gov/

[6] NASA: http://nasa3d.arc.nasa.gov/models/printable

[7] http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/4703/Additive-Manufacturing-File-Format-AMF-Allows-for-Volumetric-Specifications.aspx

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Author Biography

Hiroya Tanaka, Ph.D (Engineering), born in 1975, Associate Professor at Keio Univeristy SFC. The Founder of Fab Lab Japan. His research interests cover from 3D CAD/CAE/CAM to a novel 3D Printer. He is now leading the research team of Center of Innovation Programs in Japan, as a director of Keio University Social Fabrication Laboratory.