gVirtualXRay: Virtual X-Ray Imaging Library on GPU

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About

This project is focused on developing new software technologies for simulating X-ray images on the graphics processor unit (GPU) using OpenGL. It supports 'old' OpenGL implementation as well as modern OpenGL core profile (OpenGL 3.2+). No deprecated function in OpenGL has been used. The library takes care of matrix transformations, matrix stacks, etc.

X-ray simulations created with gVirtualXRay have been used in various applications, including:

- real-time medical simulations for training [1,2,3],
- micro-CT in material science application
  - optimisation for reverse engineering of tungsten fibres [4]
  - study of artefact causes in X-ray micro-CT [5]
- designing new clinical imaging techniques [6]
- teaching particle physics to undergraduate students [7]
- realistic data acquisition simulation in CT imaging with patient respiration [1,8,9].

Please check gVirtualXRay's website at `http://gvirtualxray.sourceforge.net/` for more information.

How to cite

If you use gVirtualXRay, cite both these papers:

1. Vidal, F. P., Garnier, M., Freud, N., Létang, J. M., & John, N. W. Simulation of X-ray attenuation on the GPU. In *Proceedings of Theory and Practice of Computer Graphics 2009*, pages 25-32, Cardiff, UK, June 2009. Eurographics Association. DOI: 10.2312/LocalChapterEvents/TPCG/TPCG09/025-032

```
@article{Vidal2016ComputMedImagingGraph,
  author = "Franck P. Vidal and Pierre-Frédéric Villard",
  title = "Development and validation of real-time simulation of X-ray
imaging
    with respiratory motion ",
  journal = "Computerized Medical Imaging and Graphics ",
  year = "2016",
  volume = "49",
  pages = "1-15",
  month = apr,
  abstract = "Abstract We present a framework that combines evolutionary
    optimisation, soft tissue modelling and ray tracing on \{GPU\} to
    simultaneously compute the respiratory motion and X-ray imaging
in
    real-time. Our aim is to provide validated building blocks with
high
    fidelity to closely match both the human physiology and the physics
of
    X-rays. A CPU-based set of algorithms is presented to model organ
    behaviours during respiration. Soft tissue deformation is computed
with an
    extension of the Chain Mail method. Rigid elements move according
to
    kinematic laws. A GPU-based surface rendering method is proposed
to
    compute the X-ray image using the Beer-Lambert law. It is provided
as an
    open-source library. A quantitative validation study is provided
to
```

```
    objectively assess the accuracy of both components: (i) the respiration
    against anatomical data, and (ii) the X-ray against the Beer-Lambert
law and
    the results of Monte Carlo simulations. Our implementation can be
used in
    various applications, such as interactive medical virtual environment
to
    train percutaneous transhepatic cholangiography in interventional
radiology,
     2D/3D registration, computation of digitally reconstructed radiograph,
     simulation of 4D sinograms to test tomography reconstruction tools.",
  doi = "10.1016/j.compmedimag.2015.12.002",
  pmid = {26773644},
  issn = "0895-6111",
  keywords = "X-ray simulation, Deterministic simulation (ray-tracing),
    Digitally reconstructed radiograph, Respiration simulation,
    Medical virtual environment, Imaging guidance,
    Interventional radiology training",
  publisher = {Elsevier},
  }
```

2. Vidal, F. P., & Villard, P.-F. (2016). Development and validation of real-time simulation of X-ray imaging with respiratory motion. *Computerized Medical Imaging and Graphics*. DOI: 10.1016/j.compmedimag.2015.12.002

```
@inproceedings{Vidal2009TPCG,
  author = {F. P. Vidal and M. Garnier and N. Freud and J. M. L\'etang
and N. W. John},
  title = {Simulation of {X-ray} Attenuation on the {GPU}},
  booktitle = {Proceedings of Theory and Practice of Computer Graphics
2009},
  year = 2009,
  pages = {25-32},
  month = jun,
  address = {Cardiff, UK},
  annotation = {Jun~17--19, 2009},
  note = {Winner of Ken Brodlie Prize for Best Paper},
  doi = {10.2312/LocalChapterEvents/TPCG/TPCG09/025-032},
  abstract = {In this paper, we propose to take advantage of computer
graphics hardware
    to achieve an accelerated simulation of X-ray transmission imaging,
    and we compare results with a fast and robust software-only implementation.
```

```
    The running times of the GPU and CPU implementations are compared
    in different test cases. The results show that the GPU implementation
    with full floating point precision is faster by a factor of about
    60 to 65 than the CPU implementation, without any significant loss
    of accuracy. The increase in performance achieved with GPU calculations
    opens up new perspectives. Notably, it paves the way for physically-
realistic
    simulation of X-ray imaging in interactive time.},
  keywords = {Physically based modeling, Raytracing, Physics},
  publisher = {Eurographics Association},
}
```

Scientific and Industrial Collaboration

If you are interested in any form of collaboration (e.g. to develop your own application) on a paper or grant proposal, drop me an email (f DOT vidal AT bangor DOT ac DOT uk).

Copyright

The source code of gVirtualXRay's is available under the BSD 3-Clause License. For details on use and redistribution please refer to `LICENSE.txt` and `http:/ /opensource.org/licenses/BSD-3-Clause`.

Build and test status of the trunk

gVirtualXRay may be built from source using CMake. It has been successfully tested on the following platforms (compilers):

- MS Windows 10, MS Visual C++ 16 2019
- MS Windows 10, MS Visual C++ 15 2017
- GNU/Linux openSUSE Leap 15.0 (x86_64), g++ 7.4.1
- GNU/Linux openSUSE Leap 15.1 (x86_64), g++ 8.?.?
- Mac OS X 10.13.6, Apple LLVM 9.1.0 (clang-902.0.39.2)
- Mac OS X 10.13.6, GNU gcc 8.3.0
- Mac OS X 10.??, g++ ?.?
- MS Windows 10, cross compilation using MXE on GNU/Linux openSUSE Leap 15.0 (x86_64) and Mac OS X 10.13

It should be possible to build it on other platforms, but this has not been tested.

gVirtualXRay has been successfully tested on the following platforms (graphics cards):

- NVIDIA GeForce 320M (laptop, Mac OS X)
- Intel HD Graphics 4000 (laptop, Mac OS X)
- AMD Radeon X1950pro (PC, GNU/Linux & Windows 10)
- NVIDIA Titan Xp (PC, GNU/Linux)

It should be possible to run it on other platforms, but this has not been tested.

References

1. Sujar, A., Meuleman, A., Villard, P.-F., García, M., & Vidal, F. P. (2017). gVirtualXRay: Virtual X-Ray Imaging Library on GPU. In *Computer Graphics and Visual Computing (CGVC)* (pp. 61–68). DOI: 10.2312/cgvc.20171279
2. Sujar, A., Kelly, G., García, M., & Vidal, F. P. (2019). Projectional Radiography Simulator: an Interactive Teaching Tool. In *Computer Graphics and Visual Computing (CGVC)*. DOI: 10.2312/cgvc.20191267
3. Zuo, Z., Qian, W. Y., Liao, X., & Heng, P. (2018). Position based catheterization and angiography simulation. In *2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH)* (pp. 1–7). DOI: 10.1109/SeGAH.2018.8401369
4. Wen, T., Mihail, R., Al-maliki, shatha, Letang, J., & Vidal, F. P. (2019). Registration of 3D Triangular Models to 2D X-ray Projections Using Blackbox Optimisation and X-ray Simulation. In *Computer Graphics and Visual Computing (CGVC)*. DOI: 10.2312/cgvc.20191265
5. Vidal, F. P. (2018). gVirtualXRay – Fast X-ray Simulation on GPU. In *Workshop on Image-Based Finite Element Method for Industry 2018 (IBFEM-4i 2018)*. DOI: 10.5281/zenodo.1452506
6. Albiol, F., Corbi, A., & Albiol, A. (n.d.). Densitometric Radiographic Imaging With Contour Sensors. *IEEE Access*, 7, 18902–18914. DOI: 10.1109/ACCESS.2019.2895925
7. Corbi, A., Burgos, D., Vidal, F. P., Albiol, F., & Albiol, A. (2020). X-ray imaging virtual online laboratory for engineering undergraduates. European Journal of Physics, 41(1), 1–31. DOI: 10.1088/1361-6404/ab5011
8. Vidal, F. P., & Villard, P.-F. (2016). Development and validation of real-time simulation of X-ray imaging with respiratory motion. *Computerized Medical Imaging and Graphics*. DOI: 10.1016/j.compmedimag.2015.12.002
9. Simulated Motion Artefact in Computed Tomography. (2015). *In Eurographics Workshop on Visual Computing for Biology and Medicine*. DOI: 10.2312/vcbm.20151228.