Rendering Mirage

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CS482 Fall 2018 Final Presentation

DEMO

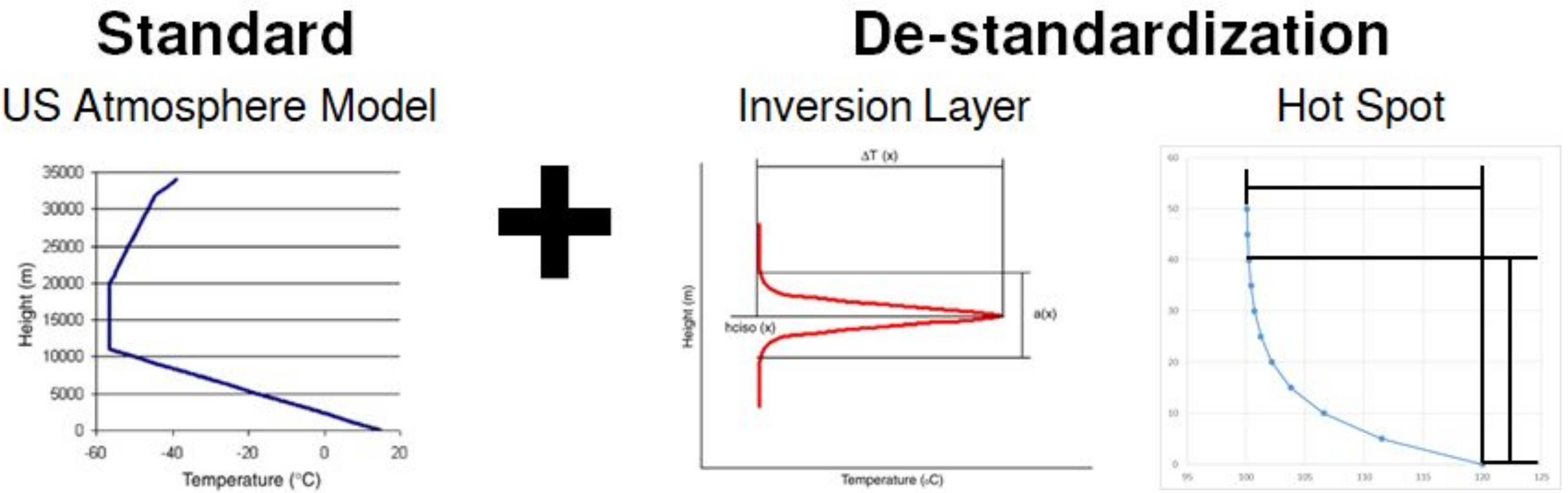
Contents

- Artistic Editing For Mirage Image
- Our Idea
- Challenges
- Implementation

Artistic Editing For Mirage Image

Refractive Index Distribution Model

Adapt **APM**[GSM*06] as a spatial encoding



Images from [GSM*06]

This slide is copied from slides of [Choi 17]

Refractive Index Distribution Model

New formulation suggested for the refractive index distribution: **Logistic Approximation**

$$
\begin{aligned}
n(h) = & \frac{k_s}{|n_{bg}| + |n_{inv}| + |n_{hotspot}|} && \text{Normalize \& Scale} \\
& \cdot \Big(f_{logistic}(n_{bg}, a_{bg}, 0, h) && \text{Background} \\
& + f_{logistic}(n_{inv}, -a_{inv}, h_{ciso}, h) && \text{Inversion Layer} \\
& + f_{logistic}(n_{hotspot}, a_{hotspot}, 0, h) \Big) && \text{Hot Spot} \\
& + 1, && \text{Baseline}
\end{aligned}
$$

$$f_{logistic}(L, k, x_0, x) := \frac{L}{1 + e^{(x_0 - x)/k}}.$$

$$\boldsymbol{k} = \begin{bmatrix} n_{bg} & n_{inv} & n_{hotspot} & h_{ciso} & a_{bg} & a_{inv} & a_{hotspot} & k_s \end{bmatrix}^T$$

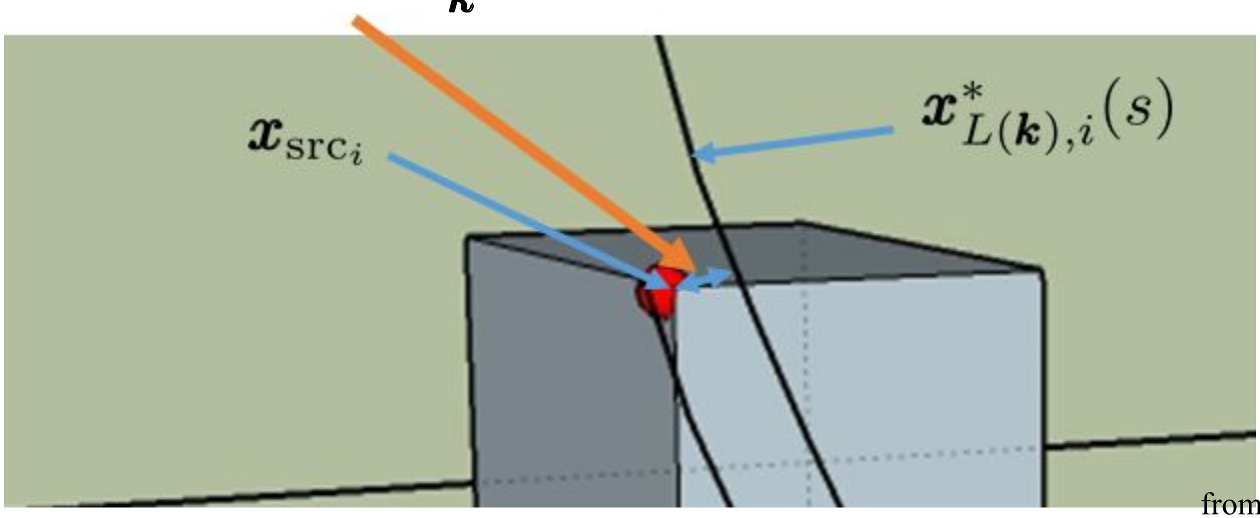
Spatial Encoding and Optimization

- **Cost Function**
  - For i-th pair, spatial encoding **L**, and parameter vector **k**

$$\mathrm{cost}(\boldsymbol{k}) := \sum_i \mathrm{dist}_{L,i}(\boldsymbol{k})$$

  - solve by **Regression**

$$\underset{\boldsymbol{k}}{\mathrm{argmin}}\ \mathrm{cost}(\boldsymbol{k})$$



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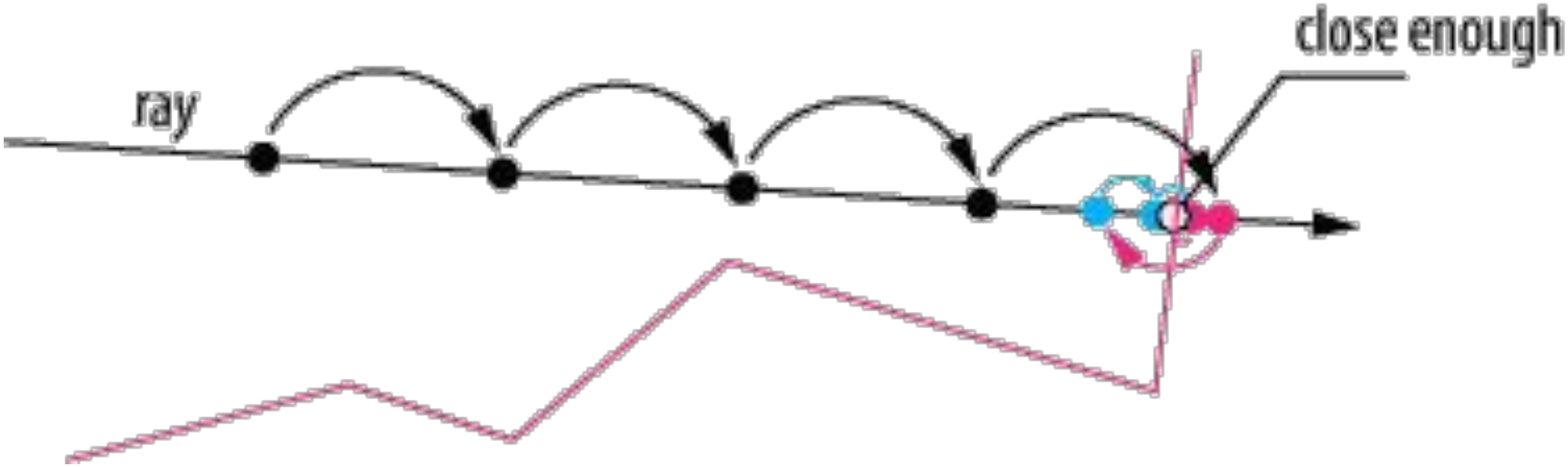
Rendering method

- **Ray-marching algorithm**



$$\frac{d\boldsymbol{v}}{ds} = \nabla_{\boldsymbol{x}} n,$$
$$\frac{d\boldsymbol{x}}{ds} = \frac{\boldsymbol{v}}{n}.$$

[ABW14]

Limitations

- This system is focused on creating static scenes
  - This formulation does not consider **the spatial location** of the hot spot
- Unintuitive UI
- No illumination model

⇒ Unrealistic mirage scenes

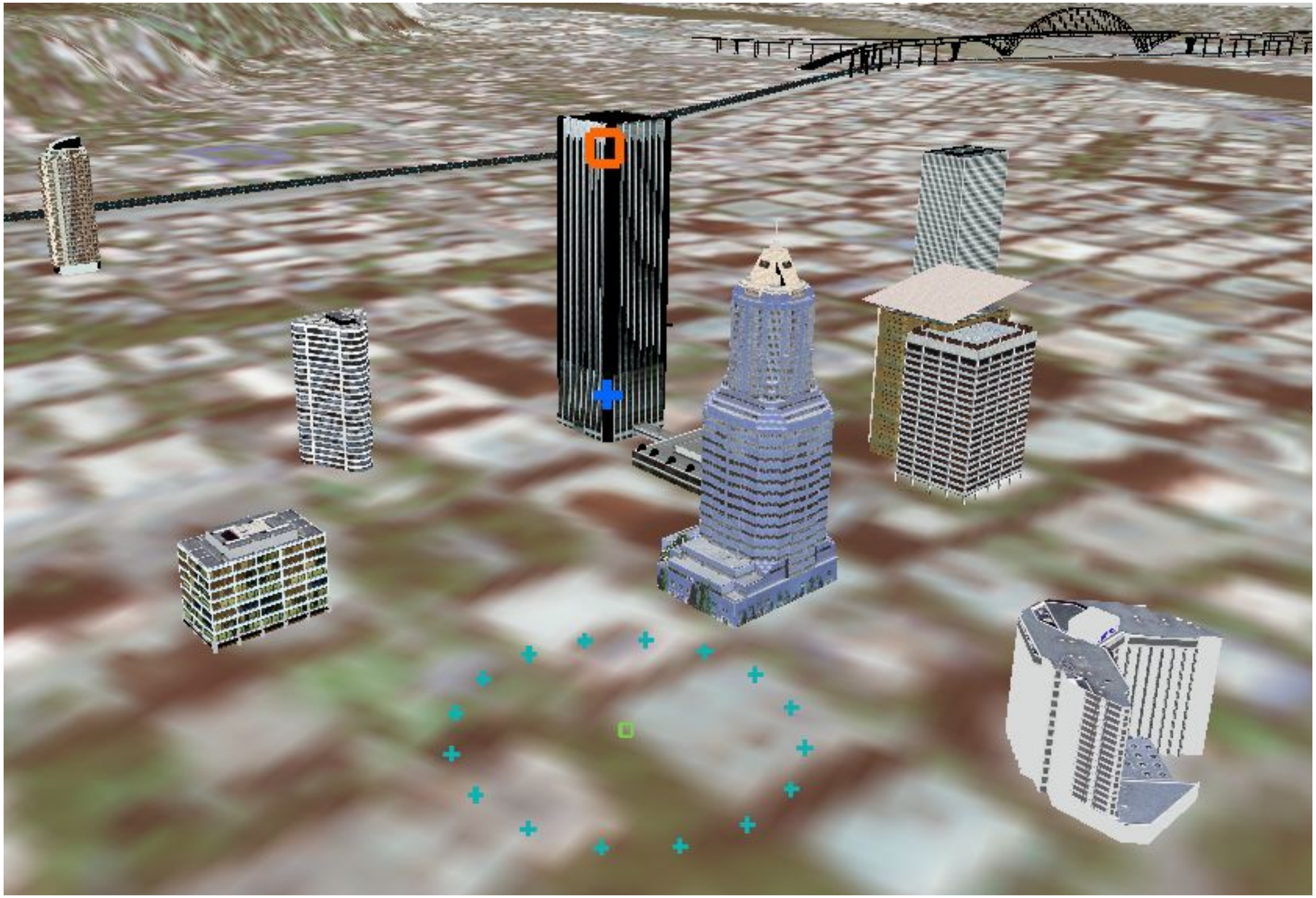
Our Ideas

Areal Hot Spot

Areal Hot Spot

- Hot spot is no longer depends on only height
- Hot spot has a circular shape that can be defined on the surface.
- user can modify its x, z position and radius.
- Optimize additional parameters using the existing optimizer
- By changing the formula to **take into account the area of the hot spot**, You can observe a light path that changes spatially.

Areal Hot Spot



Areal Hot Spot

- Save hotspot information additionally
- Sigmoid as the reduction function in distance
- We introduce new logistic formula to compute areal hot spot exactly.
- We newly compute a derivative of our new logistic function because we use RK4 method to estimate the light path.

Areal Hot Spot

- important point
  - formula 1 : new hotspot
  - $(1 - sigmoid(dist)) * f_{logistic}(n_{hotspot}, a_{hotspot}, 0, h)$
  - formula 2 : derivative of new hotspot
  - previous : 1D formula(h), current : 3D formula(x,y,z)
  - And their counterparts in fragment shader

Symbol	Description
$n_{\mathrm{bg/inv/hotspot}}$	Refractive index difference caused by background/inversion layer/hot spot
h_{ciso}	Height of inversion layer
$a_{\mathrm{bg/inv/hotspot}}$	Rate of change of refractive index for background/inversion layer/hot spot
k_{s}	Scale factor

Areal Hot Spot

```
// Solving numerically using RK4 for 2nd order ODE
void Lightpath::solve2()
{
    path.clear();

    glm::dvec3 dx1, dx2, dx3, dx4, dv1, dv2, dv3, dv4, dx, dv;
    glm::dvec3 x, v;

    x = x_0;
    v = v_0;

    for (double s = s_0; s < s_max; s += step)
    {
        path.push_back(std::tuple<double, glm::dvec3, glm::dvec3>{s, v, x});
        dx1 = step * v / pMedium->f(x);
        dv1 = step * pMedium->gradient(x);
        dx2 = step * (v + dv1 / 2.0) / pMedium->f(x + dx1 / 2.0);
        dv2 = step * pMedium->gradient(x + dx1 / 2.0);
        dx3 = step * (v + dv2 / 2.0) / pMedium->f(x + dx2 / 2.0);
        dv3 = step * pMedium->gradient(x + dx2 / 2.0);
        dx4 = step * (v + dv3) / pMedium->f(x + dx3);
        dv4 = step * pMedium->gradient(x + dx3);
        dx = (dx1 + 2.0 * dx2 + 2.0 * dx3 + dx4) / 6.0;
        dv = (dv1 + 2.0 * dv2 + 2.0 * dv3 + dv4) / 6.0;
        x += dx;
        v += dv;
    }
}
```

RK4 method

$$\frac{d\boldsymbol{v}}{ds} = \nabla_{\boldsymbol{x}} n,$$
$$\frac{d\boldsymbol{x}}{ds} = \frac{\boldsymbol{v}}{n}.$$

Areal Hot Spot

```
double TestModel::f(glm::dvec3 p)
{
    double altitude = p.y;

    double deStd =
        background(altitude) +
        inversionLayer(altitude) /*+
        hotspot(altitude, p)*/;

    for(int i =0; i< hotspotTotalNum; i++)
    {
        deStd += hotspot(altitude, p, hotspotInfo[i], hotspotNs[i], hotspotDropoffs[i]);
    }

    double hotspotNSum = 0;
    for(int i =0; i< hotspotTotalNum; i++)
    {
        hotspotNSum += abs(hotspotNs[i]);
    }

    double deStdNormalized = deStd / (abs(backgroundMaxN) + abs(inversionDeltaN) + hotspotNSum);
    double refrIdx = deStdNormalized * abs(scale) * 0.003 + 1;
    return refrIdx;
}
```

Areal Hot Spot

```
glm::dvec3 TestModel::gradient(glm::dvec3 p)
{
    double altitude = p.y;
    double deStdDeriv =
        backgroundDeriv(altitude) +
        inversionLayerDeriv(altitude) /*+
        hotspotDeriv(altitude)*/;

    glm::vec3 hotspotDerivSum = glm::vec3(0,0,0);
    for(int i =0; i< hotspotTotalNum; i++)
    {
        hotspotDerivSum += hotspotDeriv(altitude, p, hotspotInfo[i], hotspotNs[i], hotspotDropoffs[i]);
    }

    double hotspotNSum = 0;
    for(int i =0; i< hotspotTotalNum; i++)
    {
        hotspotNSum += abs(hotspotNs[i]);
    }

    glm::vec3 deStdDerivNormalized = glm::vec3(0, deStdDeriv, 0) + hotspotDerivSum;
    deStdDerivNormalized /= abs(backgroundMaxN) + abs(inversionDeltaN) + hotspotNSum;

    return deStdDerivNormalized;
}
```

Areal Hot Spot

```
inline double TestModel::hotspot(const double &altitude, const glm::dvec3 p, const std::pair<glm::vec3 *, float
{
    //std::cout << "hotspotDist : " << hotspotDist(hotspot, p) << std::endl;
    return (1 - sigmoid(10 * hotspotDist(hotspot, p))) * logistic(hotspotN, 0.3*hotspotDropoff, 0, altitude);
}
```

```
inline glm::dvec3 TestModel::hotspotDeriv(const double &altitude, const glm::dvec3 p,
{
    // d hotspot / d = - 10 * L * D' * S'.10*D - S.10*D * L'
    // for x and z, l'(y) == 0
    double logis = logistic(hotspotN, 0.3*hotspotDropoff, 0, altitude);
    double logisDeriv = logisticDeriv(hotspotN, 0.3*hotspotDropoff, 0, altitude);
    double dist = hotspotDist(hotspot, p);
    glm::dvec3 distDeriv = hotspotDistDeriv(hotspot, p);

    return glm::dvec3(
        -10 * logis * distDeriv.x * sigmoidDeriv(10 * dist),
        0,
        -10 * logis * distDeriv.z * sigmoidDeriv(10 * dist)
    );
}
```

Areal Hot Spot

```
inline double TestModel::hotspotDist(std::pair<glm::ve
{
    /*
    std::cout <<"hotspotVec : " << (*(hotspot.first)).
    std::cout <<"hotspotVec : " <<  p.x <<  p.y <<  p.
    std::cout <<"hotspotVec : " <<  glm::vec3(p).x <<
    */
    glm::vec3 hotspotPos = *hotspot.first;
    float hotspotRadius = hotspot.second;

    if (glm::isnan(sqrt(
        (hotspotPos.x - p.x)*(hotspotPos.x - p.x) +
        (hotspotPos.z - p.z)*(hotspotPos.z - p.z))))
        return -hotspotRadius;

    return sqrt(
        (hotspotPos.x - p.x)*(hotspotPos.x - p.x) +
        (hotspotPos.z - p.z)*(hotspotPos.z - p.z))
      - hotspotRadius;
```

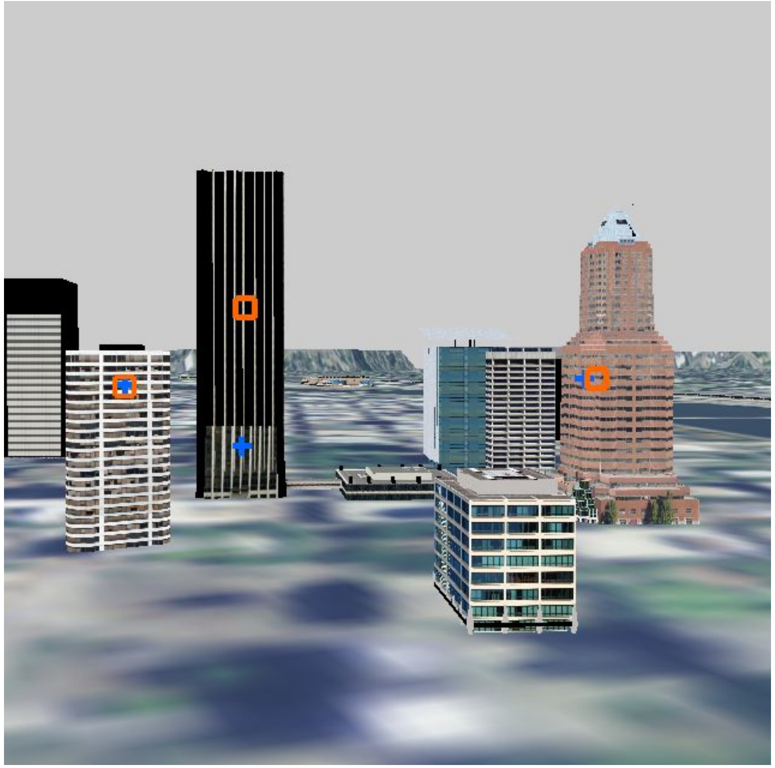
```
inline double TestModel::sigmoid(const double x) const
{
    if (x < 100)
        return (exp(x) / (exp(x) + 1));
    else
        return 1;
}

inline double TestModel::sigmoidDeriv(const double x) const
{
    if (x < 50)
        return (exp(x) / (exp(x) + 1) / (exp(x) + 1));
    else
        return 0;
}
```

```
inline glm::dvec3 TestModel::hotspotDistDeriv(std::pair<glm::vec3 *, float> hotspot, const glm::dvec3 p) const
{
    return (glm::dvec3(*(hotspot.first)) - (p)) / (glm::length(glm::dvec3(*(hotspot.first)) - p));
```

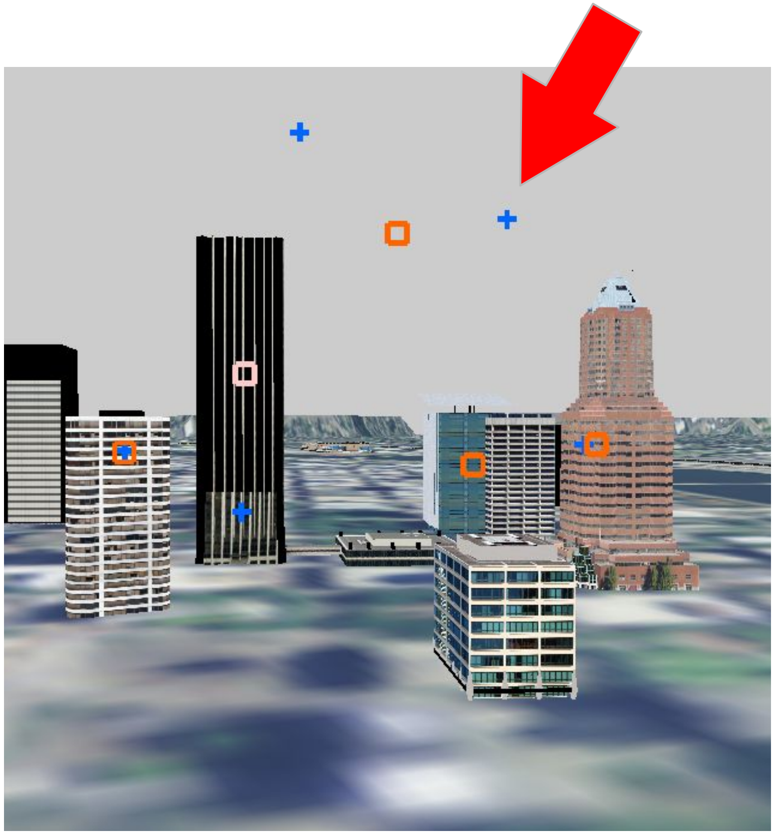
UI Improvements

Better UI

- Point positioning
  - Points can be off surface



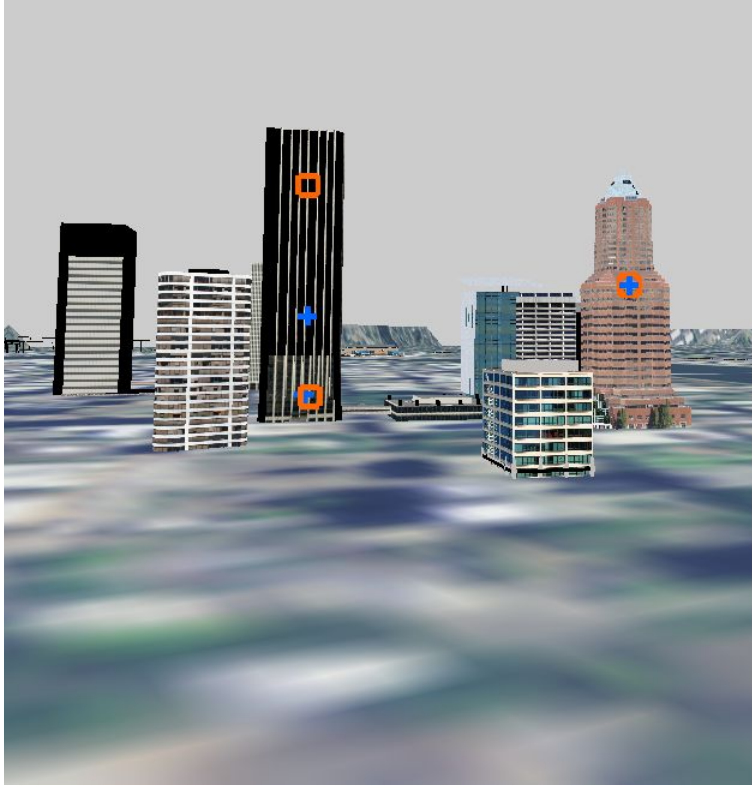
Original



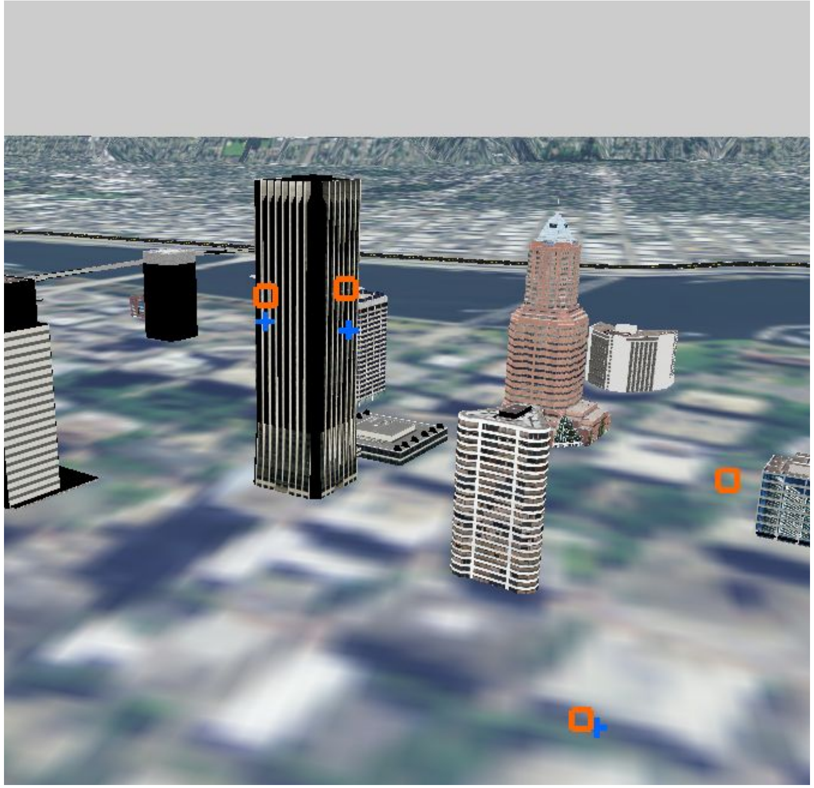
Ours

Better UI

- Free movement during point assignment



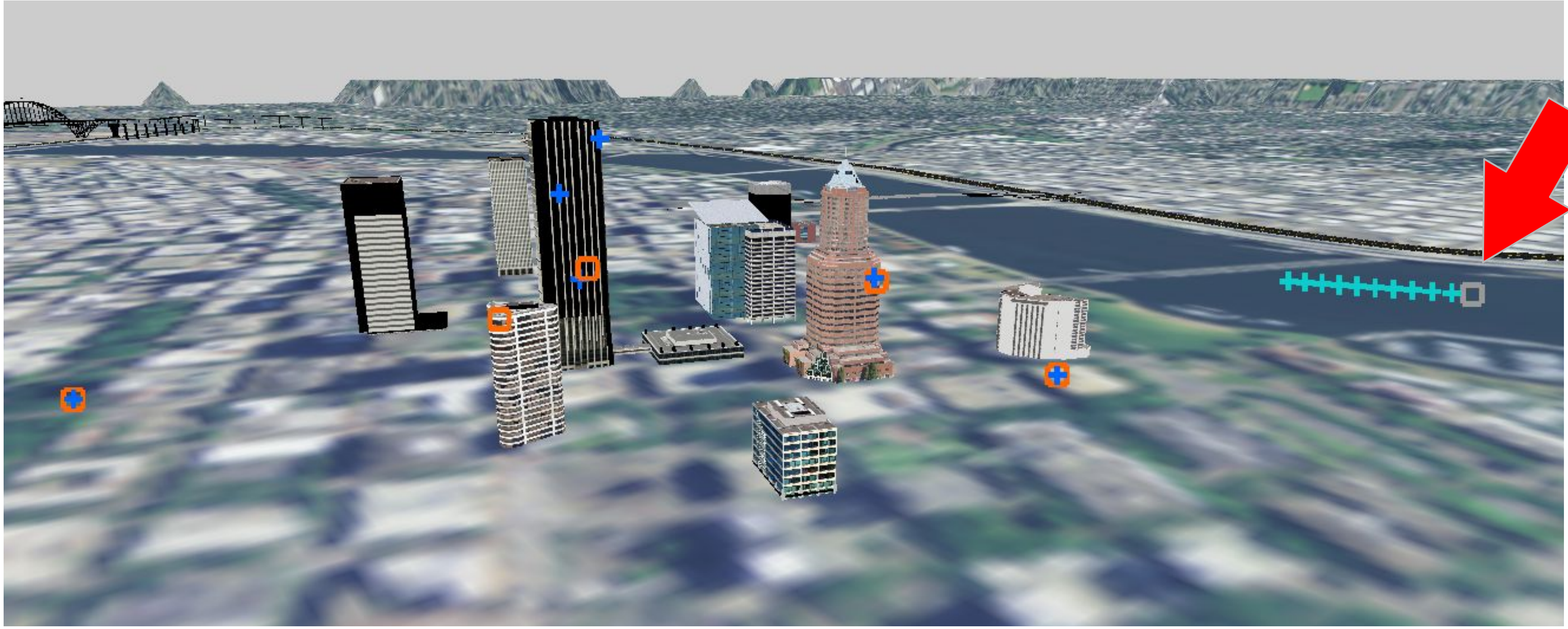
Original



Ours

Better UI

- Camera positioning
  - "C" key for camera positioning



Challenges

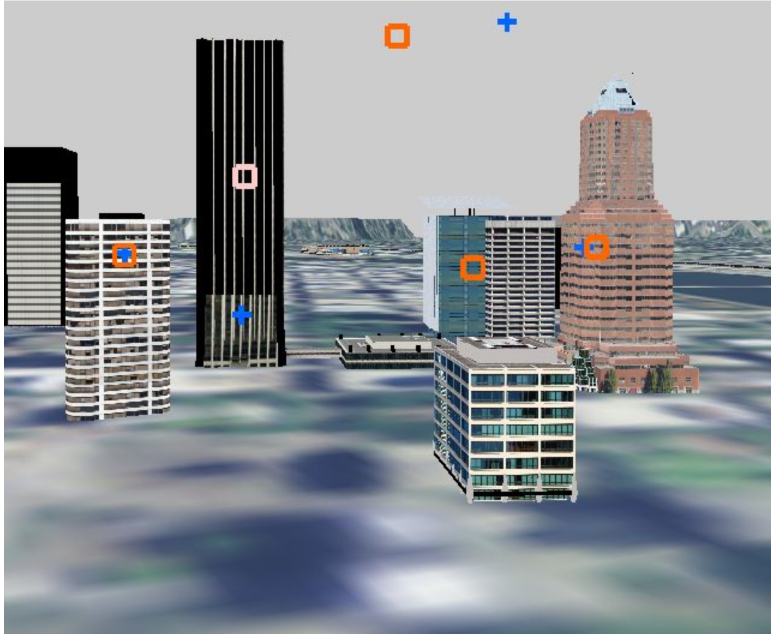
Code

- Building the code was an unexpected difficulty
- Fortunately the code itself was modular enough

- Required knowledge about SDL2, OpenGL, GLSL

UI

- Original UI was not suitable for our testing
- Freer camera
- Point movement
- New UI components for hot spot handling



Numerical Error

- C++'s floating point arithmetic is not very reliable.
- exp(x) / exp(x) + 1 is NAN when x > ~80.
- Hard to find problem, better check early.

```
inline double TestModel::sigmoid(const double x) const
{
    if (x < 100)
        return (exp(x) / (exp(x) + 1));
    else
        return 1;
}

inline double TestModel::sigmoidDeriv(const double x) const
{
    if (x < 50)
        return (exp(x) / (exp(x) + 1) / (exp(x) + 1));
    else
        return 0;
}
```

3-dimensional Extension

- Refractive radiative transfer equation & Runge-Kutta method from original code is dependent only on altitude (y axis).
- Our areal hot spot involves all three dimension.
- Need to understand RRTE & RK4, then extend it to 3D.

```
double TestModel::gradient(glm::dvec3 p)
```

```
glm::dvec3 TestModel::gradient(glm::dvec3 p)
{
```

```
glm::vec3 deStdDerivNormalized = glm::vec3(0, deStdDeriv, 0) + hotspotDerivSum;
deStdDerivNormalized /= abs(backgroundMaxN) + abs(inversionDeltaN) + hotspotNSum;
```

OpenGL & Shader

- Shader does not have “array-like” object
- Should use texture for variable length data (hot spots)
- 6x1024 2D texture can hold up to 1024 hot spots

```
for (int i = 0; i < (model->hotspotInfo).size(); i++) {
    // position
    glTexSubImage2D(GL_TEXTURE_2D, 0, 0, i, 1, 1, GL_RED, GL_FLOAT, &((model->hotspotInfo[i].first)->x));
    glTexSubImage2D(GL_TEXTURE_2D, 0, 1, i, 1, 1, GL_RED, GL_FLOAT, &((model->hotspotInfo[i].first)->y));
    glTexSubImage2D(GL_TEXTURE_2D, 0, 2, i, 1, 1, GL_RED, GL_FLOAT, &((model->hotspotInfo[i].first)->z));
    // hotspot Radius
    glTexSubImage2D(GL_TEXTURE_2D, 0, 3, i, 1, 1, GL_RED, GL_FLOAT, &(model->hotspotInfo[i].second));
    // hotspot N
    glTexSubImage2D(GL_TEXTURE_2D, 0, 4, i, 1, 1, GL_RED, GL_FLOAT, &(model->hotspotNs[i]));
    // hotspot Dropoff
    glTexSubImage2D(GL_TEXTURE_2D, 0, 5, i, 1, 1, GL_RED, GL_FLOAT, &(model->hotspotDropoffs[i]));
    // hotspot Temperture

}
```

OpenGL & Shader

- Shader does not have "array-like" object
- Should use texture for variable length data (hot spots)
- 6x1024 2D texture can hold up to 1024 hot spots

- Debugging shader
  - NAN, again
  - Shader cannot "print" or "log", as it is run on GPU
  - Always watch out the typo

Remaining Problems

Restrictions on Hot Spot

- Hot spot shape is currently circular only
  - Need several circular hot spots for other shapes
- Hot spot position is currently on surface only
  - Possibly hot spot can be on mid-air for more effect
  - Or optimizer may be able to optimize hot spot position

Quality of Mirage

- For high quality image, user should specify “good” pairs of source/destination points
- Optimization dilemma
  - More pairs, higher quality, slower speed
  - Less pairs, faster speed, lower quality
- Optimizer is somewhat unpredictable
  - Finding out optimizer-friendly pairs is difficult
  - Wave-like overfitting: background + inversion layer

Members & Roles

- Seo Hansol : Presentation, UI Improvement, Areal Hot Spot Improvement, Shader Implementation

- Lim Mingi : Presentation, Areal Hot Spot Implementation

Q & A

Runge-Kutta Method

t_new = t + h

Use k1, k2, k3, k4

k1 = h * y’ (t, y)

k2 = h * y’ (t+h/2, y+k1/2)

k3 = h * y’ (t+h/2, y+k2/2)

k4 = h * y’ (t+h, y+k3)

y_new = (k1+2*k2+2*k3+k4) / 6

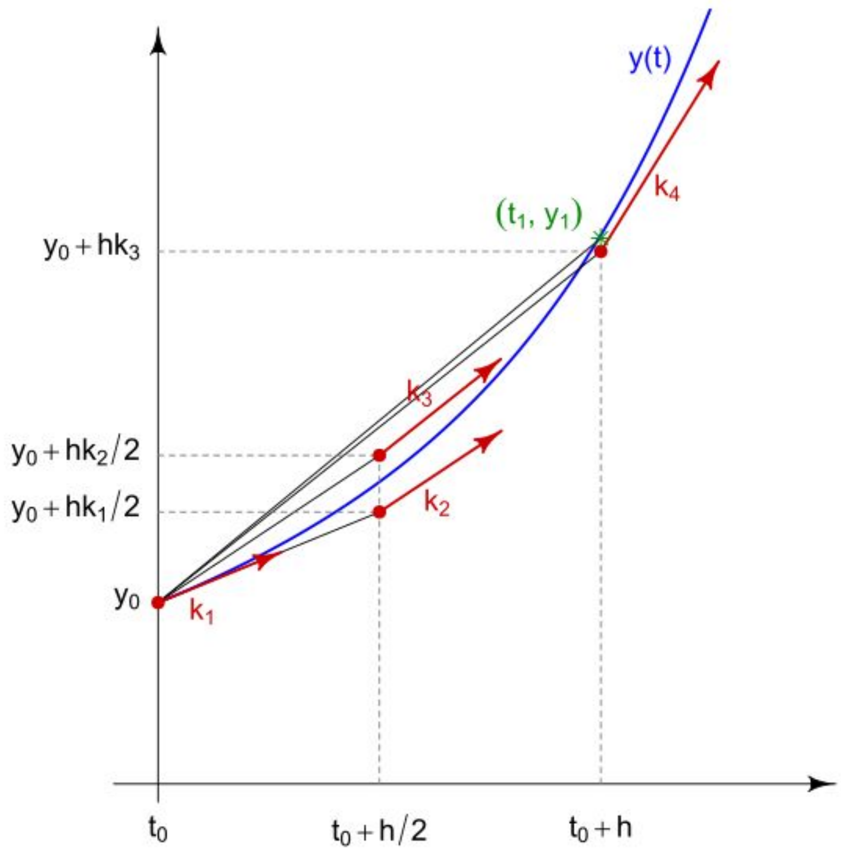


Image by HilberTraum
From https://commons.wikimedia.org/wiki/File:Runge-Kutta_slopes.svg