深蓝学院
shenlanxueyuan.com

视觉SLAM&VIO开源代码
DSO第二次作业讲评

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作业一，第一问

- 作业要求：补全track.cpp内所有TODO代码，完成基于光度误差的位姿估计

计算残差

```
// TODO calculate residual res = ref - cur may need to add huber

// residual_pattern[pattern_count] = ***;

++pattern_count;
```

计算雅可比

```
// TODO calculate Jacobian
{
    Eigen::Matrix<double, 2, 6> jacob_xyz2uv;

    // jacobian_.block(num_pattern*i_ftr, 0, num_pattern, 6) = ;
}
```

计算正规方程

```
// TODO calculate H and b
// hessian_ = ;
// jres_ = ;
```

位姿更新

```
void hw::Tracker::update(const Sophus::SE3d& old_state, Sophus::SE3d& new_state)
{
    // TODO update new state
    // new_state = ;
}
```

作业一，第一问

■ 解题思路

➢ 计算残差

思路一：观测-预测，$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$

```
// TODO calculate residual res = ref - cur may need to add huber
residual_pattern[pattern_count] = pattern_value - data_patch_ref[pattern_count];
```

思路二：预测-观测，$r_i = I(\boldsymbol{p}_{i,curr}) - I(\boldsymbol{p}_{i,ref})$

```
// TODO calculate residual res = ref - cur may need to add huber
residual_pattern[pattern_count] = data_patch_ref[pattern_count] - pattern_value;
```

两种方式均正确，不同点是会影响到整个求解过程中的符号，后面解释

作业一，第一问

■ 解题思路

➢ 计算残差-鲁棒核函数

参考DSO中的实现（src/FullSystem/CoarseInitializer.cpp:CoarseInitializer::calcResAndGS）

```
float residual = hitColor[0] - r2new_aff[0] * rlR - r2new_aff[1];
// Huber权重       gong, a year ago • commented
float hw = fabs(residual) < setting_huberTH ? 1 : setting_huberTH / fabs(residual);
// huberweight * (2-huberweight) = Objective Function
```

```
if(hw < 1) hw = sqrtf(hw); //?? 为啥开根号，答：鲁棒核函数等价于加权最小二乘
//! dxfx, dyfy
```

对应实现：

```
// TODO calculate residual res = ref - cur may need to add huber
float residual = <fake code>;
// 选择残差阈值
float setting_huberTH = 9.0f;
// apply huber kernel
hw = std::fabs(residual) < setting_huberTH ? 1 : setting_huberTH / std::fabs(residual);
if(hw < 1) hw = sqrtf(hw);
residual_pattern[pattern_count] = hw * residual;

++pattern_count;
```

作业一，第一问

解题思路

- 计算雅可比-假设残差计算为“观测-预测”

$$J = \frac{\partial r_i}{\partial \delta \xi}$$

$$r_i = I\left(\boldsymbol{p}_{i,\color{blue}{ref}}\right) - I\left(\boldsymbol{p}_{i,\color{red}{curr}}\right)$$

作业一，第一问

■ 解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

$$J = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \delta \xi}$$

$$r_i = \underbrace{\boxed{I(\boldsymbol{p}_{i,ref})}}_{\text{fixed}} - I(\boldsymbol{p}_{i,curr})$$

```
float residual = data_patch_ref[pattern_count] -    // 点 p_{i,ref}  灰度
                 pattern_value;                     // 点 p_{i,curr} 灰度
```

残差哪里来?从图像灰度差来

作业一，第一问

■ 解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

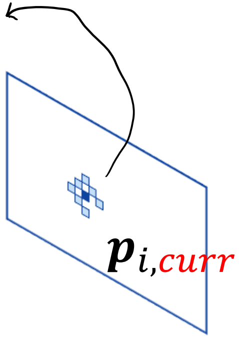
$$J = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \delta \xi}$$

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

```
float residual = data_patch_ref[pattern_count] -    // 点 p_{i,ref}  灰度
                 pattern_value;                     // 点 p_{i,curr} 灰度
```

图像灰度哪里来?访问图像得来

```
// p_{i,curr} 点灰度从图像得来
float pattern_value = utils::interpolate_uint8(
                                (img_cur_pyr.data),
                                x_img_pattern,
                                y_img_pattern,
                                stride);
```



作业一，第一问

解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

$$J = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta \xi}$$

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

$$\boldsymbol{p}_{i,curr} = s\left[z_{i,ref}^{curr} \boldsymbol{K} \boldsymbol{P}_{i,ref}^{curr}\right]_{:2}$$

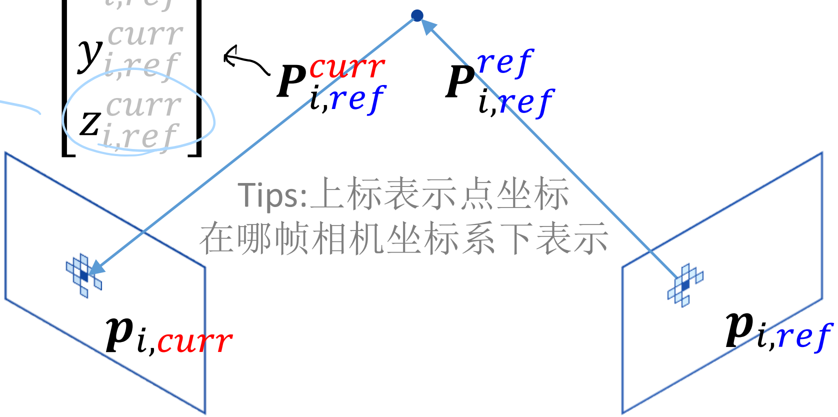
```
// project to current
Eigen::Vector3d point_ref(Cam::pixel2unitPlane(ftr_ref_x, ftr_ref_y)*ftr_depth_ref);
Eigen::Vector3d point_cur(T_cur_ref*point_ref);
Eigen::Vector2d ftr_cur = Cam::project(point_cur)*scale;
```

$\boldsymbol{p}_{i,curr}$坐标哪里来？投影得来

```
// p_{i,curr} 点灰度从图像得来
float pattern_value = utils::interpolate_uint8(
                        (img_cur_pyr.data),
                        x_img_pattern,
                        y_img_pattern,
                        stride);
```

$$\begin{bmatrix} x_{i,ref}^{curr} \\ y_{i,ref}^{curr} \\ z_{i,ref}^{curr} \end{bmatrix} \leftarrow \boldsymbol{P}_{i,ref}^{curr}$$

这其中还有一些别的变换
不过不影响求导过程



Tips:上标表示点坐标
在哪帧相机坐标系下表示

作业一，第一问

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解题思路

- 计算雅可比-假设残差计算为“观测-预测”

$$J=\frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})}\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}}\frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}^{curr}_{i,ref}}\frac{\partial \boldsymbol{P}^{curr}_{i,ref}}{\partial \delta\xi}$$

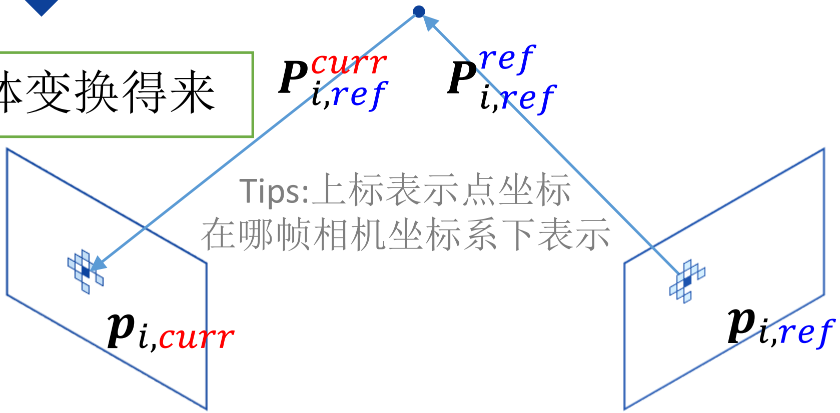
$$r_i=I(\boldsymbol{p}_{i,ref})-I(\boldsymbol{p}_{i,curr})$$

$$\boldsymbol{p}_{i,curr}=s\left[z^{curr}_{i,ref}\boldsymbol{K}\boldsymbol{P}^{curr}_{i,ref}\right]_{:2}$$

$$\boldsymbol{P}^{curr}_{i,ref}=\boldsymbol{T}_{cr}\,\boldsymbol{P}^{ref}_{i,ref}$$

```
// project to current
Eigen::Vector3d point_ref(Cam::pixel2unitPlane(ftr_ref_x, ftr_ref_y)*ftr_depth_ref);
Eigen::Vector3d point_cur(T_cur_ref*point_ref);
Eigen::Vector2d ftr_cur = Cam::project(point_cur)*scale;
```

$\boldsymbol{P}^{curr}_{i,ref}$坐标哪里来？三维刚体变换得来



作业一，第一问

解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

$$J = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

$$\frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} = -1$$

$$\boldsymbol{p}_{i,curr} = s\left[z_{i,ref}^{curr} \boldsymbol{K} \boldsymbol{P}_{i,ref}^{curr}\right]_{:2}$$

$$\boldsymbol{P}_{i,ref}^{curr} = \boldsymbol{T}_{cr} \boldsymbol{P}_{i,ref}^{ref}$$

作业一，第一问

解题思路

- 计算雅可比-假设残差计算为“观测-预测”

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

$$\boldsymbol{p}_{i,curr} = s\left[z_{i,ref}^{curr} \boldsymbol{K} \boldsymbol{P}_{i,ref}^{curr}\right]_{:2}$$

$$\boldsymbol{P}_{i,ref}^{curr} = \boldsymbol{T}_{cr} \boldsymbol{P}_{i,ref}^{ref}$$

$$\boldsymbol{p}_{i,curr} = \begin{bmatrix} u_{i,curr} \\ v_{i,curr} \end{bmatrix}$$

$$\boldsymbol{J} = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$\frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} = -1$$

$$\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} = \left[\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial u_{i,curr}}, \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial v_{i,curr}}\right] = [d_u \quad d_v]$$

作业一，第一问

解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

$$\boldsymbol{p}_{i,curr} = s\left[z_{i,ref}^{curr}\boldsymbol{K}\boldsymbol{P}_{i,ref}^{curr}\right]_{:2}$$

$$\boldsymbol{P}_{i,ref}^{curr} = \boldsymbol{T}_{cr}\boldsymbol{P}_{i,ref}^{ref}$$

$$\boldsymbol{p}_{i,curr} = \begin{bmatrix} u_{i,curr} \\ v_{i,curr} \end{bmatrix} \quad u_{i,curr} = s\left(f_x\frac{x_{i,ref}^{curr}}{z_{i,ref}^{curr}} - c_x\right)$$

$$\boldsymbol{P}_{i,ref}^{curr} = \begin{bmatrix} x_{i,ref}^{curr} \\ y_{i,ref}^{curr} \\ z_{i,ref}^{curr} \end{bmatrix} \quad v_{i,curr} = s\left(f_x\frac{y_{i,ref}^{curr}}{z_{i,ref}^{curr}} - c_x\right)$$

$$\boldsymbol{J} = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})}\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}}\frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}}\frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$\frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} = -1$$

$$\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} = \left[\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial u_{i,curr}}, \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial v_{i,curr}}\right] = \begin{bmatrix} d_u & d_v \end{bmatrix}$$

$$\frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} = s\begin{bmatrix} f_x\frac{1}{z_{i,ref}^{curr}} & 0 & -f_x\frac{x_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \\ 0 & f_y\frac{1}{z_{i,ref}^{curr}} & -f_y\frac{y_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \end{bmatrix}$$

作业一，第一问

解题思路

- 计算雅可比-假设残差计算为“观测-预测”

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr})$$

$$\boldsymbol{p}_{i,curr} = s\left[z_{i,ref}^{curr} \boldsymbol{K}\boldsymbol{P}_{i,ref}^{curr}\right]_{:2}$$

$$\boldsymbol{P}_{i,ref}^{curr} = \boldsymbol{T}_{cr}\,\boldsymbol{P}_{i,ref}^{ref}$$

参考十四讲第四讲

$$\boldsymbol{J} = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})}\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}}\frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}}\frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$\frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} = -1$$

$$\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} = \left[\frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial u_{i,curr}}, \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial v_{i,curr}}\right] = [d_u \quad d_v]$$

$$\frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} = s\begin{bmatrix} f_x\frac{1}{z_{i,ref}^{curr}} & 0 & -f_x\frac{x_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \\ 0 & f_y\frac{1}{z_{i,ref}^{curr}} & -f_y\frac{y_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \end{bmatrix}$$

$$\frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi} = \left[\boldsymbol{I} \quad -\boldsymbol{P}_{i,ref}^{curr}{}_{[\times]}\right]$$

作业一，第一问

■ 解题思路

➢ 计算雅可比-假设残差计算为“观测-预测”

$$J = \frac{\partial r_i}{\partial I(\mathbf{p}_{i,curr})}\frac{\partial I(\mathbf{p}_{i,curr})}{\partial \mathbf{p}_{i,curr}}\frac{\partial \mathbf{p}_{i,curr}}{\partial \mathbf{P}_{i,ref}^{curr}}\frac{\partial \mathbf{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$= -[d_u \quad d_v]\, s \begin{bmatrix} f_x \frac{1}{z_{i,ref}^{curr}} & 0 & -f_x \frac{x_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \\ 0 & f_y \frac{1}{z_{i,ref}^{curr}} & -f_y \frac{y_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \end{bmatrix} \begin{bmatrix} \boldsymbol{I} & -\mathbf{P}_{i,ref}^{curr}{}_{[\times]} \end{bmatrix}$$

作业一，第一问

■ 解题思路

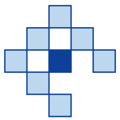
➢ 计算雅可比-最终形式

$$\boldsymbol{P}_{i,ref}^{curr} = \begin{bmatrix} x_{i,ref}^{curr} \\ y_{i,ref}^{curr} \\ z_{i,ref}^{curr} \end{bmatrix}$$

$$\boldsymbol{J} = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$= [d_u \quad d_v] \cdot -s \begin{bmatrix} f_x \frac{1}{z_{i,ref}^{curr}} & 0 & -f_x \frac{x_{i,ref}^{curr}}{z_{i,ref}^{curr\,2}} \\ 0 & f_y \frac{1}{z_{i,ref}^{curr}} & -f_y \frac{y_{i,ref}^{curr}}{z_{i,ref}^{curr\,2}} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & z_{i,ref}^{curr} & -y_{i,ref}^{curr} \\ 0 & 1 & 0 & -z_{i,ref}^{curr} & 0 & x_{i,ref}^{curr} \\ 0 & 0 & 1 & y_{i,ref}^{curr} & -x_{i,ref}^{curr} & 0 \end{bmatrix}$$

对于一个patch中的点，后面的部分是完全一样的



作业一，第一问

解题思路

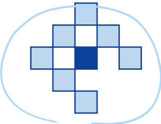
- 计算雅可比-最终形式

$$\boldsymbol{P}_{i,ref}^{curr} = \begin{bmatrix} x_{i,ref}^{curr} \\ y_{i,ref}^{curr} \\ z_{i,ref}^{curr} \end{bmatrix}$$

$$\boldsymbol{J} = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$= \begin{bmatrix} d_{u_1} & d_{v_1} \\ \vdots & \vdots \\ d_{u_8} & d_{v_8} \end{bmatrix} \cdot -s \begin{bmatrix} f_x \frac{1}{z_{i,ref}^{curr}} & 0 & -f_x \frac{x_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \\ 0 & f_y \frac{1}{z_{i,ref}^{curr}} & -f_y \frac{y_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & z_{i,ref}^{curr} & -y_{i,ref}^{curr} \\ 0 & 1 & 0 & -z_{i,ref}^{curr} & 0 & x_{i,ref}^{curr} \\ 0 & 0 & 1 & y_{i,ref}^{curr} & -x_{i,ref}^{curr} & 0 \end{bmatrix}$$

对于一个patch中的点，后面的部分是完全一样的



作业一，第一问

■ 解题思路

➢ 计算高斯牛顿法正规方程

回顾十四讲第六讲：

$$\underbrace{\boldsymbol{J}(\xi)^{\mathrm{T}}\boldsymbol{J}(\xi)}_{\boldsymbol{H}}\Delta\xi = \underbrace{-\boldsymbol{J}(\xi)^{\mathrm{T}}f(\xi)}_{\boldsymbol{g}}$$

```
// TODO calculate H and b
hessian_ =  jacobian_.transpose() * jacobian_;
jres_    = -jacobian_.transpose() * residual_;
```

➢ 位姿更新

```
// TODO update new state
      You, a few seconds ago • Uncommitted changes
new_state = Sophus::SE3d::exp(delta_x_)*old_state;
```

作业一，第一问-优秀作业展示

➢ 计算残差

```
// TODO calculate residual res = ref - cur
float residual = data_patch_ref[pattern_count] - pattern_value;
hw = std::fabs(residual) < 9 ? 1 : 9 / std::fabs(residual);
if(hw < 1) hw = sqrtf(hw);
residual_pattern[pattern_count] = hw*residual;
++pattern_count;
```

作业一，第一问-优秀作业展示

- 计算雅可比

```
// TODO calculate Jacobian
{
    Eigen::Matrix<double, 2, 6> jacob_xyz2uv;
    double x = point_cur[0];
    double y = point_cur[1];
    double invz   = 1.0 / point_cur[2];
    double invz_2 = invz * invz;

    double fx_ = -1 * Cam::fx() * scale;
    double fy_ = -1 * Cam::fy() * scale;

    jacob_xyz2uv ( 0,0 ) = invz * fx_;
    jacob_xyz2uv ( 0,1 ) = 0;
    jacob_xyz2uv ( 0,2 ) = -x * invz_2 * fx_;
    jacob_xyz2uv ( 0,3 ) = - x * y * invz_2 * fx_;
    jacob_xyz2uv ( 0,4 ) = ( 1 + ( x * x * invz_2 ) ) * fx_;
    jacob_xyz2uv ( 0,5 ) = - y * invz * fx_;

    jacob_xyz2uv ( 1,0 ) = 0;
    jacob_xyz2uv ( 1,1 ) = invz * fy_;
    jacob_xyz2uv ( 1,2 ) = -y * invz_2 * fy_;
    jacob_xyz2uv ( 1,3 ) = - ( 1 + y * y * invz_2 ) * fy_;
    jacob_xyz2uv ( 1,4 ) = x * y * invz_2 * fy_;
    jacob_xyz2uv ( 1,5 ) = x * invz * fy_;

    jacobian_.block(num_pattern * i_ftr, 0, num_pattern, 6) =
        patch_dI_.block(num_pattern * i_ftr, 0, num_pattern, 2) * jacob_xyz2uv;
```

作业一，第一问-优秀作业展示

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➢ 计算正规方程

```
// TODO calculate H and b
hessian_ =  jacobian_.transpose() * jacobian_;
jres_     = -jacobian_.transpose() * residual_;
```

➢ 位姿更新

```
// TODO update new state
      You, a few seconds ago • Uncommitted changes
new_state = Sophus::SE3d::exp(delta_x_)*old_state;
```

作业一，第一问-易错点

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- 符号（负号）不统一

$$r_i = I(\boldsymbol{p}_{i,ref}) - I(\boldsymbol{p}_{i,curr}) \Rightarrow \boldsymbol{J}$$

$$r_i = I(\boldsymbol{p}_{i,curr}) - I(\boldsymbol{p}_{i,ref}) \Rightarrow -\boldsymbol{J}$$

$$\boldsymbol{J}(\xi)^{\mathrm{T}}\boldsymbol{J}(\xi)\Delta\xi = -\boldsymbol{J}(\xi)^{\mathrm{T}}f(\xi) \Rightarrow \delta\xi$$

$$\boldsymbol{J}(\xi)^{\mathrm{T}}\boldsymbol{J}(\xi)\Delta\xi = \boldsymbol{J}(\xi)^{\mathrm{T}}f(\xi) \Rightarrow -\delta\xi$$

- 误差和能量搞混

作业一，第一问-易错点

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- 雅可比计算时，不同图层没有乘尺度
- 雅可比计算时，只计算了一个点，漏了patch中其他的点

$$J = \frac{\partial r_i}{\partial I(\boldsymbol{p}_{i,curr})} \frac{\partial I(\boldsymbol{p}_{i,curr})}{\partial \boldsymbol{p}_{i,curr}} \frac{\partial \boldsymbol{p}_{i,curr}}{\partial \boldsymbol{P}_{i,ref}^{curr}} \frac{\partial \boldsymbol{P}_{i,ref}^{curr}}{\partial \delta\xi}$$

$$= \begin{bmatrix} d_{u_1} & d_{v_1} \\ \vdots & \vdots \\ d_{u_8} & d_{v_8} \end{bmatrix} \cdot -s \begin{bmatrix} f_x \frac{1}{z_{i,ref}^{curr}} & 0 & -f_x \frac{x_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \\ 0 & f_y \frac{1}{z_{i,ref}^{curr}} & -f_y \frac{y_{i,ref}^{curr}}{{z_{i,ref}^{curr}}^2} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & z_{i,ref}^{curr} & -y_{i,ref}^{curr} \\ 0 & 1 & 0 & -z_{i,ref}^{curr} & 0 & x_{i,ref}^{curr} \\ 0 & 0 & 1 & y_{i,ref}^{curr} & -x_{i,ref}^{curr} & 0 \end{bmatrix}$$

作业一，第二问

■ 作业要求

➢ 修改grid_size达到提取不同点数目的目的，研究平均误差与使用点的数目之间的关系，判断使用多少个点最合适？

■ 解题思路

➢ 修改grid_size，统计误差和耗时，绘图说明

■ BUG

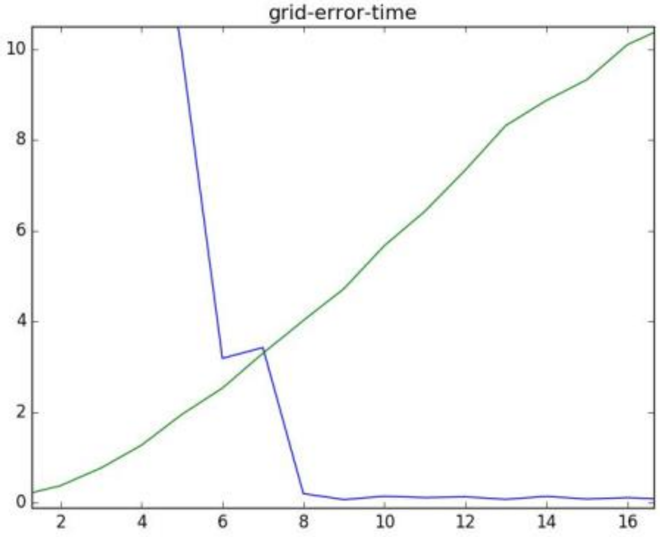
➢ 作业源码有个BUG，grid_size过大时会出现段错误或double free错误

➢ 在计算角点部分，cols_per_grid和rows_per_grid分别加一，即可避免

作业一，第二问

■ 优秀作业展示

图中蓝色曲线为总误差随 grid_size 的变化趋势，绿色曲线为总耗时（s）随 grid_size 的变化曲线。可以看出 grid_size=9 时，最为合适，总误差小，且耗时相对不高。



作业一，第二问

- ■ **易错点**
  - ➢ 第一问的雅可比计算错误，得到错误结论
  - ➢ 只分析了精度，忽视了耗时

作业二

■ 优秀作业展示

3 关键帧选取策略

（1）dso 中的关键帧选取策略，整体思路是保证前后帧和光度误差的量变化的不宜过大，其中直接看光流的大小可以作为判断，其次看平移相关的光流大小也作为判断，为了保证出现遮挡和出遮挡等明显有光度误差变化时，后续系统能够及时 track 成功，毕竟此时光度误差的变化容易使得之后的优化不容易收敛到好的值，因此需要插入关键帧。其次曝光时间变换明显的，因为也导致了光度的变化，因此也选择插入关键帧。

（2）orbslam 中的关键帧选取策略，包括：a）很多帧没有插入关键帧了，那么直接插入关键帧，比较简单粗暴的策略，使得关键帧安排的比较紧凑；b）如果 localmapping 线程不是很忙，也直接插入关键帧，和 a）中策略类似，也是保证关键帧比较紧凑；c）新的一帧跟踪地图点比例比较少，说明这一帧运动可能比较大，也插入关键帧；d）如果和上一关键帧的跟踪的点重复度不是很高，也直接插入关键帧。可见，总体来说 orbslam 的关键帧选取是很宽松的，尽可能多插入关键帧，这样的好处是及时将有变化的关键帧放入 localmapping 线程进行优化，更重要的是后面还有删除冗余关键帧的操作，因此不会担心关键帧的选取太宽松。

（3）vins 中的关键帧选取策略，因为其用的也是滑动窗口算法，因此也是不能随意插入关键帧的，其策略也是计算是否要插入的关键帧和最新关键帧之间的特征点的平均视差，如果超过一定范围，那就插入关键帧，有些类似 dso 的操作方法，但是没有 dso 那么要求的细致，因为 vins 是 vio 系统，加入了 imu 后比较鲁棒，因此关键帧策略应该说不需要特别精细。

感谢各位聆听！

Thanks for Listening