Best Practice for Multiscale Visualisation in VPH

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1. Introduction

The term “multiscale visualisation” is generally understood to mean that an image or scene contains detail over a range of scales that exceeds the resolution of the display or the human eye. The term encompasses a wide variety of types of data and the techniques required to visualise it; for example, the multiscale may be spatial or temporal; data may be a single image, a multi-object scene, or perhaps a high-resolution graph; and techniques may be required to deal with occlusions, ill-conditioning, levels-of-detail and scene navigation.

VPH projects are confronted by the complexity exhibited in biomedical problems, especially as multiscale data collection and modelling have recently become synonymous with integrative research. Thus, it is likely that multiscale visualisation will be demanded increasingly by VPH projects in coming years. The temporal issue makes this problem even more complicated. So far, there is no unified solution for such a challenging task.

The MSV (Multiscale Spatiotemporal Visualisation) project [1] attempts to provide a viable structure for multiscale visualisation. It is defining a visualisation paradigm for biomedical multiscale data, validating it on the large collections produced by the VPH project, and developing a concrete implementation as an extension to the Visualization Toolkit (VTK), ready to be incorporated by virtually any biomedical modelling software.

While a companion paper [2] presents a general description of the project, this paper looks more closely at the context associated with the multiscale visualisation problems encountered within VPH and the range of visualisation techniques that can be applied to address them. By examining existing best practice, a set of guidelines for designing visualisation approaches to multiscale problems can be developed.

2. Nature of multiscale encountered in VPH projects

When browsing through VPH projects [3], we can identify the highly multiscale nature of the problems being addressed. LHDL provides scales of data from whole body images to nano-CT of bone trabeculae; in the electrical simulation of the Heart (euHeart), a cell electrical model is used for the simulation of the entire electrical activity; in AIRPROM, the airway model comprises integrated micro-scale and macro-scale models informed and validated by omic data and ex vivo models at scales from genome to organ; the VIGOR++ project aims to create a multiscale, personalised GI tract model to facilitate detection of Crohn’s disease; and there are many more such examples. Multiscale problems also exist in the biomedical area outside VPH. One example in which multiscale visualisation is integral to the solution is in simulating and visualising the clotting protein fibrin [4], which requires time-varying visualisation supporting simultaneous user interaction at multiple scales.

Part of the work of MSV has been to investigate how the multiscale nature of such projects is manifested in the data, and the inherent problems it presents. From the large datasets assembled by MSV’s contacts with VPH and other projects, we selected four typical examples to analyse the factors that might be important in determining appropriate techniques for multiscale visualisation. Details are listed in Table 1.

3. Analysis

A number of factors were identified that can help to characterise the form of multiscale inherent in an application: range of spatial scale; range of temporal scale; gaps between scales; size of data; number of target objects; scene structure; occlusions; fibrous structures; periodicity in time; ill-conditioning. We consider techniques that can be used in assessing the impact of the factors and suggesting approaches most suited to the associated visualisation.

Multiscale is characterised by the presence of small detail and a large range of spatial or temporal frequencies, so frequency domain techniques such as Fourier, wavelets and fractal analysis are often useful. The range of spatial scales normally requires no special analysis. With temporal data, Fourier analysis will reveal the frequencies at which activity occurs. However, it does not follow that it is worth inspecting high-frequency features at the highest resolution. More sophisticated methods, such as scale saliency [5], can be applied.

The size of the data and the number of target objects can normally be determined without the need for mathematical techniques. Scene structure is amenable to analysis. Methods exist to construct a hierarchical scene graph from a scene, such as Bounding Volume Hierarchy (BVH) [6] or Oriented Bounding Box Tree. The BVH is constructed by analysing the relative sizes and overlaps of the oriented bounding boxes of objects. Occlusions are important because they cause embedded sub-scale data to be hidden and the BVH is useful for quantifying occlusion. Fibrous structures arise from streamlines in vector fields and their presence is known a priori.

The inspection of periodic time signals is likely to require a gating facility that allows the user to step from one example of a given feature to the next. Gating requires frequency-domain analysis to determine the period of the data and some template matching or heuristics for accurate location of the feature. Ill conditioning can arise when objects are located far from the origin in a much larger scene, and when coordinates in absolute terms are beyond the limits of floating point storage format and the graphics platform.

4. Classification of multiscale techniques

Most of the current multiscale techniques can be grouped under 8 functional components of a multiscale view.

1) *Out-of-core*: Communication between fast internal and slower external memory is a bottleneck in many large-scale applications. Solution include the use of chunking, according to the expected type of query and data access, pre-fetching or the use of a separate thread to overlap rendering with data I/O. Surveys of methods for out-of-core handling of large datasets can be found in [7].
2) *Interaction mode*: Scene-in-hand is the type of interaction most commonly used to interact with objects on a desktop display: the user can rotate, translate and scale the display. The fly-through interaction is that of the user being immersed in the scene and walking or flying through the scene. It is well-suited for large, complex scenes, such as cities. A form of fly-through frequently used in medicine is virtual endoscopy [8].
3) *Indication of sub-scale data*: If sub-scale data is too small to be resolved on the display, one can use placeholder tokens in uncluttered scenes such as slice visualisation [9], annotated call-outs in scenes in which a placeholder token would be occluded, and hyperlinks to indicate metadata. Free-form selection of sub-volumes can be defined interactively for cropping and panels or overlays are useful in cluttered scenes.
4) *Magnification of sub-scale data*: When details of sub-scale are required, the simple and generally applicable way is zooming in. When simultaneous display of scale levels is needed, especially with temporal data, splitting the screen is a good idea. Lensing can also be applied in 3D with the context and connectivity well retained by magnification of details in place [10]. Another applicable way is magnifying call-out [11]; it can both display multiple scale levels simultaneously and preserve the link to global position.
5) *Level of Detail (LoD)*: For mesh data, LoD algorithms include vertex clustering, vertex decimation, quadric error metrics, reverse simplification, image-driven simplification and skip-strips. Also, bundling is needed for streamline bundles, as in fibre clustering, to capture flow features of varying scales [12].
6) *Global context*: Loss of context can cause user confusion when navigating in 3D. In large or complex scenes, external navigation panels, maps, scene hierarchy and overlays are good navigation aids [13] and in fly-through navigation, wayfinding widgets are useful.
7) *Handling of ill-conditionin*g: Placing objects relative to parents in the hierarchy instead of world coordinates or using a mobile origin would reduce the ill-conditioning caused by positioning a small object in a large scene. For scenes with large distances between small objects, power-scaled coordinates [14] provide smooth adaptive speed control. Double precision, if supported by the software/hardware, can be a simple solution**.**
8) *Temporal multiscale*: Temporal zoom expands the time-axis to show the activity at a particular scale. Wavelet analysis can assist the user in locating the times and timescales of interest in the data and time gating can select and track small periodic features over longer timescales [15].

Strictly speaking, multiscale techniques are not visualisation styles in their own right; they generally provide navigation features that are integrated into a view once the user has determined the visualisation style. The design of a multiscale view consists of selecting an appropriate technique (if necessary) for each function.

5. Conclusions

When we consider which multiscale techniques need to be recruited into the visualisation, the features in the data should be carefully identified. We have identified a total of 10 factors, and some formal analysis techniques have been suggested for quantifying them. After that, a series of techniques is briefly described which are grouped into 8 functional components. The design of a multiscale visualisation system then consists of selecting appropriate techniques for the functions needed.

For most applications, multiscale visualisation does not involve specific new techniques, but the complexity of the interaction does demand a unified and carefully planned approach. Currently it takes considerable research and programming effort to create a multiscale visualisation for an application, but with guidelines to provide a suitable infrastructure for design, and a software library that supports a range of multiscale methods, including the possibility to employ different methods at different scales within a single application, with each scale using the approach most appropriate to its needs, multiscale visualisation will become much more amenable to solution. This is what the MSV project aims: a relevant and versatile software library compatible with VTK, and a set of design guidelines building on previous best practice, to make multiscale visualisation more accessible.

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Examples Factors	**LHDL: the human bones**	**euHeart: Electrical simulation of the Heart**	**@aneurist: cerebral aneurysm flow dynamics**	**Fibrin: the clotting protein fibrin**
Range of spatial scales	Dataset has scales from the whole body to the nano-CT bone	Cell electrical model of the heart is used for the whole electrical activity	The vessel meshes are at organ level, simulation results are performed in small regions	The data consists of molecular level, proto fibrils, single fibres, fibres and networks
Range of temporal scales		Temporal scale issues exist due to the rapidity at which activation spreads across the model	The visualisation of fluid interaction requires some time-varying zoom	The molecular dynamics takes place at a scale of ns. So multi temporal scales are needed
Gaps between scales	Micro-CT data is available at a small portion of the bone			Molecular: 5-8 nm wide, 45nm long; Blood clots: mm or cm in size
Size of data	Micro CT data (800 Mb)	Electrical simulation (6 Gb)	CGNS simulation (13.7 Gb). All images(2.2 Gb)	A total of 30 datasets
Number of objects	Each bone is a separate model			30 datasets with different parameters
Scene structure	The objects form a hierarchy			The data has a hierarchical structure
Occlusions	Data from different scales are nested			Data from different scales are nested
Fibrous features			Blood flow simulation uses streamlines	Fibre clutters exist
Periodicity in time		The spiral wave follows a meandering pattern and has periodicity		Force extension simulation has timescales of 100ns and time steps in range of fs
Ill-conditioning	Micro-CT and nano-CT data are registered with the bone			The sizes range from nm, micron to mm/cm

Table 1. Multiscale factors covered in the example datasets

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