Skeletal Animation and skinning

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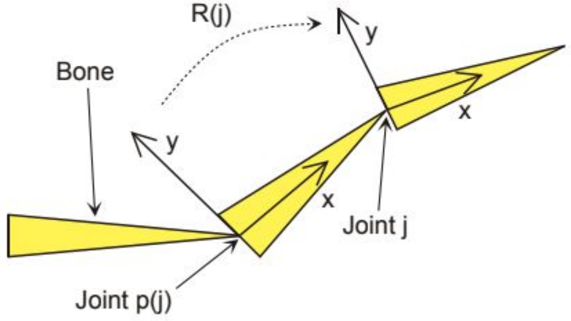
Reference: Ladislav Kavan University of Utah CS 4600 lecture slides

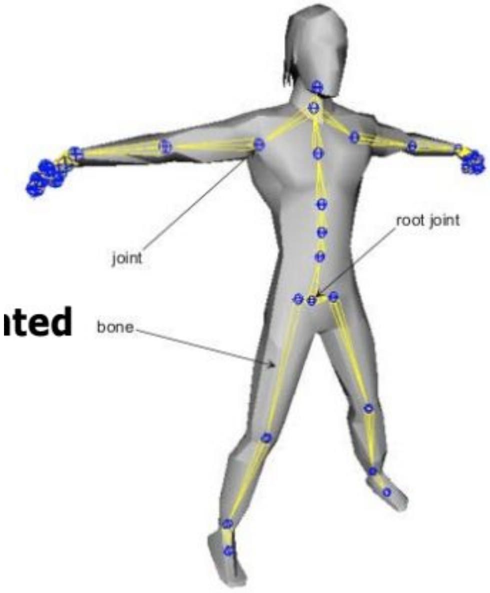
Background

- Project from CS 4600 Computer Graphics
- Animation
  - Skeletal animation (Joints Transformation)
  - Skinning
- Using Visual Studio community 2017
- Parallelize with TBB
- OpenGL 1.0 to render animation
- 8 Cores

Skeletal Animation

- Skeleton is represented by a tree of nodes(joints) and edges (bones)
  - Joints are local coordinate systems (frames)
- Animation (by matrix)
  - Root node (have no parent, value in parent matrix = -1)
  - Rest pose matrix(R)
  - Transformation matrix (T)
    - Includes rotation and translation
  - Animation pose matrix (F)
  - Parent matrix (p)
- Goal is to compute animation matrix from Rest pose and transformation matrix
- Algorithm: F(j) = F(p(j)) R(j) T(j)



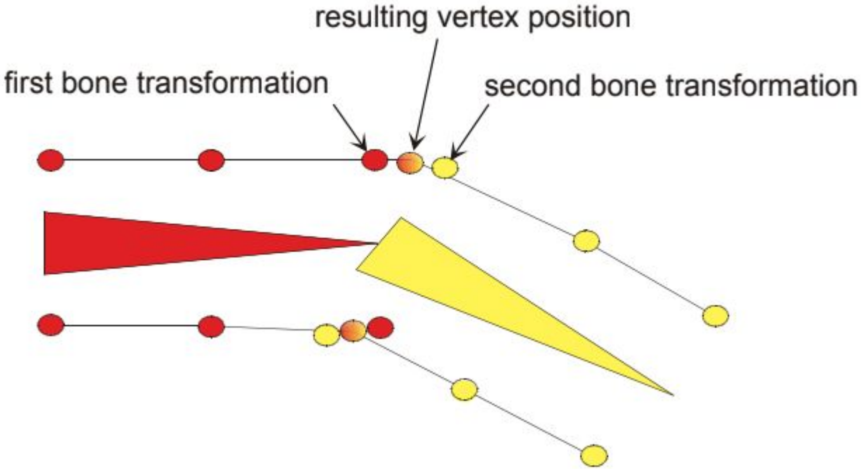


Code

```
void computeJointTransformations(
        const std::vector<Matrix4f>& p_local,
        const std::vector<Matrix4f>& p_offset,
        const std::vector<int>& p_jointParent,
        const unsigned int p_numJoints,
        std::vector<Matrix4f>& p_global,
        int start, int end)
{
        p_global[0] = p_offset[0] * p_local[0];
                for (unsigned int j = 1; j < p_numJoints; j++)
                {
                        p_global[j] = p_global[p_jointParent[j]] * p_offset[j] *p_local[j];
                }
}
```

Linear blend skinning (LBS)

- Each vertex v attached to multiple joints with given weights
- The weight wi describes the amount of influence of joint ji
- Algorithm: v' = sum(W*F(j) *A(j)^(-1)*v)
    - V' - vertex position in the animated pose
    - V - vertex position in the rest pose
    - F(j) - joint transformation matrix
    - A(j)^(-1) - inverse of joint transformation matrix
    - W - Weights for each vertex


resulting vertex position
first bone transformation
second bone transformation

Code (serial)

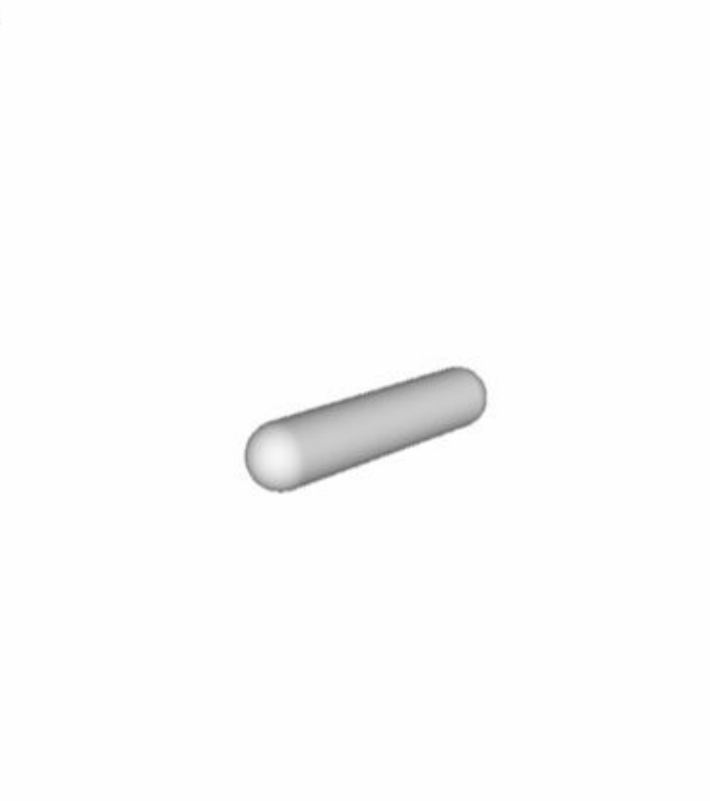
```
void skinning(
    const std::vector<Vector3f>& p_vertices,
    const unsigned int p_numJoints,
    const std::vector<Matrix4f>& p_jointTrans,
    const std::vector<Matrix4f>& p_jointTransRestInv,
    const std::vector<std::vector<float>>& p_weights,
    std::vector<Vector3f>& p_deformedVertices) {

    for (unsigned int v = 0; v < p_vertices.size(); v++) {
    Vector4f tmp;
    tmp.setZero();

    for (unsigned int i = 1; i < p_numJoints; i++) {
        tmp += p_weights[i - 1][v] * p_jointTrans[i - 1]
* p_jointTransRestInv[i - 1] * toHomog(p_vertices[v]);
        }
        p_deformedVertices[v] = fromHomog(tmp);
    }
}
```

Code (parallel)

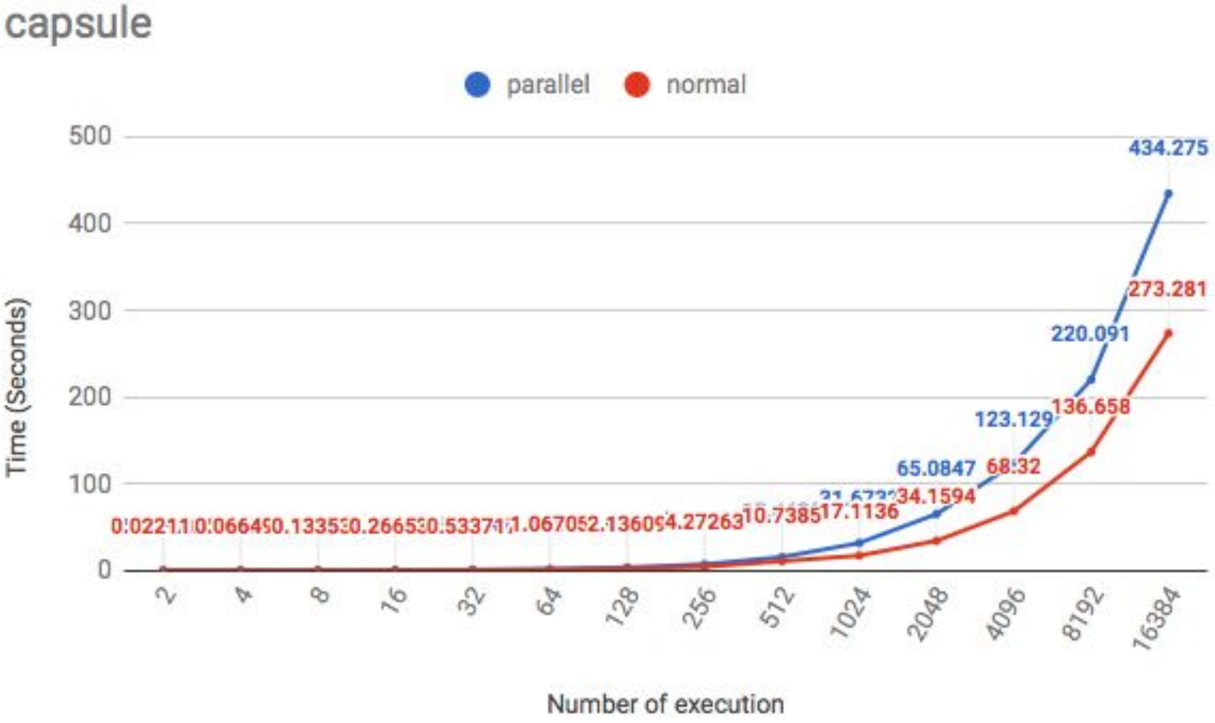
```
void skinning(
        const std::vector<Vector3f>& p_vertices,
        const unsigned int p_numJoints,
        const std::vector<Matrix4f>& p_jointTrans,
        const std::vector<Matrix4f>& p_jointTransRestInv,
        const std::vector<std::vector<float>>& p_weights,
        std::vector<Vector3f>& p_deformedVertices,
        int start, int end) {
        tbb::task_group g;
        if (end < p_vertices.size() - 1) {
                int tmpSize = end - start;
                // start next section
                g.run([=] {skinning(p_vertices, p_numJoints, p_jointTrans, p_jointTransRestInv, p_weights, g_deformedVertices, end, end +
tmpSize); });
        } else {
                end = p_vertices.size();
        }
        for (unsigned int v = start; v < end; v++) {
                Vector4f tmp;
                tmp.setZero();

                for (unsigned int i = 1; i < p_numJoints; i++){
                        tmp += p_weights[i - 1][v] * p_jointTrans[i - 1] * p_jointTransRestInv[i - 1] * toHomog(p_vertices[v]);
                }
                //skinningInnerLoop(p_vertices, p_numJoints, p_jointTrans, p_jointTransRestInv, p_weights, 0, 1, v, tmp);
                p_deformedVertices[v] = fromHomog(tmp);
        }
        g.wait(); }
```

Results

Capsule

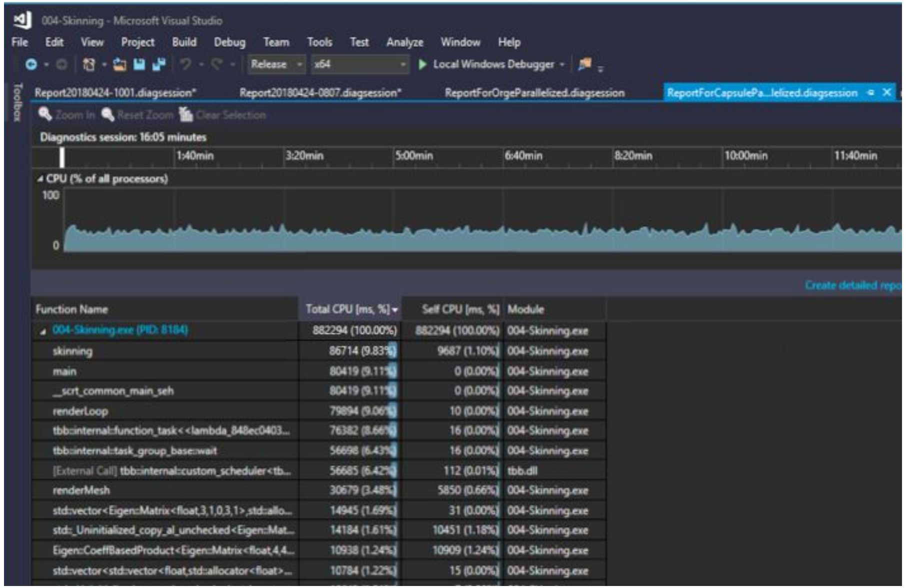


Capsule


capsule
parallel
normal
500
400
300
200
100
0
Time (Seconds)
434.275
273.281
220.091
136.658
123.129
68.32
65.0847
31.673
34.1594
17.1136
10.7385
4.27263
2.13609
1.06705
0.53371
0.26653
0.13353
0.06645
0.02211
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
Number of execution

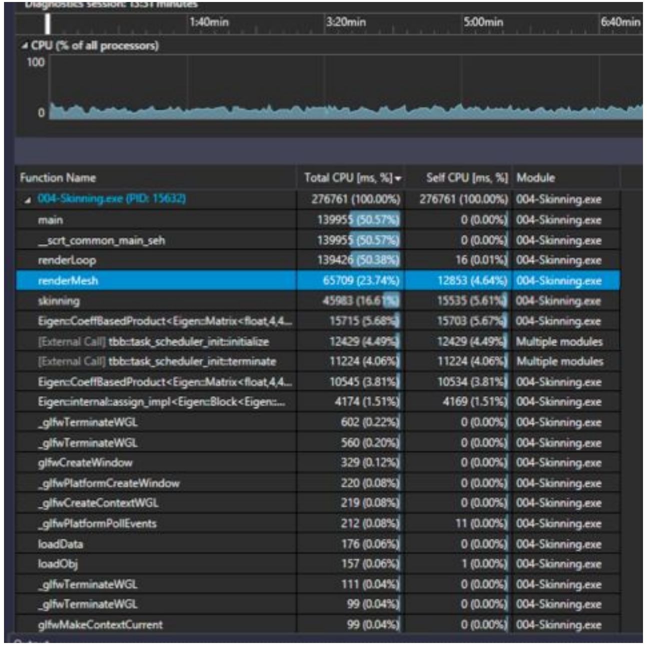
Capsule

Parallel:
Total CPU: 9.83% Self CPU: 1.10%


004-Skinning - Microsoft Visual Studio
File
Edit
View
Project
Build
Debug
Team
Tools
Test
Analyze
Window
Help
Release
x64
Local Windows Debugger
Toolbox
Report20180424-1001.diagsession*
Report20180424-0807.diagsession*
ReportForOrgeParallelized.diagsession
ReportForCapsulePa...lelized.diagsession
Zoom In
Reset Zoom
Clear Selection
Diagnostics session: 16:05 minutes
1:40min
3:20min
5:00min
6:40min
8:20min
10:00min
11:40min
CPU (% of all processors)
100
0
Create detailed repo

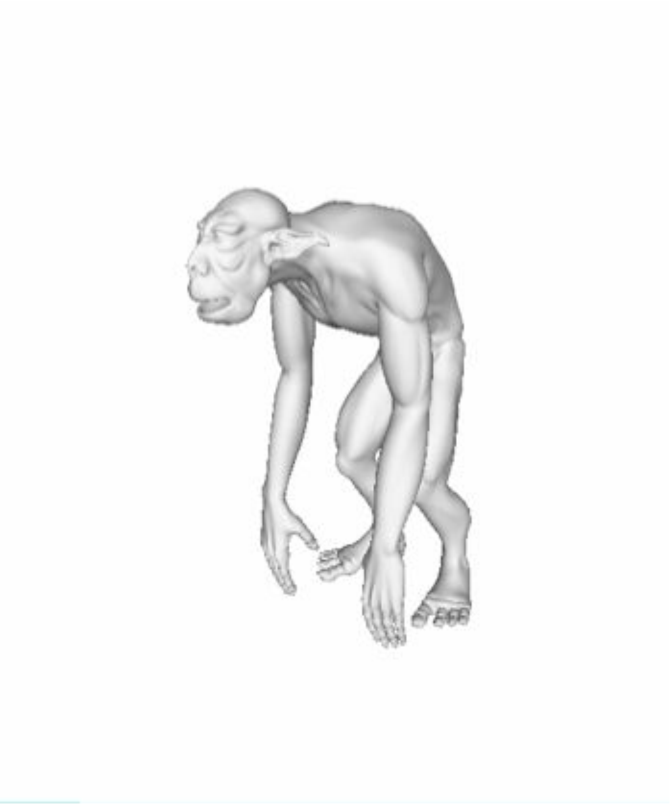
Function Name	Total CPU [ms, %]	Self CPU [ms, %]	Module
004-Skinning.exe (PID: 8184)	882294 (100.00%)	882294 (100.00%)	004-Skinning.exe
skinning	86714 (9.83%)	9687 (1.10%)	004-Skinning.exe
main	80419 (9.11%)	0 (0.00%)	004-Skinning.exe
__scrt_common_main_seh	80419 (9.11%)	0 (0.00%)	004-Skinning.exe
renderLoop	79894 (9.06%)	10 (0.00%)	004-Skinning.exe
tbb::internal::function_task<<lambda_848ec0403...	76382 (8.66%)	16 (0.00%)	004-Skinning.exe
tbb::internal::task_group_base::wait	56698 (6.43%)	16 (0.00%)	004-Skinning.exe
[External Call] tbb::internal::custom_scheduler<tb...	56685 (6.42%)	112 (0.01%)	tbb.dll
renderMesh	30679 (3.48%)	5850 (0.66%)	004-Skinning.exe
std::vector<Eigen::Matrix<float,3,1,0,3,1>,std::allo...	14945 (1.69%)	31 (0.00%)	004-Skinning.exe
std::_Uninitialized_copy_al_unchecked<Eigen::Mat...	14184 (1.61%)	10451 (1.18%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	10938 (1.24%)	10909 (1.24%)	004-Skinning.exe
std::vector<std::vector<float,std::allocator<float>...	10784 (1.22%)	15 (0.00%)	004-Skinning.exe

serial:
Total CPU: 16.6% Self CPU: 4.64%

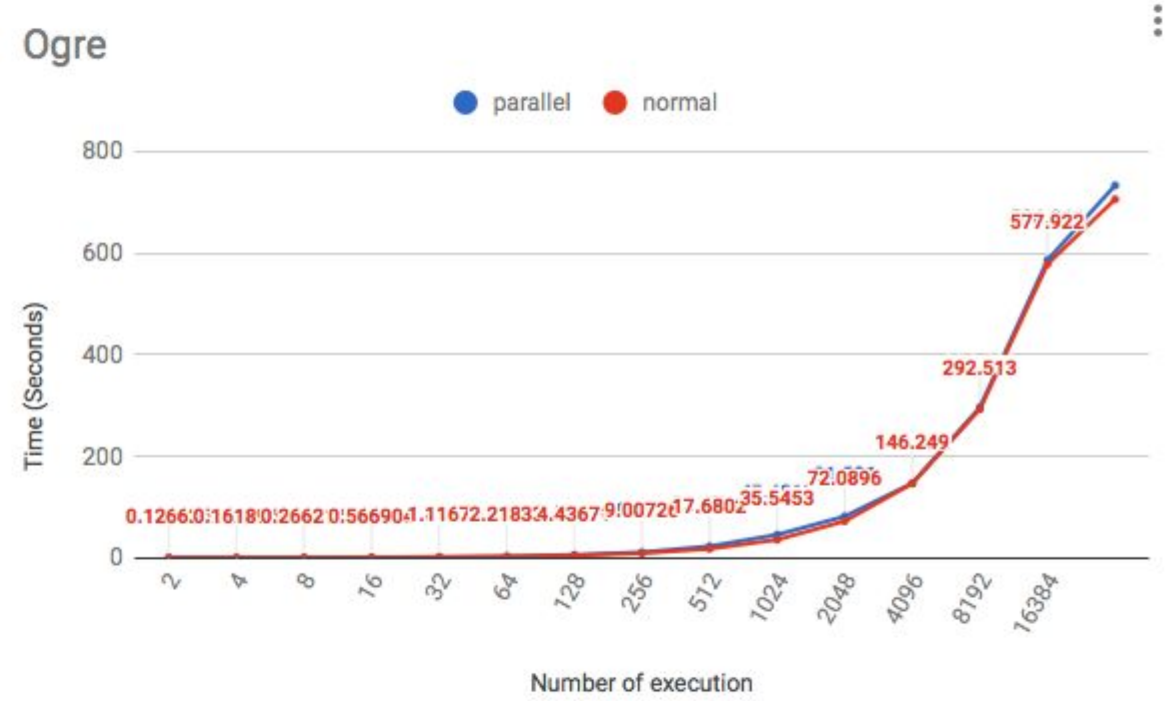


Function Name	Total CPU [ms, %]	Self CPU [ms, %]	Module
004-Skinning.exe (PID: 15632)	276761 (100.00%)	276761 (100.00%)	004-Skinning.exe
main	139955 (50.57%)	0 (0.00%)	004-Skinning.exe
__scrt_common_main_seh	139955 (50.57%)	0 (0.00%)	004-Skinning.exe
renderLoop	139426 (50.38%)	16 (0.01%)	004-Skinning.exe
renderMesh	65709 (23.74%)	12853 (4.64%)	004-Skinning.exe
skinning	45983 (16.61%)	15535 (5.61%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	15715 (5.68%)	15703 (5.67%)	004-Skinning.exe
[External Call] tbb::task_scheduler_init::initialize	12429 (4.49%)	12429 (4.49%)	Multiple modules
[External Call] tbb::task_scheduler_init::terminate	11224 (4.06%)	11224 (4.06%)	Multiple modules
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	10545 (3.81%)	10534 (3.81%)	004-Skinning.exe
Eigen::internal::assign_impl<Eigen::Block<Eigen::...	4174 (1.51%)	4169 (1.51%)	004-Skinning.exe
_glfwTerminateWGL	602 (0.22%)	0 (0.00%)	004-Skinning.exe
_glfwTerminateWGL	560 (0.20%)	0 (0.00%)	004-Skinning.exe
glfwCreateWindow	329 (0.12%)	0 (0.00%)	004-Skinning.exe
_glfwPlatformCreateWindow	220 (0.08%)	0 (0.00%)	004-Skinning.exe
_glfwCreateContextWGL	219 (0.08%)	0 (0.00%)	004-Skinning.exe
_glfwPlatformPollEvents	212 (0.08%)	11 (0.00%)	004-Skinning.exe
loadData	176 (0.06%)	0 (0.00%)	004-Skinning.exe
loadObj	157 (0.06%)	1 (0.00%)	004-Skinning.exe
_glfwTerminateWGL	111 (0.04%)	0 (0.00%)	004-Skinning.exe
_glfwTerminateWGL	99 (0.04%)	0 (0.00%)	004-Skinning.exe
glfwMakeContextCurrent	99 (0.04%)	0 (0.00%)	004-Skinning.exe

Ogre

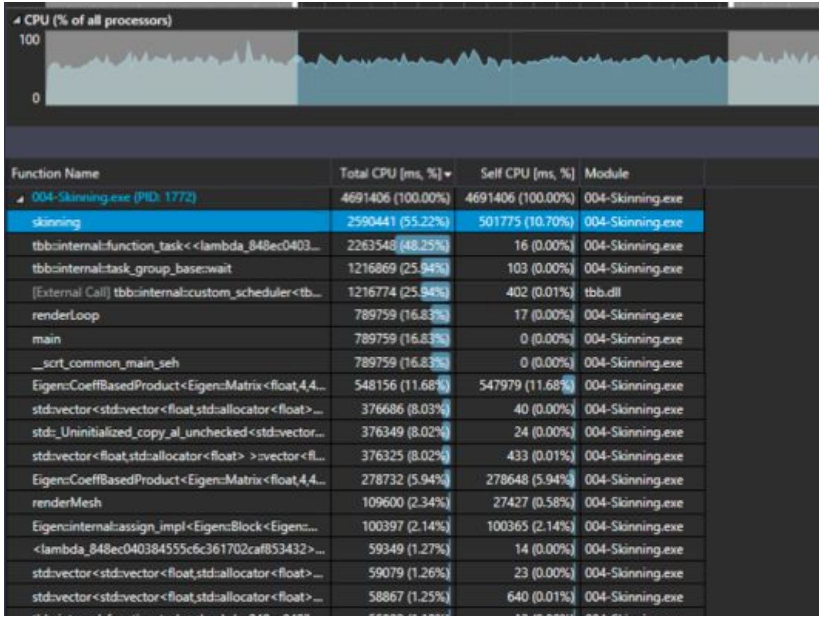


Ogre


Ogre
● parallel
● normal
800
600
400
200
0
Time (Seconds)
0.1266
0.1618
0.2662
0.56690
1.1167
2.2183
4.4367
9.0072
17.6802
35.5453
72.0896
146.249
292.513
577.922
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
Number of execution

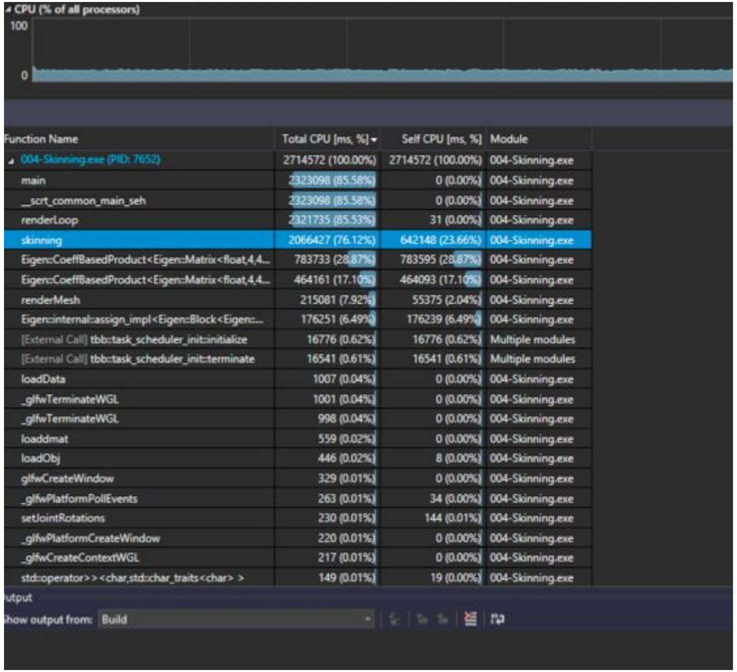
Ogre

Parallel:
Total CPU: 55.22% Self CPU: 10.7%



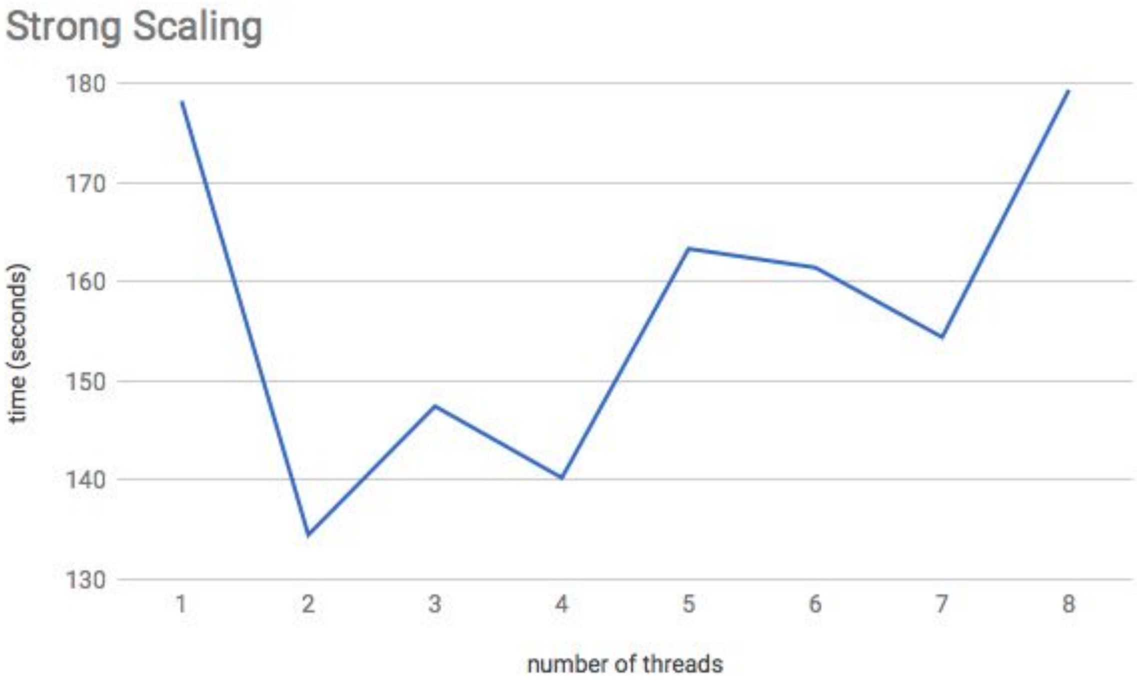
Function Name	Total CPU [ms, %]	Self CPU [ms, %]	Module
004-Skinning.exe (PID: 1772)	4691406 (100.00%)	4691406 (100.00%)	004-Skinning.exe
skinning	2590441 (55.22%)	501775 (10.70%)	004-Skinning.exe
tbb::internal::function_task<<lambda_848ec0403...	2263548 (48.25%)	16 (0.00%)	004-Skinning.exe
tbb::internal::task_group_base::wait	1216869 (25.94%)	103 (0.00%)	004-Skinning.exe
[External Call] tbb::internal::custom_scheduler<tb...	1216774 (25.94%)	402 (0.01%)	tbb.dll
renderLoop	789759 (16.83%)	17 (0.00%)	004-Skinning.exe
main	789759 (16.83%)	0 (0.00%)	004-Skinning.exe
__scrt_common_main_seh	789759 (16.83%)	0 (0.00%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	548156 (11.68%)	547979 (11.68%)	004-Skinning.exe
std::vector<std::vector<float,std::allocator<float>...	376686 (8.03%)	40 (0.00%)	004-Skinning.exe
std::_Uninitialized_copy_al_unchecked<std::vector...	376349 (8.02%)	24 (0.00%)	004-Skinning.exe
std::vector<float,std::allocator<float> >::vector<fl...	376325 (8.02%)	433 (0.01%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	278732 (5.94%)	278648 (5.94%)	004-Skinning.exe
renderMesh	109600 (2.34%)	27427 (0.58%)	004-Skinning.exe
Eigen::internal::assign_impl<Eigen::Block<Eigen::...	100397 (2.14%)	100365 (2.14%)	004-Skinning.exe
<lambda_848ec040384555c6c361702caf853432>...	59349 (1.27%)	14 (0.00%)	004-Skinning.exe
std::vector<std::vector<float,std::allocator<float>...	59079 (1.26%)	23 (0.00%)	004-Skinning.exe
std::vector<std::vector<float,std::allocator<float>...	58867 (1.25%)	640 (0.01%)	004-Skinning.exe

serial:
Total CPU: 76.12% Self CPU: 23.84%

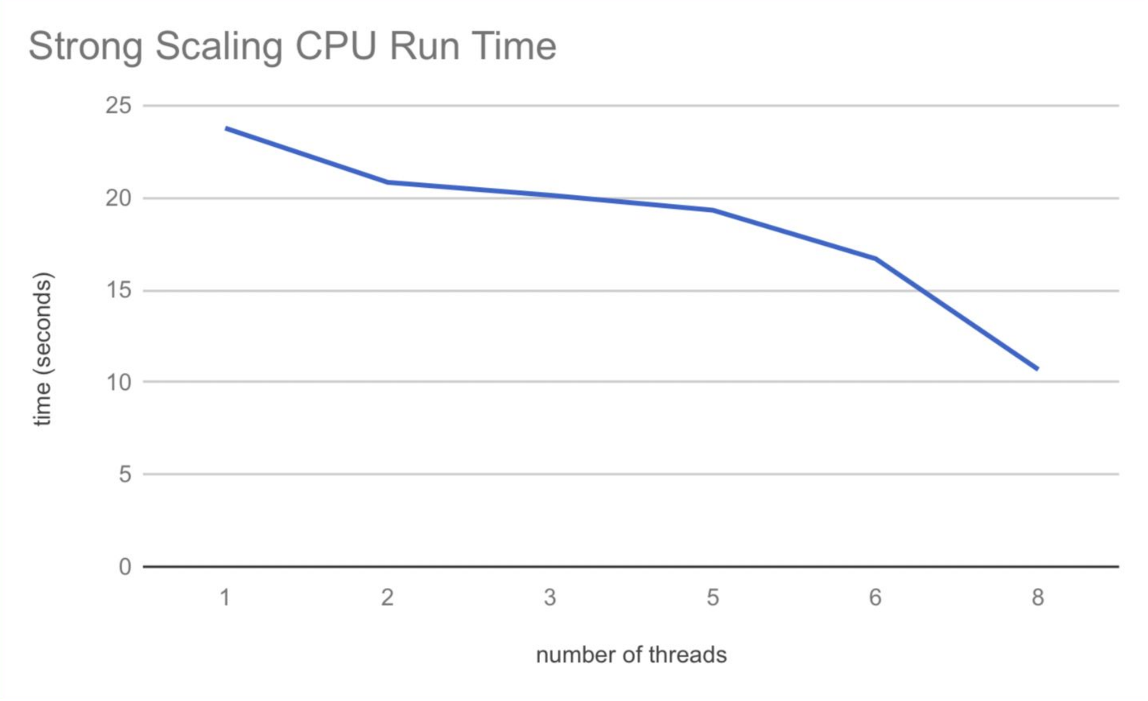


Function Name	Total CPU [ms, %]	Self CPU [ms, %]	Module
004-Skinning.exe (PID: 7652)	2714572 (100.00%)	2714572 (100.00%)	004-Skinning.exe
main	2323098 (85.58%)	0 (0.00%)	004-Skinning.exe
__scrt_common_main_seh	2323098 (85.58%)	0 (0.00%)	004-Skinning.exe
renderLoop	2321735 (85.53%)	31 (0.00%)	004-Skinning.exe
skinning	2066427 (76.12%)	642148 (23.66%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	783733 (28.87%)	783595 (28.87%)	004-Skinning.exe
Eigen::CoeffBasedProduct<Eigen::Matrix<float,4,4...	464161 (17.10%)	464093 (17.10%)	004-Skinning.exe
renderMesh	215081 (7.92%)	55375 (2.04%)	004-Skinning.exe
Eigen::internal::assign_impl<Eigen::Block<Eigen::...	176251 (6.49%)	176239 (6.49%)	004-Skinning.exe
[External Call] tbb::task_scheduler_init::initialize	16776 (0.62%)	16776 (0.62%)	Multiple modules
[External Call] tbb::task_scheduler_init::terminate	16541 (0.61%)	16541 (0.61%)	Multiple modules
loadData	1007 (0.04%)	0 (0.00%)	004-Skinning.exe
_glfwTerminateWGL	1001 (0.04%)	0 (0.00%)	004-Skinning.exe
_glfwTerminateWGL	998 (0.04%)	0 (0.00%)	004-Skinning.exe
loaddmat	559 (0.02%)	0 (0.00%)	004-Skinning.exe
loadObj	446 (0.02%)	8 (0.00%)	004-Skinning.exe
glfwCreateWindow	329 (0.01%)	0 (0.00%)	004-Skinning.exe
_glfwPlatformPollEvents	263 (0.01%)	34 (0.00%)	004-Skinning.exe
setJointRotations	230 (0.01%)	144 (0.01%)	004-Skinning.exe
_glfwPlatformCreateWindow	220 (0.01%)	0 (0.00%)	004-Skinning.exe
_glfwCreateContextWGL	217 (0.01%)	0 (0.00%)	004-Skinning.exe
std::operator>><char,std::char_traits<char> >	149 (0.01%)	19 (0.00%)	004-Skinning.exe

Ogre


Strong Scaling
180
170
160
150
140
130
time (seconds)
1
2
3
4
5
6
7
8
number of threads

Ogre


Strong Scaling CPU Run Time
25
20
15
10
5
0
time (seconds)
1
2
3
5
6
8
number of threads

Questions