原 x264源代码简单分析：宏块分析（Analysis）部分-帧内宏块（Intra）

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H.264源代码分析文章列表：

【编码 - x264】

【解码 - libavcodec H.264 解码器】

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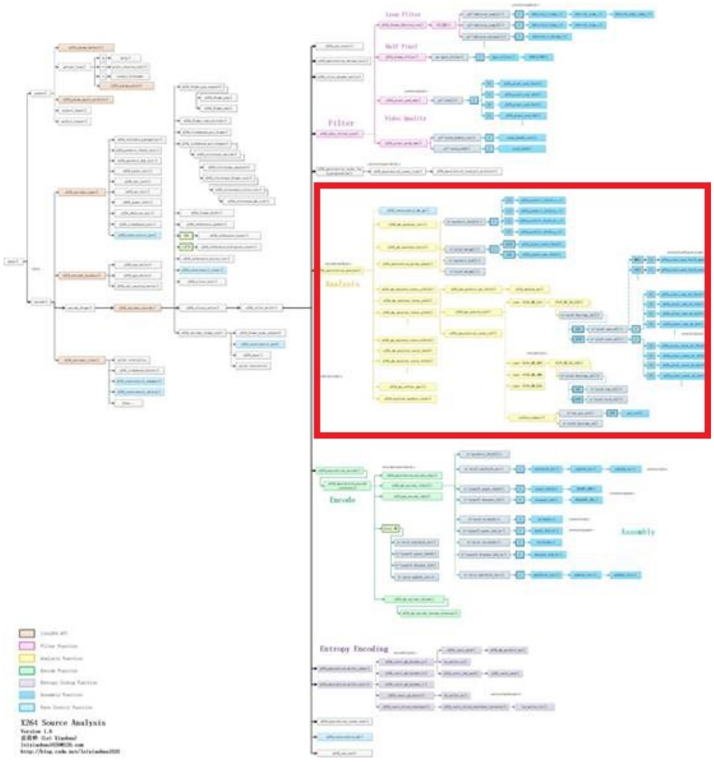
本文记录x264的　x264_slice_write()函数中调用的x264_macroblock_analyse()的源代码。x264_macroblock_analyse()对应着x264中的分析模块。分析模块主要完成了下面2个方面的功能：

（1）对于帧内宏块，分析帧内预测模式
（2）对于帧间宏块，进行运动估计，分析帧间预测模式

由于分析模块比较复杂，因此分成两篇文章记录其中的源代码：本文记录帧内宏块预测模式的分析，下一篇文章记录帧间宏块预测模式的分析。

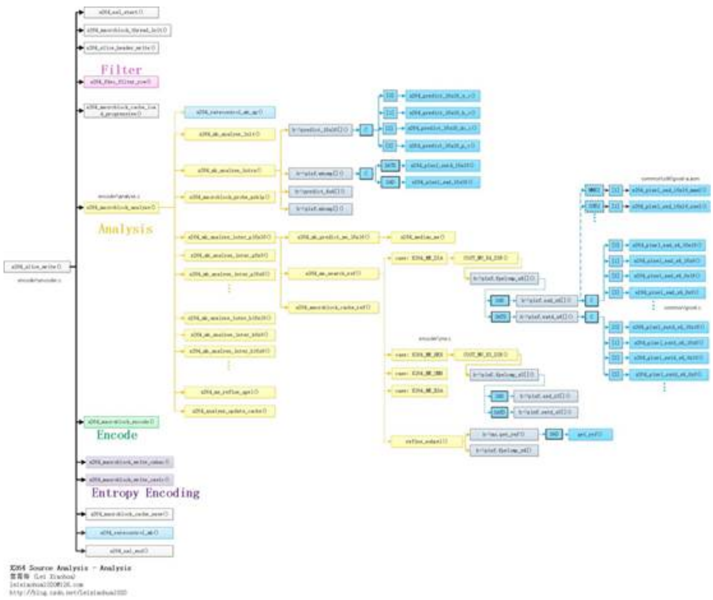
函数调用关系图

宏块分析（Analysis）部分的源代码在整个x264中的位置如下图所示。



单击查看更清晰的图片

宏块分析（Analysis）部分的函数调用关系如下图所示。



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从图中可以看出，分析模块的x264_macroblock_analyse()调用了如下函数（只列举了几个有代表性的函数）：

x264_mb_analyse_init()：Analysis模块初始化。

x264_mb_analyse_intra()：Intra宏块帧内预测模式分析。

x264_macroblock_probe_pskip()：分析是否是skip模式。

x264_mb_analyse_inter_p16x16()：P16x16宏块帧间预测模式分析。

x264_mb_analyse_inter_p8x8()：P8x8宏块帧间预测模式分析。

x264_mb_analyse_inter_p16x8()：P16x8宏块帧间预测模式分析。

x264_mb_analyse_inter_b16x16()：B16x16宏块帧间预测模式分析。

x264_mb_analyse_inter_b8x8()：B8x8宏块帧间预测模式分析。

x264_mb_analyse_inter_b16x8()：B16x8宏块帧间预测模式分析。

本文重点分析其中帧内宏块（Intra宏块）的分析函数x264_mb_analyse_intra()。下一篇文章再对x264_mb_analyse_inter_p16x16()等一系列帧间宏块的分析函数。

x264_slice_write()

x264_slice_write()是x264项目的核心，它完成了编码了一个Slice的工作。有关该函数的分析可以参考文章《 x264源代码简单分析：x264_slice_write() 》。本文分析其

调用的x264_mb_analyse()函数。

x264_macroblock_analyse()

x264_macroblock_analyse()用于分析宏块的预测模式。该函数的定义位于encoder\analyse.c，如下所示。

```cpp
/****************************************************************************
 * 分析-帧内预测模式选择、帧间运动估计等
 *
 * 注释和处理：雷霄骅
 * http://blog.csdn.net/leixiaohua1020
 * leixiaohua1020@126.com
 ****************************************************************************/
void x264_macroblock_analyse( x264_t *h )
{
    x264_mb_analysis_t analysis;
    int i_cost = COST_MAX;
    //通过码率控制方法，获取本宏块QP
    h->mb.i_qp = x264_ratecontrol_mb_qp( h );
    /* If the QP of this MB is within 1 of the previous MB, code the same QP as the previous MB,
     * to lower the bit cost of the qp_delta.  Don't do this if QPRD is enabled. */
    if( h->param.rc.i_aq_mode && h->param.analyse.i_subpel_refine < 10 )
        h->mb.i_qp = abs(h->mb.i_qp - h->mb.i_last_qp) == 1 ? h->mb.i_last_qp : h->mb.i_qp;

    if( h->param.analyse.b_mb_info )
        h->fdec->effective_qp[h->mb.i_mb_xy] = h->mb.i_qp; /* Store the real analysis QP. */
    //初始化
    x264_mb_analyse_init( h, &analysis, h->mb.i_qp );

    /*--------------------------- Do the analysis ---------------------------*/
    //I帧：只使用帧内预测，分别计算亮度16x16（4种）和4x4（9种）所有模式的代价值，选出代价最小的模式

    //P帧：计算帧内模式和帧间模式（ P Slice允许有Intra宏块和P宏块；同理B帧也支持Intra宏块）。
    //对P帧的每一种分割进行帧间预测，得到最佳的运动矢量及最佳匹配块。
    //帧间预测过程：选出最佳矢量——>找到最佳的整像素点——>找到最佳的二分之一像素点——>找到最佳的1/4像素点
    //然后取代价最小的为最佳MV和分割方式
    //最后从帧内模式和帧间模式中选择代价比较小的方式（有可能没有找到很好的匹配块，这时候就直接使用帧内预测而不是帧间预测）。

    if( h->sh.i_type == SLICE_TYPE_I )
    {
        //I slice
        //通过一系列帧内预测模式（16x16的4种,4x4的9种）代价的计算得出代价最小的最优模式
intra_analysis:
        if( analysis.i_mbrd )
            x264_mb_init_fenc_cache( h, analysis.i_mbrd >= 2 );
        //帧内预测分析
        //从16×16的SAD,4个8×8的SAD和，16个4×4SAD中选出最优方式
        x264_mb_analyse_intra( h, &analysis, COST_MAX );
        if( analysis.i_mbrd )
            x264_intra_rd( h, &analysis, COST_MAX );
        //分析结果都存储在analysis结构体中
        //开销
        i_cost = analysis.i_satd_i16x16;
        h->mb.i_type = I_16x16;
        //如果I4x4或者I8x8开销更小的话就拷贝
        //copy if little
        COPY2_IF_LT( i_cost, analysis.i_satd_i4x4, h->mb.i_type, I_4x4 );
        COPY2_IF_LT( i_cost, analysis.i_satd_i8x8, h->mb.i_type, I_8x8 );
        //画面极其特殊的时候，才有可能用到PCM
        if( analysis.i_satd_pcm < i_cost )
            h->mb.i_type = I_PCM;

        else if( analysis.i_mbrd >= 2 )
            x264_intra_rd_refine( h, &analysis );
    }
    else if( h->sh.i_type == SLICE_TYPE_P )
    {
        //P slice

        int b_skip = 0;

        h->mc.prefetch_ref( h->mb.pic.p_fref[0][0][h->mb.i_mb_x&3], h->mb.pic.i_stride[0], 0 );

        analysis.b_try_skip = 0;
        if( analysis.b_force_intra )
        {
            if( !h->param.analyse.b_psy )
            {
                x264_mb_analyse_init_qp( h, &analysis, X264_MAX( h->mb.i_qp - h->mb.ip_offset, h->param.rc.i_qp_min ) );
                goto intra_analysis;
            }
        }
        else
        {
            /* Special fast-skip logic using information from mb_info. */
            if( h->fdec->mb_info && (h->fdec->mb_info[h->mb.i_mb_xy]&X264_MBINFO_CONSTANT) )
            {
```

```c
                if( !SLICE_MBAFF && (h->fdec->i_frame - h->fref[0][0]->i_frame) == 1 && !h->sh.b_weighted_pred &&
                    h->fref[0][0]->effective_qp[h->mb.i_mb_xy] <= h->mb.i_qp )
                {
                    h->mb.i_partition = D_16x16;
                    /* Use the P-SKIP MV if we can... */
                    if( !M32(h->mb.cache.pskip_mv) )
                    {
                        b_skip = 1;
                        h->mb.i_type = P_SKIP;
                    }
                    /* Otherwise, just force a 16x16 block. */
                    else
                    {
                        h->mb.i_type = P_L0;
                        analysis.l0.me16x16.i_ref = 0;
                        M32( analysis.l0.me16x16.mv ) = 0;
                    }
                    goto skip_analysis;
                }
                /* Reset the information accordingly */
                else if( h->param.analyse.b_mb_info_update )
                    h->fdec->mb_info[h->mb.i_mb_xy] &= ~X264_MBINFO_CONSTANT;
            }

            int skip_invalid = h->i_thread_frames > 1 && h->mb.cache.pskip_mv[1] > h->mb.mv_max_spel[1];
            /* If the current macroblock is off the frame, just skip it. */
            if( HAVE_INTERLACED && !MB_INTERLACED && h->mb.i_mb_y * 16 >= h->param.i_height && !skip_invalid )
                b_skip = 1;
            /* Fast P_SKIP detection */
            else if( h->param.analyse.b_fast_pskip )
            {
                if( skip_invalid )
                    // FIXME don't need to check this if the reference frame is done
                    {}
                else if( h->param.analyse.i_subpel_refine >= 3 )
                    analysis.b_try_skip = 1;
                else if( h->mb.i_mb_type_left[0] == P_SKIP ||
                         h->mb.i_mb_type_top == P_SKIP ||
                         h->mb.i_mb_type_topleft == P_SKIP ||
                         h->mb.i_mb_type_topright == P_SKIP )
                    b_skip = x264_macroblock_probe_pskip( h );//检查是否是Skip类型
            }
        }

        h->mc.prefetch_ref( h->mb.pic.p_fref[0][0][h->mb.i_mb_x&3], h->mb.pic.i_stride[0], 1 );

        if( b_skip )
        {
            h->mb.i_type = P_SKIP;
            h->mb.i_partition = D_16x16;
            assert( h->mb.cache.pskip_mv[1] <= h->mb.mv_max_spel[1] || h->i_thread_frames == 1 );
skip_analysis:
            /* Set up MVs for future predictors */
            for( int i = 0; i < h->mb.pic.i_fref[0]; i++ )
                M32( h->mb.mvr[0][i][h->mb.i_mb_xy] ) = 0;
        }
        else
        {
            const unsigned int flags = h->param.analyse.inter;
            int i_type;
            int i_partition;
            int i_satd_inter, i_satd_intra;

            x264_mb_analyse_load_costs( h, &analysis );
            /*
             * 16x16 帧间预测宏块分析-P
             *
             * +--------+--------+
             * |                 |
             * |                 |
             * |                 |
             * +        +        +
             * |                 |
             * |                 |
             * |                 |
             * +--------+--------+
             *
             */
            x264_mb_analyse_inter_p16x16( h, &analysis );

            if( h->mb.i_type == P_SKIP )
            {
                for( int i = 1; i < h->mb.pic.i_fref[0]; i++ )
                    M32( h->mb.mvr[0][i][h->mb.i_mb_xy] ) = 0;
                return;
            }

            if( flags & X264_ANALYSE_PSUB16x16 )
            {
                if( h->param.analyse.b_mixed_references )
                    x264_mb_analyse_inter_p8x8_mixed_ref( h, &analysis );
```

```
                else{
                    /*
                     * 8x8帧间预测宏块分析-P
                     * +--------+
                     * |        |
                     * |        |
                     * |        |
                     * +--------+
                     */
                    x264_mb_analyse_inter_p8x8( h, &analysis );
                }
            }

            /* Select best inter mode */
            i_type = P_L0;
            i_partition = D_16x16;
            i_cost = analysis.l0.me16x16.cost;

            //如果8x8的代价值小于16x16
            //则进行8x8子块分割的处理

            //处理的数据源自于l0
            if( ( flags & X264_ANALYSE_PSUB16x16 ) && (!analysis.b_early_terminate ||
                analysis.l0.i_cost8x8 < analysis.l0.me16x16.cost) )
            {
                i_type = P_8x8;
                i_partition = D_8x8;
                i_cost = analysis.l0.i_cost8x8;

                /* Do sub 8x8 */
                if( flags & X264_ANALYSE_PSUB8x8 )
                {
                    for( int i = 0; i < 4; i++ )
                    {
                        //8x8块的子块的分析
                        /*
                         * 4x4
                         * +----+----+
                         * |    |    |
                         * +----+----+
                         * |    |    |
                         * +----+----+
                         *
                         */
                        x264_mb_analyse_inter_p4x4( h, &analysis, i );
                        int i_thresh8x4 = analysis.l0.me4x4[i][1].cost_mv + analysis.l0.me4x4[i][2].cost_mv;
                        //如果4x4小于8x8
                        //则再分析8x4，4x8的代价
                        if( !analysis.b_early_terminate || analysis.l0.i_cost4x4[i] < analysis.l0.me8x8[i].cost + i_thresh8x4 )
                        {
                            int i_cost8x8 = analysis.l0.i_cost4x4[i];
                            h->mb.i_sub_partition[i] = D_L0_4x4;
                            /*
                             * 8x4
                             * +----+----+
                             * |         |
                             * +----+----+
                             * |         |
                             * +----+----+
                             *
                             */
                            //如果8x4小于8x8
                            x264_mb_analyse_inter_p8x4( h, &analysis, i );
                            COPY2_IF_LT( i_cost8x8, analysis.l0.i_cost8x4[i],
                                         h->mb.i_sub_partition[i], D_L0_8x4 );
                            /*
                             * 4x8
                             * +----+----+
                             * |    |    |
                             * +    +    +
                             * |    |    |
                             * +----+----+
                             *
                             */
                            //如果4x8小于8x8
                            x264_mb_analyse_inter_p4x8( h, &analysis, i );
                            COPY2_IF_LT( i_cost8x8, analysis.l0.i_cost4x8[i],
                                         h->mb.i_sub_partition[i], D_L0_4x8 );

                            i_cost += i_cost8x8 - analysis.l0.me8x8[i].cost;
                        }
                        x264_mb_cache_mv_p8x8( h, &analysis, i );
                    }
                    analysis.l0.i_cost8x8 = i_cost;
                }
            }

            /* Now do 16x8/8x16 */
            int i_thresh16x8 = analysis.l0.me8x8[1].cost_mv + analysis.l0.me8x8[2].cost_mv;

            //前提要求8x8的代价值小于16x16
```

```
            if( ( flags & X264_ANALYSE_PSUB16x16 ) && (!analysis.b_early_terminate ||
                analysis.l0.i_cost8x8 < analysis.l0.me16x16.cost + i_thresh16x8) )
            {
                int i_avg_mv_ref_cost = (analysis.l0.me8x8[2].cost_mv + analysis.l0.me8x8[2].i_ref_cost
                                      + analysis.l0.me8x8[3].cost_mv + analysis.l0.me8x8[3].i_ref_cost + 1) >> 1;
                analysis.i_cost_est16x8[1] = analysis.i_satd8x8[0][2] + analysis.i_satd8x8[0][3] + i_avg_mv_ref_cost;
                /*
                 * 16x8 宏块划分
                 *
                 * +--------+--------+
                 * |        |        |
                 * |        |        |
                 * |        |        |
                 * +--------+--------+
                 *
                 */
                x264_mb_analyse_inter_p16x8( h, &analysis, i_cost );
                COPY3_IF_LT( i_cost, analysis.l0.i_cost16x8, i_type, P_L0, i_partition, D_16x8 );

                i_avg_mv_ref_cost = (analysis.l0.me8x8[1].cost_mv + analysis.l0.me8x8[1].i_ref_cost
                                  + analysis.l0.me8x8[3].cost_mv + analysis.l0.me8x8[3].i_ref_cost + 1) >> 1;
                analysis.i_cost_est8x16[1] = analysis.i_satd8x8[0][1] + analysis.i_satd8x8[0][3] + i_avg_mv_ref_cost;
                /*
                 * 8x16 宏块划分
                 *
                 * +--------+
                 * |        |
                 * |        |
                 * |        |
                 * +--------+
                 * |        |
                 * |        |
                 * |        |
                 * +--------+
                 *
                 */
                x264_mb_analyse_inter_p8x16( h, &analysis, i_cost );
                COPY3_IF_LT( i_cost, analysis.l0.i_cost8x16, i_type, P_L0, i_partition, D_8x16 );
            }

            h->mb.i_partition = i_partition;

            /* refine qpel */
            //亚像素精度搜索
            //FIXME mb_type costs?
            if( analysis.i_mbrd || !h->mb.i_subpel_refine )
            {
                /* refine later */
            }
            else if( i_partition == D_16x16 )
            {
                x264_me_refine_qpel( h, &analysis.l0.me16x16 );
                i_cost = analysis.l0.me16x16.cost;
            }
            else if( i_partition == D_16x8 )
            {
                x264_me_refine_qpel( h, &analysis.l0.me16x8[0] );
                x264_me_refine_qpel( h, &analysis.l0.me16x8[1] );
                i_cost = analysis.l0.me16x8[0].cost + analysis.l0.me16x8[1].cost;
            }
            else if( i_partition == D_8x16 )
            {
                x264_me_refine_qpel( h, &analysis.l0.me8x16[0] );
                x264_me_refine_qpel( h, &analysis.l0.me8x16[1] );
                i_cost = analysis.l0.me8x16[0].cost + analysis.l0.me8x16[1].cost;
            }
            else if( i_partition == D_8x8 )
            {
                i_cost = 0;
                for( int i8x8 = 0; i8x8 < 4; i8x8++ )
                {
                    switch( h->mb.i_sub_partition[i8x8] )
                    {
                        case D_L0_8x8:
                            x264_me_refine_qpel( h, &analysis.l0.me8x8[i8x8] );
                            i_cost += analysis.l0.me8x8[i8x8].cost;
                            break;
                        case D_L0_8x4:
                            x264_me_refine_qpel( h, &analysis.l0.me8x4[i8x8][0] );
                            x264_me_refine_qpel( h, &analysis.l0.me8x4[i8x8][1] );
                            i_cost += analysis.l0.me8x4[i8x8][0].cost +
                                      analysis.l0.me8x4[i8x8][1].cost;
                            break;
                        case D_L0_4x8:
                            x264_me_refine_qpel( h, &analysis.l0.me4x8[i8x8][0] );
                            x264_me_refine_qpel( h, &analysis.l0.me4x8[i8x8][1] );
                            i_cost += analysis.l0.me4x8[i8x8][0].cost +
                                      analysis.l0.me4x8[i8x8][1].cost;
                            break;

                        case D_L0_4x4:
```

```c
                            x264_me_refine_qpel( h, &analysis.l0.me4x4[i8x8][0] );
                            x264_me_refine_qpel( h, &analysis.l0.me4x4[i8x8][1] );
                            x264_me_refine_qpel( h, &analysis.l0.me4x4[i8x8][2] );
                            x264_me_refine_qpel( h, &analysis.l0.me4x4[i8x8][3] );
                            i_cost += analysis.l0.me4x4[i8x8][0].cost +
                                      analysis.l0.me4x4[i8x8][1].cost +
                                      analysis.l0.me4x4[i8x8][2].cost +
                                      analysis.l0.me4x4[i8x8][3].cost;
                            break;
                        default:
                            x264_log( h, X264_LOG_ERROR, "internal error (!8x8 && !4x4)\n" );
                            break;
                    }
                }
            }

            if( h->mb.b_chroma_me )
            {
                if( CHROMA444 )
                {
                    x264_mb_analyse_intra( h, &analysis, i_cost );
                    x264_mb_analyse_intra_chroma( h, &analysis );
                }
                else
                {
                    x264_mb_analyse_intra_chroma( h, &analysis );
                    x264_mb_analyse_intra( h, &analysis, i_cost - analysis.i_satd_chroma );
                }
                analysis.i_satd_i16x16 += analysis.i_satd_chroma;
                analysis.i_satd_i8x8   += analysis.i_satd_chroma;
                analysis.i_satd_i4x4   += analysis.i_satd_chroma;
            }
            else
                x264_mb_analyse_intra( h, &analysis, i_cost );//P Slice中也允许有Intra宏块，所以也要进行分析

            i_satd_inter = i_cost;
            i_satd_intra = X264_MIN3( analysis.i_satd_i16x16,
                                      analysis.i_satd_i8x8,
                                      analysis.i_satd_i4x4 );

            if( analysis.i_mbrd )
            {
                x264_mb_analyse_p_rd( h, &analysis, X264_MIN(i_satd_inter, i_satd_intra) );
                i_type = P_L0;
                i_partition = D_16x16;
                i_cost = analysis.l0.i_rd16x16;
                COPY2_IF_LT( i_cost, analysis.l0.i_cost16x8, i_partition, D_16x8 );
                COPY2_IF_LT( i_cost, analysis.l0.i_cost8x16, i_partition, D_8x16 );
                COPY3_IF_LT( i_cost, analysis.l0.i_cost8x8, i_partition, D_8x8, i_type, P_8x8 );
                h->mb.i_type = i_type;
                h->mb.i_partition = i_partition;
                if( i_cost < COST_MAX )
                    x264_mb_analyse_transform_rd( h, &analysis, &i_satd_inter, &i_cost );
                x264_intra_rd( h, &analysis, i_satd_inter * 5/4 + 1 );
            }
            //获取最小的代价
            COPY2_IF_LT( i_cost, analysis.i_satd_i16x16, i_type, I_16x16 );
            COPY2_IF_LT( i_cost, analysis.i_satd_i8x8, i_type, I_8x8 );
            COPY2_IF_LT( i_cost, analysis.i_satd_i4x4, i_type, I_4x4 );
            COPY2_IF_LT( i_cost, analysis.i_satd_pcm, i_type, I_PCM );

            h->mb.i_type = i_type;

            if( analysis.b_force_intra && !IS_INTRA(i_type) )
            {
                /* Intra masking: copy fdec to fenc and re-encode the block as intra in order to make it appear as if
                 * it was an inter block. */
                x264_analyse_update_cache( h, &analysis );
                x264_macroblock_encode( h );
                for( int p = 0; p < (CHROMA444 ? 3 : 1); p++ )
                    h->mc.copy[PIXEL_16x16]( h->mb.pic.p_fenc[p], FENC_STRIDE, h->mb.pic.p_fdec[p], FDEC_STRIDE, 16 );
                if( !CHROMA444 )
                {
                    int height = 16 >> CHROMA_V_SHIFT;
                    h->mc.copy[PIXEL_8x8]  ( h->mb.pic.p_fenc[1], FENC_STRIDE, h->mb.pic.p_fdec[1], FDEC_STRIDE, height );
                    h->mc.copy[PIXEL_8x8]  ( h->mb.pic.p_fenc[2], FENC_STRIDE, h->mb.pic.p_fdec[2], FDEC_STRIDE, height );
                }
                x264_mb_analyse_init_qp( h, &analysis, X264_MAX( h->mb.i_qp - h->mb.ip_offset, h->param.rc.i_qp_min ) );
                goto intra_analysis;
            }

            if( analysis.i_mbrd >= 2 && h->mb.i_type != I_PCM )
            {
                if( IS_INTRA( h->mb.i_type ) )
                {
                    x264_intra_rd_refine( h, &analysis );
                }
                else if( i_partition == D_16x16 )
                {
                    x264_macroblock_cache_ref( h, 0, 0, 4, 4, 0, analysis.l0.me16x16.i_ref );
                    analysis.l0.me16x16.cost = i_cost;
```

```
                    x264_me_refine_qpel_rd( h, &analysis.l0.me16x16, analysis.i_lambda2, 0, 0 );
                }
                else if( i_partition == D_16x8 )
                {
                    h->mb.i_sub_partition[0] = h->mb.i_sub_partition[1] =
                    h->mb.i_sub_partition[2] = h->mb.i_sub_partition[3] = D_L0_8x8;
                    x264_macroblock_cache_ref( h, 0, 0, 4, 2, 0, analysis.l0.me16x8[0].i_ref );
                    x264_macroblock_cache_ref( h, 0, 2, 4, 2, 0, analysis.l0.me16x8[1].i_ref );
                    x264_me_refine_qpel_rd( h, &analysis.l0.me16x8[0], analysis.i_lambda2, 0, 0 );
                    x264_me_refine_qpel_rd( h, &analysis.l0.me16x8[1], analysis.i_lambda2, 8, 0 );
                }
                else if( i_partition == D_8x16 )
                {
                    h->mb.i_sub_partition[0] = h->mb.i_sub_partition[1] =
                    h->mb.i_sub_partition[2] = h->mb.i_sub_partition[3] = D_L0_8x8;
                    x264_macroblock_cache_ref( h, 0, 0, 2, 4, 0, analysis.l0.me8x16[0].i_ref );
                    x264_macroblock_cache_ref( h, 2, 0, 2, 4, 0, analysis.l0.me8x16[1].i_ref );
                    x264_me_refine_qpel_rd( h, &analysis.l0.me8x16[0], analysis.i_lambda2, 0, 0 );
                    x264_me_refine_qpel_rd( h, &analysis.l0.me8x16[1], analysis.i_lambda2, 4, 0 );
                }
                else if( i_partition == D_8x8 )
                {
                    x264_analyse_update_cache( h, &analysis );
                    for( int i8x8 = 0; i8x8 < 4; i8x8++ )
                    {
                        if( h->mb.i_sub_partition[i8x8] == D_L0_8x8 )
                        {
                            x264_me_refine_qpel_rd( h, &analysis.l0.me8x8[i8x8], analysis.i_lambda2, i8x8*4, 0 );
                        }
                        else if( h->mb.i_sub_partition[i8x8] == D_L0_8x4 )
                        {
                            x264_me_refine_qpel_rd( h, &analysis.l0.me8x4[i8x8][0], analysis.i_lambda2, i8x8*4+0, 0 );
                            x264_me_refine_qpel_rd( h, &analysis.l0.me8x4[i8x8][1], analysis.i_lambda2, i8x8*4+2, 0 );
                        }
                        else if( h->mb.i_sub_partition[i8x8] == D_L0_4x8 )
                        {
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x8[i8x8][0], analysis.i_lambda2, i8x8*4+0, 0 );
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x8[i8x8][1], analysis.i_lambda2, i8x8*4+1, 0 );
                        }
                        else if( h->mb.i_sub_partition[i8x8] == D_L0_4x4 )
                        {
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x4[i8x8][0], analysis.i_lambda2, i8x8*4+0, 0 );
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x4[i8x8][1], analysis.i_lambda2, i8x8*4+1, 0 );
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x4[i8x8][2], analysis.i_lambda2, i8x8*4+2, 0 );
                            x264_me_refine_qpel_rd( h, &analysis.l0.me4x4[i8x8][3], analysis.i_lambda2, i8x8*4+3, 0 );
                        }
                    }
                }
            }
        }
    }
    else if( h->sh.i_type == SLICE_TYPE_B )//B Slice的时候
    {
        int i_bskip_cost = COST_MAX;
        int b_skip = 0;

        if( analysis.i_mbrd )
            x264_mb_init_fenc_cache( h, analysis.i_mbrd >= 2 );

        h->mb.i_type = B_SKIP;
        if( h->mb.b_direct_auto_write )
        {
            /* direct=auto heuristic: prefer whichever mode allows more Skip macroblocks */
            for( int i = 0; i < 2; i++ )
            {
                int b_changed = 1;
                h->sh.b_direct_spatial_mv_pred ^= 1;
                analysis.b_direct_available = x264_mb_predict_mv_direct16x16( h, i && analysis.b_direct_available ? &b_changed : NULL

                if( analysis.b_direct_available )
                {
                    if( b_changed )
                    {
                        x264_mb_mc( h );
                        b_skip = x264_macroblock_probe_bskip( h );
                    }
                    h->stat.frame.i_direct_score[ h->sh.b_direct_spatial_mv_pred ] += b_skip;
                }
                else
                    b_skip = 0;
            }
        }
        else
            analysis.b_direct_available = x264_mb_predict_mv_direct16x16( h, NULL );

        analysis.b_try_skip = 0;
        if( analysis.b_direct_available )
        {
            if( !h->mb.b_direct_auto_write )
                x264_mb_mc( h );
            /* If the current macroblock is off the frame, just skip it. */
            if( HAVE_INTERLACED && !MB_INTERLACED && h->mb.i_mb_y * 16 >= h->param.i_height )
```

```
            if( HAVE_INTERLACED && !MB_INTERLACED && h->mb.i_mb_y * 16 >= h->param.i_height )
                b_skip = 1;
            else if( analysis.i_mbrd )
            {
                i_bskip_cost = ssd_mb( h );
                /* 6 = minimum cavlc cost of a non-skipped MB */
                b_skip = h->mb.b_skip_mc = i_bskip_cost <= ((6 * analysis.i_lambda2 + 128) >> 8);
            }
            else if( !h->mb.b_direct_auto_write )
            {
                /* Conditioning the probe on neighboring block types
                 * doesn't seem to help speed or quality. */
                analysis.b_try_skip = x264_macroblock_probe_bskip( h );
                if( h->param.analyse.i_subpel_refine < 3 )
                    b_skip = analysis.b_try_skip;
            }
            /* Set up MVs for future predictors */
            if( b_skip )
            {
                for( int i = 0; i < h->mb.pic.i_fref[0]; i++ )
                    M32( h->mb.mvr[0][i][h->mb.i_mb_xy] ) = 0;
                for( int i = 0; i < h->mb.pic.i_fref[1]; i++ )
                    M32( h->mb.mvr[1][i][h->mb.i_mb_xy] ) = 0;
            }
        }

        if( !b_skip )
        {
            const unsigned int flags = h->param.analyse.inter;
            int i_type;
            int i_partition;
            int i_satd_inter;
            h->mb.b_skip_mc = 0;
            h->mb.i_type = B_DIRECT;

            x264_mb_analyse_load_costs( h, &analysis );

            /* select best inter mode */
            /* direct must be first */
            if( analysis.b_direct_available )
                x264_mb_analyse_inter_direct( h, &analysis );
            /*
             * 16x16 帧间预测宏块分析-B
             *
             * +--------+--------+
             * |                 |
             * |                 |
             * |                 |
             * +        +        +
             * |                 |
             * |                 |
             * |                 |
             * +--------+--------+
             *
             */
            x264_mb_analyse_inter_b16x16( h, &analysis );

            if( h->mb.i_type == B_SKIP )
            {
                for( int i = 1; i < h->mb.pic.i_fref[0]; i++ )
                    M32( h->mb.mvr[0][i][h->mb.i_mb_xy] ) = 0;
                for( int i = 1; i < h->mb.pic.i_fref[1]; i++ )
                    M32( h->mb.mvr[1][i][h->mb.i_mb_xy] ) = 0;
                return;
            }

            i_type = B_L0_L0;
            i_partition = D_16x16;
            i_cost = analysis.l0.me16x16.cost;
            COPY2_IF_LT( i_cost, analysis.l1.me16x16.cost, i_type, B_L1_L1 );
            COPY2_IF_LT( i_cost, analysis.i_cost16x16bi, i_type, B_BI_BI );
            COPY2_IF_LT( i_cost, analysis.i_cost16x16direct, i_type, B_DIRECT );

            if( analysis.i_mbrd && analysis.b_early_terminate && analysis.i_cost16x16direct <= i_cost * 33/32 )
            {
                x264_mb_analyse_b_rd( h, &analysis, i_cost );
                if( i_bskip_cost < analysis.i_rd16x16direct &&
                    i_bskip_cost < analysis.i_rd16x16bi &&
                    i_bskip_cost < analysis.l0.i_rd16x16 &&
                    i_bskip_cost < analysis.l1.i_rd16x16 )
                {
                    h->mb.i_type = B_SKIP;
                    x264_analyse_update_cache( h, &analysis );
                    return;
                }
            }

            if( flags & X264_ANALYSE_BSUB16x16 )
            {

                /*
                 * 8x8 帧间预测宏块分析-B
```

```
             * +--------+
             * |        |
             * |        |
             * |        |
             * +--------+
             *
             */

            if( h->param.analyse.b_mixed_references )
                x264_mb_analyse_inter_b8x8_mixed_ref( h, &analysis );
            else
                x264_mb_analyse_inter_b8x8( h, &analysis );

            COPY3_IF_LT( i_cost, analysis.i_cost8x8bi, i_type, B_8x8, i_partition, D_8x8 );

            /* Try to estimate the cost of b16x8/b8x16 based on the satd scores of the b8x8 modes */
            int i_cost_est16x8bi_total = 0, i_cost_est8x16bi_total = 0;
            int i_mb_type, i_partition16x8[2], i_partition8x16[2];
            for( int i = 0; i < 2; i++ )
            {
                int avg_l0_mv_ref_cost, avg_l1_mv_ref_cost;
                int i_l0_satd, i_l1_satd, i_bi_satd, i_best_cost;
                // 16x8
                i_best_cost = COST_MAX;
                i_l0_satd = analysis.i_satd8x8[0][i*2] + analysis.i_satd8x8[0][i*2+1];
                i_l1_satd = analysis.i_satd8x8[1][i*2] + analysis.i_satd8x8[1][i*2+1];
                i_bi_satd = analysis.i_satd8x8[2][i*2] + analysis.i_satd8x8[2][i*2+1];
                avg_l0_mv_ref_cost = ( analysis.l0.me8x8[i*2].cost_mv + analysis.l0.me8x8[i*2].i_ref_cost
                                     + analysis.l0.me8x8[i*2+1].cost_mv + analysis.l0.me8x8[i*2+1].i_ref_cost + 1 ) >> 1;
                avg_l1_mv_ref_cost = ( analysis.l1.me8x8[i*2].cost_mv + analysis.l1.me8x8[i*2].i_ref_cost
                                     + analysis.l1.me8x8[i*2+1].cost_mv + analysis.l1.me8x8[i*2+1].i_ref_cost + 1 ) >> 1;
                COPY2_IF_LT( i_best_cost, i_l0_satd + avg_l0_mv_ref_cost, i_partition16x8[i], D_L0_8x8 );
                COPY2_IF_LT( i_best_cost, i_l1_satd + avg_l1_mv_ref_cost, i_partition16x8[i], D_L1_8x8 );
                COPY2_IF_LT( i_best_cost, i_bi_satd + avg_l0_mv_ref_cost + avg_l1_mv_ref_cost, i_partition16x8[i], D_BI_8x8 );
                analysis.i_cost_est16x8[i] = i_best_cost;

                // 8x16
                i_best_cost = COST_MAX;
                i_l0_satd = analysis.i_satd8x8[0][i] + analysis.i_satd8x8[0][i+2];
                i_l1_satd = analysis.i_satd8x8[1][i] + analysis.i_satd8x8[1][i+2];
                i_bi_satd = analysis.i_satd8x8[2][i] + analysis.i_satd8x8[2][i+2];
                avg_l0_mv_ref_cost = ( analysis.l0.me8x8[i].cost_mv + analysis.l0.me8x8[i].i_ref_cost
                                     + analysis.l0.me8x8[i+2].cost_mv + analysis.l0.me8x8[i+2].i_ref_cost + 1 ) >> 1;
                avg_l1_mv_ref_cost = ( analysis.l1.me8x8[i].cost_mv + analysis.l1.me8x8[i].i_ref_cost
                                     + analysis.l1.me8x8[i+2].cost_mv + analysis.l1.me8x8[i+2].i_ref_cost + 1 ) >> 1;
                COPY2_IF_LT( i_best_cost, i_l0_satd + avg_l0_mv_ref_cost, i_partition8x16[i], D_L0_8x8 );
                COPY2_IF_LT( i_best_cost, i_l1_satd + avg_l1_mv_ref_cost, i_partition8x16[i], D_L1_8x8 );
                COPY2_IF_LT( i_best_cost, i_bi_satd + avg_l0_mv_ref_cost + avg_l1_mv_ref_cost, i_partition8x16[i], D_BI_8x8 );
                analysis.i_cost_est8x16[i] = i_best_cost;
            }
            i_mb_type = B_L0_L0 + (i_partition16x8[0]>>2) * 3 + (i_partition16x8[1]>>2);
            analysis.i_cost_est16x8[1] += analysis.i_lambda * i_mb_b16x8_cost_table[i_mb_type];
            i_cost_est16x8bi_total = analysis.i_cost_est16x8[0] + analysis.i_cost_est16x8[1];
            i_mb_type = B_L0_L0 + (i_partition8x16[0]>>2) * 3 + (i_partition8x16[1]>>2);
            analysis.i_cost_est8x16[1] += analysis.i_lambda * i_mb_b16x8_cost_table[i_mb_type];
            i_cost_est8x16bi_total = analysis.i_cost_est8x16[0] + analysis.i_cost_est8x16[1];

            /* We can gain a little speed by checking the mode with the lowest estimated cost first */
            int try_16x8_first = i_cost_est16x8bi_total < i_cost_est8x16bi_total;
            if( try_16x8_first && (!analysis.b_early_terminate || i_cost_est16x8bi_total < i_cost) )
            {
                x264_mb_analyse_inter_b16x8( h, &analysis, i_cost );
                COPY3_IF_LT( i_cost, analysis.i_cost16x8bi, i_type, analysis.i_mb_type16x8, i_partition, D_16x8 );
            }
            if( !analysis.b_early_terminate || i_cost_est8x16bi_total < i_cost )
            {
                x264_mb_analyse_inter_b8x16( h, &analysis, i_cost );
                COPY3_IF_LT( i_cost, analysis.i_cost8x16bi, i_type, analysis.i_mb_type8x16, i_partition, D_8x16 );
            }
            if( !try_16x8_first && (!analysis.b_early_terminate || i_cost_est16x8bi_total < i_cost) )
            {
                x264_mb_analyse_inter_b16x8( h, &analysis, i_cost );
                COPY3_IF_LT( i_cost, analysis.i_cost16x8bi, i_type, analysis.i_mb_type16x8, i_partition, D_16x8 );
            }
        }

        if( analysis.i_mbrd || !h->mb.i_subpel_refine )
        {
            /* refine later */
        }
        /* refine qpel */
        else if( i_partition == D_16x16 )
        {
            analysis.l0.me16x16.cost -= analysis.i_lambda * i_mb_b_cost_table[B_L0_L0];
            analysis.l1.me16x16.cost -= analysis.i_lambda * i_mb_b_cost_table[B_L1_L1];
            if( i_type == B_L0_L0 )
            {
                x264_me_refine_qpel( h, &analysis.l0.me16x16 );
                i_cost = analysis.l0.me16x16.cost
                       + analysis.i_lambda * i_mb_b_cost_table[B_L0_L0];
            }
```

```
            else if( i_type == B_L1_L1 )
            {
                x264_me_refine_qpel( h, &analysis.l1.me16x16 );
                i_cost = analysis.l1.me16x16.cost
                       + analysis.i_lambda * i_mb_b_cost_table[B_L1_L1];
            }
            else if( i_type == B_BI_BI )
            {
                x264_me_refine_qpel( h, &analysis.l0.bi16x16 );
                x264_me_refine_qpel( h, &analysis.l1.bi16x16 );
            }
        }
        else if( i_partition == D_16x8 )
        {
            for( int i = 0; i < 2; i++ )
            {
                if( analysis.i_mb_partition16x8[i] != D_L1_8x8 )
                    x264_me_refine_qpel( h, &analysis.l0.me16x8[i] );
                if( analysis.i_mb_partition16x8[i] != D_L0_8x8 )
                    x264_me_refine_qpel( h, &analysis.l1.me16x8[i] );
            }
        }
        else if( i_partition == D_8x16 )
        {
            for( int i = 0; i < 2; i++ )
            {
                if( analysis.i_mb_partition8x16[i] != D_L1_8x8 )
                    x264_me_refine_qpel( h, &analysis.l0.me8x16[i] );
                if( analysis.i_mb_partition8x16[i] != D_L0_8x8 )
                    x264_me_refine_qpel( h, &analysis.l1.me8x16[i] );
            }
        }
        else if( i_partition == D_8x8 )
        {
            for( int i = 0; i < 4; i++ )
            {
                x264_me_t *m;
                int i_part_cost_old;
                int i_type_cost;
                int i_part_type = h->mb.i_sub_partition[i];
                int b_bidir = (i_part_type == D_BI_8x8);

                if( i_part_type == D_DIRECT_8x8 )
                    continue;
                if( x264_mb_partition_listX_table[0][i_part_type] )
                {
                    m = &analysis.l0.me8x8[i];
                    i_part_cost_old = m->cost;
                    i_type_cost = analysis.i_lambda * i_sub_mb_b_cost_table[D_L0_8x8];
                    m->cost -= i_type_cost;
                    x264_me_refine_qpel( h, m );
                    if( !b_bidir )
                        analysis.i_cost8x8bi += m->cost + i_type_cost - i_part_cost_old;
                }
                if( x264_mb_partition_listX_table[1][i_part_type] )
                {
                    m = &analysis.l1.me8x8[i];
                    i_part_cost_old = m->cost;
                    i_type_cost = analysis.i_lambda * i_sub_mb_b_cost_table[D_L1_8x8];
                    m->cost -= i_type_cost;
                    x264_me_refine_qpel( h, m );
                    if( !b_bidir )
                        analysis.i_cost8x8bi += m->cost + i_type_cost - i_part_cost_old;
                }
                /* TODO: update mvp? */
            }
        }

        i_satd_inter = i_cost;

        if( analysis.i_mbrd )
        {
            x264_mb_analyse_b_rd( h, &analysis, i_satd_inter );
            i_type = B_SKIP;
            i_cost = i_bskip_cost;
            i_partition = D_16x16;
            COPY2_IF_LT( i_cost, analysis.l0.i_rd16x16, i_type, B_L0_L0 );
            COPY2_IF_LT( i_cost, analysis.l1.i_rd16x16, i_type, B_L1_L1 );
            COPY2_IF_LT( i_cost, analysis.i_rd16x16bi, i_type, B_BI_BI );
            COPY2_IF_LT( i_cost, analysis.i_rd16x16direct, i_type, B_DIRECT );
            COPY3_IF_LT( i_cost, analysis.i_rd16x8bi, i_type, analysis.i_mb_type16x8, i_partition, D_16x8 );
            COPY3_IF_LT( i_cost, analysis.i_rd8x16bi, i_type, analysis.i_mb_type8x16, i_partition, D_8x16 );
            COPY3_IF_LT( i_cost, analysis.i_rd8x8bi, i_type, B_8x8, i_partition, D_8x8 );

            h->mb.i_type = i_type;
            h->mb.i_partition = i_partition;
        }

        if( h->mb.b_chroma_me )
        {
            if( CHROMA444 )
```

```c
                {
                    x264_mb_analyse_intra( h, &analysis, i_satd_inter );
                    x264_mb_analyse_intra_chroma( h, &analysis );
                }
                else
                {
                    x264_mb_analyse_intra_chroma( h, &analysis );
                    x264_mb_analyse_intra( h, &analysis, i_satd_inter - analysis.i_satd_chroma );
                }
                analysis.i_satd_i16x16 += analysis.i_satd_chroma;
                analysis.i_satd_i8x8   += analysis.i_satd_chroma;
                analysis.i_satd_i4x4   += analysis.i_satd_chroma;
            }
            else
                x264_mb_analyse_intra( h, &analysis, i_satd_inter );

            if( analysis.i_mbrd )
            {
                x264_mb_analyse_transform_rd( h, &analysis, &i_satd_inter, &i_cost );
                x264_intra_rd( h, &analysis, i_satd_inter * 17/16 + 1 );
            }

            COPY2_IF_LT( i_cost, analysis.i_satd_i16x16, i_type, I_16x16 );
            COPY2_IF_LT( i_cost, analysis.i_satd_i8x8, i_type, I_8x8 );
            COPY2_IF_LT( i_cost, analysis.i_satd_i4x4, i_type, I_4x4 );
            COPY2_IF_LT( i_cost, analysis.i_satd_pcm, i_type, I_PCM );

            h->mb.i_type = i_type;
            h->mb.i_partition = i_partition;

            if( analysis.i_mbrd >= 2 && IS_INTRA( i_type ) && i_type != I_PCM )
                x264_intra_rd_refine( h, &analysis );
            if( h->mb.i_subpel_refine >= 5 )
                x264_refine_bidir( h, &analysis );

            if( analysis.i_mbrd >= 2 && i_type > B_DIRECT && i_type < B_SKIP )
            {
                int i_biweight;
                x264_analyse_update_cache( h, &analysis );

                if( i_partition == D_16x16 )
                {
                    if( i_type == B_L0_L0 )
                    {
                        analysis.l0.me16x16.cost = i_cost;
                        x264_me_refine_qpel_rd( h, &analysis.l0.me16x16, analysis.i_lambda2, 0, 0 );
                    }
                    else if( i_type == B_L1_L1 )
                    {
                        analysis.l1.me16x16.cost = i_cost;
                        x264_me_refine_qpel_rd( h, &analysis.l1.me16x16, analysis.i_lambda2, 0, 1 );
                    }
                    else if( i_type == B_BI_BI )
                    {
                        i_biweight = h->mb.bipred_weight[analysis.l0.bi16x16.i_ref][analysis.l1.bi16x16.i_ref];
                        x264_me_refine_bidir_rd( h, &analysis.l0.bi16x16, &analysis.l1.bi16x16, i_biweight, 0, analysis.i_lambda2 );
                    }
                }
                else if( i_partition == D_16x8 )
                {
                    for( int i = 0; i < 2; i++ )
                    {
                        h->mb.i_sub_partition[i*2] = h->mb.i_sub_partition[i*2+1] = analysis.i_mb_partition16x8[i];
                        if( analysis.i_mb_partition16x8[i] == D_L0_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l0.me16x8[i], analysis.i_lambda2, i*8, 0 );
                        else if( analysis.i_mb_partition16x8[i] == D_L1_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l1.me16x8[i], analysis.i_lambda2, i*8, 1 );
                        else if( analysis.i_mb_partition16x8[i] == D_BI_8x8 )
                        {
                            i_biweight = h->mb.bipred_weight[analysis.l0.me16x8[i].i_ref][analysis.l1.me16x8[i].i_ref];
                            x264_me_refine_bidir_rd( h, &analysis.l0.me16x8[i], &analysis.l1.me16x8[i], i_biweight, i*2, analysis.i_l
da2 );
                        }
                    }
                }
                else if( i_partition == D_8x16 )
                {
                    for( int i = 0; i < 2; i++ )
                    {
                        h->mb.i_sub_partition[i] = h->mb.i_sub_partition[i+2] = analysis.i_mb_partition8x16[i];
                        if( analysis.i_mb_partition8x16[i] == D_L0_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l0.me8x16[i], analysis.i_lambda2, i*4, 0 );
                        else if( analysis.i_mb_partition8x16[i] == D_L1_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l1.me8x16[i], analysis.i_lambda2, i*4, 1 );
                        else if( analysis.i_mb_partition8x16[i] == D_BI_8x8 )
                        {
                            i_biweight = h->mb.bipred_weight[analysis.l0.me8x16[i].i_ref][analysis.l1.me8x16[i].i_ref];
                            x264_me_refine_bidir_rd( h, &analysis.l0.me8x16[i], &analysis.l1.me8x16[i], i_biweight, i, analysis.i_lam
2 );
                        }
                    }
```

```
                }
                else if( i_partition == D_8x8 )
                {
                    for( int i = 0; i < 4; i++ )
                    {
                        if( h->mb.i_sub_partition[i] == D_L0_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l0.me8x8[i], analysis.i_lambda2, i*4, 0 );
                        else if( h->mb.i_sub_partition[i] == D_L1_8x8 )
                            x264_me_refine_qpel_rd( h, &analysis.l1.me8x8[i], analysis.i_lambda2, i*4, 1 );
                        else if( h->mb.i_sub_partition[i] == D_BI_8x8 )
                        {
                            i_biweight = h->mb.bipred_weight[analysis.l0.me8x8[i].i_ref][analysis.l1.me8x8[i].i_ref];
                            x264_me_refine_bidir_rd( h, &analysis.l0.me8x8[i], &analysis.l1.me8x8[i], i_biweight, i, analysis.i_lambd
);
                        }
                    }
                }
            }
        }
    }

    x264_analyse_update_cache( h, &analysis );

    /* In rare cases we can end up qpel-RDing our way back to a larger partition size
     * without realizing it.  Check for this and account for it if necessary. */
    if( analysis.i_mbrd >= 2 )
    {
        /* Don't bother with bipred or 8x8-and-below, the odds are incredibly low. */
        static const uint8_t check_mv_lists[X264_MBTYPE_MAX] = {[P_L0]=1, [B_L0_L0]=1, [B_L1_L1]=2};
        int list = check_mv_lists[h->mb.i_type] - 1;
        if( list >= 0 && h->mb.i_partition != D_16x16 &&
            M32( &h->mb.cache.mv[list][x264_scan8[0]] ) == M32( &h->mb.cache.mv[list][x264_scan8[12]] ) &&
            h->mb.cache.ref[list][x264_scan8[0]] == h->mb.cache.ref[list][x264_scan8[12]] )
                h->mb.i_partition = D_16x16;
    }

    if( !analysis.i_mbrd )
        x264_mb_analyse_transform( h );

    if( analysis.i_mbrd == 3 && !IS_SKIP(h->mb.i_type) )
        x264_mb_analyse_qp_rd( h, &analysis );

    h->mb.b_trellis = h->param.analyse.i_trellis;
    h->mb.b_noise_reduction = h->mb.b_noise_reduction || (!!h->param.analyse.i_noise_reduction && !IS_INTRA( h->mb.i_type ));

    if( !IS_SKIP(h->mb.i_type) && h->mb.i_psy_trellis && h->param.analyse.i_trellis == 1 )
        x264_psy_trellis_init( h, 0 );
    if( h->mb.b_trellis == 1 || h->mb.b_noise_reduction )
        h->mb.i_skip_intra = 0;
}
```

尽管x264_macroblock_analyse()的源代码比较长，但是它的逻辑比较清晰，如下所示：

（1）如果当前是I Slice，调用x264_mb_analyse_intra()进行Intra宏块的帧内预测模式分析。

（2）如果当前是P Slice，则进行下面流程的分析：

a)调用x264_macroblock_probe_pskip()分析是否为Skip宏块，如果是的话则不再进行下面分析。

b)调用x264_mb_analyse_inter_p16x16()分析P16x16帧间预测的代价。

c)调用x264_mb_analyse_inter_p8x8()分析P8x8帧间预测的代价。

d)如果P8x8代价值小于P16x16，则依次对4个8x8的子宏块分割进行判断：

i.调用x264_mb_analyse_inter_p4x4()分析P4x4帧间预测的代价。

ii.如果P4x4代价值小于P8x8，则调用 x264_mb_analyse_inter_p8x4()和x264_mb_analyse_inter_p4x8()分析P8x4和P4x8帧间预测的代价。

e)如果P8x8代价值小于P16x16，调用x264_mb_analyse_inter_p16x8()和x264_mb_analyse_inter_p8x16()分析P16x8和P8x16帧间预测的代价。

f)此外还要调用x264_mb_analyse_intra()，检查当前宏块作为Intra宏块编码的代价是否小于作为P宏块编码的代价（P Slice中也允许有Intra宏块）。

（3）如果当前是B Slice，则进行和P Slice类似的处理。

本文记录这一流程中Intra宏块的帧内预测模式分析函数x264_mb_analyse_intra()。

x264_mb_analyse_intra()

x264_mb_analyse_intra()用于对Intra宏块进行帧内预测模式的分析。该函数的定义位于encoder\analyse.c，如下所示。

[cpp]

```cpp
//帧内预测分析-从16x16的SAD,4个8x8的SAD和，16个4x4SAD中选出最优方式
static void x264_mb_analyse_intra( x264_t *h, x264_mb_analysis_t *a, int i_satd_inter )
{
    const unsigned int flags = h->sh.i_type == SLICE_TYPE_I ? h->param.analyse.intra : h->param.analyse.inter;
    //计算
```

```
    //p_fenc是编码帧
    pixel *p_src = h->mb.pic.p_fenc[0];
    //p_fdec是重建帧
    pixel *p_dst = h->mb.pic.p_fdec[0];

    static const int8_t intra_analysis_shortcut[2][2][2][5] =
    {
        {{{I_PRED_4x4_HU, -1, -1, -1, -1},
          {I_PRED_4x4_DDL, I_PRED_4x4_VL, -1, -1, -1}},
         {{I_PRED_4x4_DDR, I_PRED_4x4_HD, I_PRED_4x4_HU, -1, -1},
          {I_PRED_4x4_DDL, I_PRED_4x4_DDR, I_PRED_4x4_VR, I_PRED_4x4_VL, -1}}},
        {{{I_PRED_4x4_HU, -1, -1, -1, -1},
          {-1, -1, -1, -1, -1}},
         {{I_PRED_4x4_DDR, I_PRED_4x4_HD, I_PRED_4x4_HU, -1, -1},
          {I_PRED_4x4_DDR, I_PRED_4x4_VR, -1, -1, -1}}},
    };

    int idx;
    int lambda = a->i_lambda;

    /*---------------- Try all mode and calculate their score ---------------*
    /* Disabled i16x16 for AVC-Intra compat */
    //帧内16x16
    if( !h->param.i_avcintra_class )
    {
        //获得可用的帧内预测模式-针对帧内16x16
        /*
         * 16x16块
         *
         * +--------+--------+
         * |                 |
         * |                 |
         * |                 |
         * +        +        +
         * |                 |
         * |                 |
         * |                 |
         * +--------+--------+
         *
         */
        //左侧是否有可用数据？上方是否有可用数据？
        const int8_t *predict_mode = predict_16x16_mode_available( h->mb.i_neighbour_intra );

        /* Not heavily tuned */
        static const uint8_t i16x16_thresh_lut[11] = { 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4 };
        int i16x16_thresh = a->b_fast_intra ? (i16x16_thresh_lut[h->mb.i_subpel_refine]*i_satd_inter)>>1 : COST_MAX;

        if( !h->mb.b_lossless && predict_mode[3] >= 0 )
        {
            h->pixf.intra_mbcmp_x3_16x16( p_src, p_dst, a->i_satd_i16x16_dir );
            a->i_satd_i16x16_dir[0] += lambda * bs_size_ue(0);
            a->i_satd_i16x16_dir[1] += lambda * bs_size_ue(1);
            a->i_satd_i16x16_dir[2] += lambda * bs_size_ue(2);
            COPY2_IF_LT( a->i_satd_i16x16, a->i_satd_i16x16_dir[0], a->i_predict16x16, 0 );
            COPY2_IF_LT( a->i_satd_i16x16, a->i_satd_i16x16_dir[1], a->i_predict16x16, 1 );
            COPY2_IF_LT( a->i_satd_i16x16, a->i_satd_i16x16_dir[2], a->i_predict16x16, 2 );

            /* Plane is expensive, so don't check it unless one of the previous modes was useful. */
            if( a->i_satd_i16x16 <= i16x16_thresh )
            {
                h->predict_16x16[I_PRED_16x16_P]( p_dst );
                a->i_satd_i16x16_dir[I_PRED_16x16_P] = h->pixf.mbcmp[PIXEL_16x16]( p_dst, FDEC_STRIDE, p_src, FENC_STRIDE );
                a->i_satd_i16x16_dir[I_PRED_16x16_P] += lambda * bs_size_ue(3);
                COPY2_IF_LT( a->i_satd_i16x16, a->i_satd_i16x16_dir[I_PRED_16x16_P], a->i_predict16x16, 3 );
            }
        }
        else
        {
            //遍历所有的可用的Intra16x16帧内预测模式
            //最多4种
            for( ; *predict_mode >= 0; predict_mode++ )
            {
                int i_satd;
                int i_mode = *predict_mode;

                //帧内预测汇编函数：根据左边和上边的像素计算出预测值
                /*
                 * 帧内预测举例
                 * Vertical预测方式
                 *    |X1 X2 ... X16
                 *  --+---------------
                 *    |X1 X2 ... X16
                 *    |X1 X2 ... X16
                 *    |.. .. ... X16
                 *    |X1 X2 ... X16
                 *
                 * Horizontal预测方式
                 *    |
                 *  --+---------------
                 *  X1| X1  X1 ...  X1
                 *  X2| X2  X2 ...  X2
```

```
                 *  ..| ..  .. ...  ..
                 * X16|X16 X16 ... X16
                 *
                 * DC预测方式
                 *    |X1 X2 ... X16
                 *  --+---------------
                 * X17|
                 * X18|     Y
                 *  ..|
                 * X32|
                 *
                 * Y=(X1+X2+X3+X4+...+X31+X32)/32
                 *
                 */
                if( h->mb.b_lossless )
                    x264_predict_lossless_16x16( h, 0, i_mode );
                else
                    h->predict_16x16[i_mode]( p_dst );//计算结果存储在p_dst重建帧中

                //计算SAD或者是SATD（SATD(transformed)是经过Hadamard变换之后的SAD）
                //即编码代价
                //数据位于p_dst和p_src
                i_satd = h->pixf.mbcmp[PIXEL_16x16]( p_dst, FDEC_STRIDE, p_src, FENC_STRIDE ) +
                         lambda * bs_size_ue( x264_mb_pred_mode16x16_fix[i_mode] );

                //COPY2_IF_LT()函数的意思是“copy if little”。即如果值更小（代价更小），就拷贝。
                //宏定义展开后如下所示
                //if((i_satd)<(a->i_satd_i16x16))
                //{
                //    (a->i_satd_i16x16)=(i_satd);
                //    (a->i_predict16x16)=(i_mode);
                //}
                COPY2_IF_LT( a->i_satd_i16x16, i_satd, a->i_predict16x16, i_mode );
                //每种模式的代价都会存储
                a->i_satd_i16x16_dir[i_mode] = i_satd;
            }
        }

        if( h->sh.i_type == SLICE_TYPE_B )
            /* cavlc mb type prefix */
            a->i_satd_i16x16 += lambda * i_mb_b_cost_table[I_16x16];

        if( a->i_satd_i16x16 > i16x16_thresh )
            return;
    }

    uint16_t *cost_i4x4_mode = (uint16_t*)ALIGN((intptr_t)x264_cost_i4x4_mode,64) + a->i_qp*32 + 8;
    /* 8x8 prediction selection */
    //帧内8x8（没研究过）
    if( flags & X264_ANALYSE_I8x8 )
    {
        ALIGNED_ARRAY_32( pixel, edge,[36] );
        x264_pixel_cmp_t sa8d = (h->pixf.mbcmp[0] == h->pixf.satd[0]) ? h->pixf.sa8d[PIXEL_8x8] : h->pixf.mbcmp[PIXEL_8x8];
        int i_satd_thresh = a->i_mbrd ? COST_MAX : X264_MIN( i_satd_inter, a->i_satd_i16x16 );

        // FIXME some bias like in i4x4?
        int i_cost = lambda * 4; /* base predmode costs */
        h->mb.i_cbp_luma = 0;

        if( h->sh.i_type == SLICE_TYPE_B )
            i_cost += lambda * i_mb_b_cost_table[I_8x8];

        for( idx = 0;; idx++ )
        {
            int x = idx&1;
            int y = idx>>1;
            pixel *p_src_by = p_src + 8*x + 8*y*FENC_STRIDE;
            pixel *p_dst_by = p_dst + 8*x + 8*y*FDEC_STRIDE;
            int i_best = COST_MAX;
            int i_pred_mode = x264_mb_predict_intra4x4_mode( h, 4*idx );

            const int8_t *predict_mode = predict_8x8_mode_available( a->b_avoid_topright, h->mb.i_neighbour8[idx], idx );
            h->predict_8x8_filter( p_dst_by, edge, h->mb.i_neighbour8[idx], ALL_NEIGHBORS );

            if( h->pixf.intra_mbcmp_x9_8x8 && predict_mode[8] >= 0 )
            {
                /* No shortcuts here. The SSSE3 implementation of intra_mbcmp_x9 is fast enough. */
                i_best = h->pixf.intra_mbcmp_x9_8x8( p_src_by, p_dst_by, edge, cost_i4x4_mode-i_pred_mode, a->i_satd_i8x8_dir[idx] );
                i_cost += i_best & 0xffff;
                i_best >>= 16;
                a->i_predict8x8[idx] = i_best;
                if( idx == 3 || i_cost > i_satd_thresh )
                    break;
                x264_macroblock_cache_intra8x8_pred( h, 2*x, 2*y, i_best );
            }
            else
            {
                if( !h->mb.b_lossless && predict_mode[5] >= 0 )
                {
                    ALIGNED_ARRAY_16( int32_t, satd,[9] );
```

```c
                    h->pixf.intra_mbcmp_x3_8x8( p_src_by, edge, satd );
                    int favor_vertical = satd[I_PRED_4x4_H] > satd[I_PRED_4x4_V];
                    satd[i_pred_mode] -= 3 * lambda;
                    for( int i = 2; i >= 0; i-- )
                    {
                        int cost = satd[i];
                        a->i_satd_i8x8_dir[idx][i] = cost + 4 * lambda;
                        COPY2_IF_LT( i_best, cost, a->i_predict8x8[idx], i );
                    }

                    /* Take analysis shortcuts: don't analyse modes that are too
                     * far away direction-wise from the favored mode. */
                    if( a->i_mbrd < 1 + a->b_fast_intra )
                        predict_mode = intra_analysis_shortcut[a->b_avoid_topright][predict_mode[8] >= 0][favor_vertical];
                    else
                        predict_mode += 3;
                }

                for( ; *predict_mode >= 0 && (i_best >= 0 || a->i_mbrd >= 2); predict_mode++ )
                {
                    int i_satd;
                    int i_mode = *predict_mode;

                    if( h->mb.b_lossless )
                        x264_predict_lossless_8x8( h, p_dst_by, 0, idx, i_mode, edge );
                    else
                        h->predict_8x8[i_mode]( p_dst_by, edge );

                    i_satd = sa8d( p_dst_by, FDEC_STRIDE, p_src_by, FENC_STRIDE );
                    if( i_pred_mode == x264_mb_pred_mode4x4_fix(i_mode) )
                        i_satd -= 3 * lambda;

                    COPY2_IF_LT( i_best, i_satd, a->i_predict8x8[idx], i_mode );
                    a->i_satd_i8x8_dir[idx][i_mode] = i_satd + 4 * lambda;
                }
                i_cost += i_best + 3*lambda;

                if( idx == 3 || i_cost > i_satd_thresh )
                    break;
                if( h->mb.b_lossless )
                    x264_predict_lossless_8x8( h, p_dst_by, 0, idx, a->i_predict8x8[idx], edge );
                else
                    h->predict_8x8[a->i_predict8x8[idx]]( p_dst_by, edge );
                x264_macroblock_cache_intra8x8_pred( h, 2*x, 2*y, a->i_predict8x8[idx] );
            }
            /* we need to encode this block now (for next ones) */
            x264_mb_encode_i8x8( h, 0, idx, a->i_qp, a->i_predict8x8[idx], edge, 0 );
        }

        if( idx == 3 )
        {
            a->i_satd_i8x8 = i_cost;
            if( h->mb.i_skip_intra )
            {
                h->mc.copy[PIXEL_16x16]( h->mb.pic.i8x8_fdec_buf, 16, p_dst, FDEC_STRIDE, 16 );
                h->mb.pic.i8x8_nnz_buf[0] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 0]] );
                h->mb.pic.i8x8_nnz_buf[1] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 2]] );
                h->mb.pic.i8x8_nnz_buf[2] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 8]] );
                h->mb.pic.i8x8_nnz_buf[3] = M32( &h->mb.cache.non_zero_count[x264_scan8[10]] );
                h->mb.pic.i8x8_cbp = h->mb.i_cbp_luma;
                if( h->mb.i_skip_intra == 2 )
                    h->mc.memcpy_aligned( h->mb.pic.i8x8_dct_buf, h->dct.luma8x8, sizeof(h->mb.pic.i8x8_dct_buf) );
            }
        }
        else
        {
            static const uint16_t cost_div_fix8[3] = {1024,512,341};
            a->i_satd_i8x8 = COST_MAX;
            i_cost = (i_cost * cost_div_fix8[idx]) >> 8;
        }
        /* Not heavily tuned */
        static const uint8_t i8x8_thresh[11] = { 4, 4, 4, 5, 5, 5, 6, 6, 6, 6, 6 };
        if( a->b_early_terminate && X264_MIN(i_cost, a->i_satd_i16x16) > (i_satd_inter*i8x8_thresh[h->mb.i_subpel_refine])>>2 )
            return;
    }

    /* 4x4 prediction selection */
    //帧内4x4
    if( flags & X264_ANALYSE_I4x4 )
    {
        /*
         * 16x16 宏块被划分为16个4x4子块
         *
         * +----+----+----+----+
         * |    |    |    |    |
         * +----+----+----+----+
         * |    |    |    |    |
         * +----+----+----+----+
         * |    |    |    |    |
         * +----+----+----+----+
         * |    |    |    |    |
```

```
         * +----+----+----+----+
         *
         */
        int i_cost = lambda * (24+16); /* 24from JVT (SATD0), 16 from base predmode costs */
        int i_satd_thresh = a->b_early_terminate ? X264_MIN3( i_satd_inter, a->i_satd_i16x16, a->i_satd_i8x8 ) : COST_MAX;
        h->mb.i_cbp_luma = 0;

        if( a->b_early_terminate && a->i_mbrd )
            i_satd_thresh = i_satd_thresh * (10-a->b_fast_intra)/8;

        if( h->sh.i_type == SLICE_TYPE_B )
            i_cost += lambda * i_mb_b_cost_table[I_4x4];
        //循环所有的4x4块
        for( idx = 0;; idx++ )
        {
            //编码帧中的像素
            //block_idx_xy_fenc[]记录了4x4小块在p_fenc中的偏移地址
            pixel *p_src_by = p_src + block_idx_xy_fenc[idx];
            //重建帧中的像素
            //block_idx_xy_fdec[]记录了4x4小块在p_fdec中的偏移地址
            pixel *p_dst_by = p_dst + block_idx_xy_fdec[idx];

            int i_best = COST_MAX;
            int i_pred_mode = x264_mb_predict_intra4x4_mode( h, idx );
            //获得可用的帧内预测模式-针对帧内4x4
            //左侧是否有可用数据？上方是否有可用数据？
            const int8_t *predict_mode = predict_4x4_mode_available( a->b_avoid_topright, h->mb.i_neighbour4[idx], idx );

            if( (h->mb.i_neighbour4[idx] & (MB_TOPRIGHT|MB_TOP)) == MB_TOP )
                /* emulate missing topright samples */
                MPIXEL_X4( &p_dst_by[4 - FDEC_STRIDE] ) = PIXEL_SPLAT_X4( p_dst_by[3 - FDEC_STRIDE] );

            if( h->pixf.intra_mbcmp_x9_4x4 && predict_mode[8] >= 0 )
            {
                /* No shortcuts here. The SSSE3 implementation of intra_mbcmp_x9 is fast enough. */
                i_best = h->pixf.intra_mbcmp_x9_4x4( p_src_by, p_dst_by, cost_i4x4_mode-i_pred_mode );
                i_cost += i_best & 0xffff;
                i_best >>= 16;
                a->i_predict4x4[idx] = i_best;
                if( i_cost > i_satd_thresh || idx == 15 )
                    break;
                h->mb.cache.intra4x4_pred_mode[x264_scan8[idx]] = i_best;
            }
            else
            {
                if( !h->mb.b_lossless && predict_mode[5] >= 0 )
                {
                    ALIGNED_ARRAY_16( int32_t, satd,[9] );

                    h->pixf.intra_mbcmp_x3_4x4( p_src_by, p_dst_by, satd );
                    int favor_vertical = satd[I_PRED_4x4_H] > satd[I_PRED_4x4_V];
                    satd[i_pred_mode] -= 3 * lambda;
                    i_best = satd[I_PRED_4x4_DC]; a->i_predict4x4[idx] = I_PRED_4x4_DC;
                    COPY2_IF_LT( i_best, satd[I_PRED_4x4_H], a->i_predict4x4[idx], I_PRED_4x4_H );
                    COPY2_IF_LT( i_best, satd[I_PRED_4x4_V], a->i_predict4x4[idx], I_PRED_4x4_V );

                    /* Take analysis shortcuts: don't analyse modes that are too
                     * far away direction-wise from the favored mode. */
                    if( a->i_mbrd < 1 + a->b_fast_intra )
                        predict_mode = intra_analysis_shortcut[a->b_avoid_topright][predict_mode[8] >= 0][favor_vertical];
                    else
                        predict_mode += 3;
                }

                if( i_best > 0 )
                {
                    //遍历所有Intra4x4帧内模式，最多9种
                    for( ; *predict_mode >= 0; predict_mode++ )
                    {
                        int i_satd;
                        int i_mode = *predict_mode;
                        /*
                         * 4x4帧内预测举例
                         *
                         * Vertical预测方式
                         *   |X1 X2 X3 X4
                         * --+-----------
                         *   |X1 X2 X3 X4
                         *   |X1 X2 X3 X4
                         *   |X1 X2 X3 X4
                         *   |X1 X2 X3 X4
                         *
                         * Horizontal预测方式
                         *   |
                         * --+-----------
                         * X5|X5 X5 X5 X5
                         * X6|X6 X6 X6 X6
                         * X7|X7 X7 X7 X7
                         * X8|X8 X8 X8 X8
                         *
                         * DC预测方式
                         *   |X1 X2 X3 X4
```

```
                         * |X1 X2 X3 X4
                         * --+-----------
                         * X5|
                         * X6|     Y
                         * X7|
                         * X8|
                         *
                         * Y=(X1+X2+X3+X4+X5+X6+X7+X8)/8
                         *
                         */
                        if( h->mb.b_lossless )
                            x264_predict_lossless_4x4( h, p_dst_by, 0, idx, i_mode );
                        else
                            h->predict_4x4[i_mode]( p_dst_by );//帧内预测汇编函数-存储在重建帧中

                        //计算SAD或者是SATD（SATD（Transformed）是经过Hadamard变换之后的SAD）
                        //即编码代价
                        //p_src_by编码帧，p_dst_by重建帧
                        i_satd = h->pixf.mbcmp[PIXEL_4x4]( p_dst_by, FDEC_STRIDE, p_src_by, FENC_STRIDE );
                        if( i_pred_mode == x264_mb_pred_mode4x4_fix(i_mode) )
                        {
                            i_satd -= lambda * 3;
                            if( i_satd <= 0 )
                            {
                                i_best = i_satd;
                                a->i_predict4x4[idx] = i_mode;
                                break;
                            }
                        }
                        //COPY2_IF_LT()函数的意思是“copy if little”。即如果值更小（代价更小），就拷贝。
                        //宏定义展开后如下所示
                        //if((i_satd)<(i_best))
                        //{
                        //    (i_best)=(i_satd);
                        //    (a->i_predict4x4[idx])=(i_mode);
                        //}

                        //看看代价是否更小
                        //i_best中存储了最小的代价值
                        //i_predict4x4[idx]中存储了代价最小的预测模式（idx为4x4小块的序号）
                        COPY2_IF_LT( i_best, i_satd, a->i_predict4x4[idx], i_mode );
                    }
                }
                //累加各个4x4块的代价（累加每个块的最小代价）
                i_cost += i_best + 3 * lambda;
                if( i_cost > i_satd_thresh || idx == 15 )
                    break;
                if( h->mb.b_lossless )
                    x264_predict_lossless_4x4( h, p_dst_by, 0, idx, a->i_predict4x4[idx] );
                else
                    h->predict_4x4[a->i_predict4x4[idx]]( p_dst_by );

                /*
                 * 将mode填充至intra4x4_pred_mode_cache
                 *
                 * 用简单图形表示intra4x4_pred_mode_cache如下。数字代表填充顺序（一共填充16次）
                 *   |
                 * --+-------------------
                 *   | 0 0 0 0  0  0  0  0
                 *   | 0 0 0 0  1  2  5  6
                 *   | 0 0 0 0  3  4  7  8
                 *   | 0 0 0 0  9 10 13 14
                 *   | 0 0 0 0 11 12 15 16
                 *
                 */
                h->mb.cache.intra4x4_pred_mode[x264_scan8[idx]] = a->i_predict4x4[idx];
            }
            /* we need to encode this block now (for next ones) */
            x264_mb_encode_i4x4( h, 0, idx, a->i_qp, a->i_predict4x4[idx], 0 );
        }
        if( idx == 15 )//处理最后一个4x4小块（一共16个块）
        {
            //开销（累加完的）
            a->i_satd_i4x4 = i_cost;
            if( h->mb.i_skip_intra )
            {
                h->mc.copy[PIXEL_16x16]( h->mb.pic.i4x4_fdec_buf, 16, p_dst, FDEC_STRIDE, 16 );
                h->mb.pic.i4x4_nnz_buf[0] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 0]] );
                h->mb.pic.i4x4_nnz_buf[1] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 2]] );
                h->mb.pic.i4x4_nnz_buf[2] = M32( &h->mb.cache.non_zero_count[x264_scan8[ 8]] );
                h->mb.pic.i4x4_nnz_buf[3] = M32( &h->mb.cache.non_zero_count[x264_scan8[10]] );
                h->mb.pic.i4x4_cbp = h->mb.i_cbp_luma;
                if( h->mb.i_skip_intra == 2 )
                    h->mc.memcpy_aligned( h->mb.pic.i4x4_dct_buf, h->dct.luma4x4, sizeof(h->mb.pic.i4x4_dct_buf) );
            }
        }
        else
            a->i_satd_i4x4 = COST_MAX;
    }
}
```

总体说来x264_mb_analyse_intra()通过计算Intra16x16，Intra8x8（暂时没有研究），Intra4x4这3中帧内预测模式的代价，比较后得到最佳的帧内预测模式。该函数的等流程大致如下：

（1）进行Intra16X16模式的预测

a)调用predict_16x16_mode_available()根据周围宏块的情况判断其可用的预测模式（主要检查左边和上边的块是否可用）。

b)循环计算4种Intra16x16帧内预测模式：

i.调用predict_16x16[]()汇编函数进行Intra16x16帧内预测

ii.调用x264_pixel_function_t中的mbcmp[]()计算编码代价（mbcmp[]()指向SAD或者SATD汇编函数）。

c)获取最小代价的Intra16x16模式。

（2）进行Intra8x8模式的预测（未研究，流程应该类似）

（3）进行Intra4X4块模式的预测

a)循环处理16个4x4的块：

i.调用x264_mb_predict_intra4x4_mode()根据周围宏块情况判断该块可用的预测模式。

ii.循环计算9种Intra4x4的帧内预测模式：

1)调用predict_4x4 []()汇编函数进行Intra4x4帧内预测

2)调用x264_pixel_function_t中的mbcmp[]()计算编码代价（mbcmp[]()指向SAD或者SATD汇编函数）。

iii.获取最小代价的Intra4x4模式。

b)将16个4X4块的最小代价相加，得到总代价。

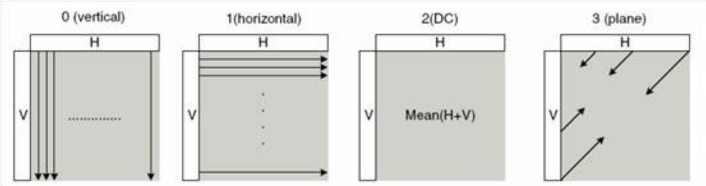
（4）将上述3中模式的代价进行对比，取最小者为当前宏块的帧内预测模式。

后文将会对其中涉及到的几种汇编函数进行分析。在看源代码之前，简单记录一下相关的知识。

帧内预测知识

简单记录一下帧内预测的方法。帧内预测根据宏块左边和上边的边界像素值推算宏块内部的像素值，帧内预测的效果如下图所示。其中左边的图为图像原始画面，右边的图为经过帧内预测后没有叠加残差的画面。

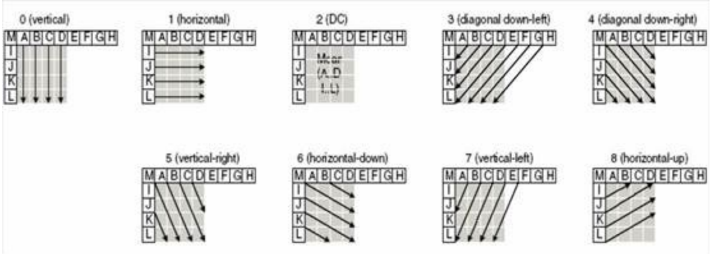
H.264中有两种帧内预测模式：16x16亮度帧内预测模式和4x4亮度帧内预测模式。其中16x16帧内预测模式一共有4种，如下图所示。



这4种模式列表如下。

模式	描述
Vertical	由上边像素推出相应像素值
Horizontal	由左边像素推出相应像素值
DC	由上边和左边像素平均值推出相应像素值
Plane	由上边和左边像素推出相应像素值

4x4帧内预测模式一共有9种，如下图所示。



可以看出，Intra4x4帧内预测模式中前4种和Intra16x16是一样的。后面多增加了几种预测箭头不是45度角的方式——前面的箭头位于“口”中，而后面的箭头位于“日”中。

像素比较知识

帧内预测代价计算的过程中涉及到SAD和SATD像素计算，简单记录几个相关的概念。有关SAD、SATD、SSD的定义如下：

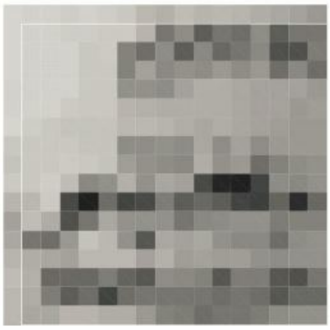
SAD（Sum of Absolute Difference）也可以称为SAE（Sum of Absolute Error），即绝对误差和。它的计算方法就是求出两个像素块对应像素点的差值，将这些差值分别求绝对值之后再进行累加。

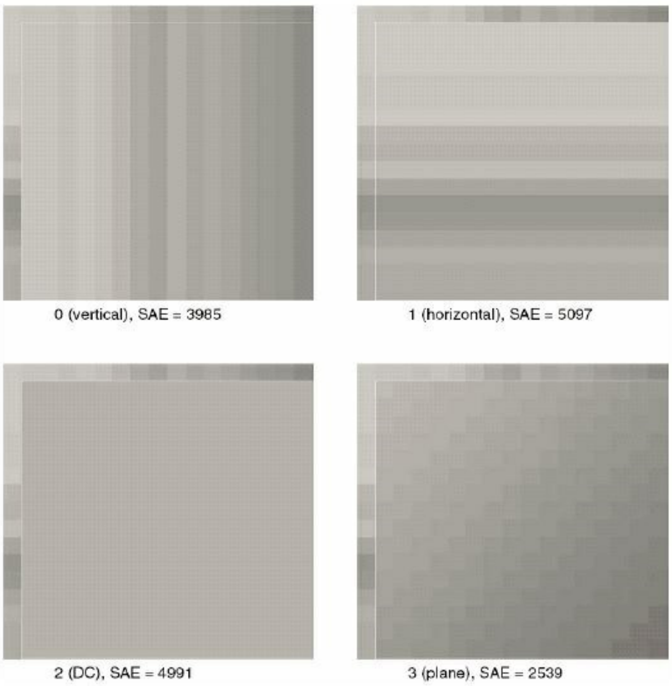
SATD（Sum of Absolute Transformed Difference）即Hadamard变换后再绝对值求和。它和SAD的区别在于多了一个“变换”。

SSD（Sum of Squared Difference）也可以称为SSE（Sum of Squared Error），即差值的平方和。它和SAD的区别在于多了一个“平方”。

H.264中使用SAD和SATD进行宏块预测模式的判断。早期的编码器使用SAD进行计算，近期的编码器多使用SATD进行计算。为什么使用SATD而不使用SAD呢？关键原因在于编码之后码流的大小是和图像块DCT变换后频域信息紧密相关的，而和变换前的时域信息关联性小一些。SAD只能反应时域信息；SATD却可以反映频域信息，而且计算复杂度也低于DCT变换，因此是比较合适的模式选择的依据。

使用SAD进行模式选择的示例如下所示。下面这张图代表了一个普通的Intra16x16的宏块的像素。它的下方包含了使用Vertical，Horizontal，DC和Plane四种帧内预测模式预测的像素。通过计算可以得到这几种预测像素和原始像素之间的SAD（SAE）分别为3985，5097，4991，2539。由于Plane模式的SAD取值最小，由此可以断定Plane模式对于这个宏块来说是最好的帧内预测模式。





0 (vertical), SAE = 3985

1 (horizontal), SAE = 5097

2 (DC), SAE = 4991

3 (plane), SAE = 2539

下面按照Intra16x16预测，Intra4x4预测，像素计算的顺序记录依次记录各个模块的汇编函数源代码。

Intra16x16帧内预测源代码

Intra16x16帧内预测模块的初始化函数是x264_predict_16x16_init()。该函数对x264_predict_t结构体中的函数指针进行了赋值。X264运行的过程中只要调用x264_predict_t的函数指针就可以完成相应的功能。

x264_predict_16x16_init()

x264_predict_16x16_init()用于初始化Intra16x16帧内预测汇编函数。该函数的定义位于x264\common\predict.c，如下所示。

[cpp]

```cpp
//Intra16x16帧内预测汇编函数初始化
void x264_predict_16x16_init( int cpu, x264_predict_t pf[7] )
{
    //C语言版本
    //================================================
    //垂直 Vertical
    pf[I_PRED_16x16_V ]     = x264_predict_16x16_v_c;
    //水平 Horizontal
    pf[I_PRED_16x16_H ]     = x264_predict_16x16_h_c;
    //DC
    pf[I_PRED_16x16_DC]     = x264_predict_16x16_dc_c;
    //Plane
    pf[I_PRED_16x16_P ]     = x264_predict_16x16_p_c;
    //这几种是啥？
    pf[I_PRED_16x16_DC_LEFT]= x264_predict_16x16_dc_left_c;
    pf[I_PRED_16x16_DC_TOP ]= x264_predict_16x16_dc_top_c;
    pf[I_PRED_16x16_DC_128 ]= x264_predict_16x16_dc_128_c;
    //================================================
    //MMX版本
#if HAVE_MMX
    x264_predict_16x16_init_mmx( cpu, pf );
#endif
    //ALTIVEC版本
#if HAVE_ALTIVEC
    if( cpu&X264_CPU_ALTIVEC )
        x264_predict_16x16_init_altivec( pf );
#endif
    //ARMV6版本
#if HAVE_ARMV6
    x264_predict_16x16_init_arm( cpu, pf );
#endif
    //AARCH64版本
#if ARCH_AARCH64
    x264_predict_16x16_init_aarch64( cpu, pf );
#endif
}
```

从源代码可看出，x264_predict_16x16_init()首先对帧内预测函数指针数组x264_predict_t[]中的元素赋值了C语言版本的函数x264_predict_16x16_v_c()，x264_predict_16x16_h_c()，x264_predict_16x16_dc_c()，x264_predict_16x16_p_c()；然后会判断系统平台的特性，如果平台支持的话，会调用x264_predict_16x16_init_mmx()，x264_predict_16x16_init_arm()等给x264_predict_t[]中的元素赋值经过汇编优化的函数。下文首先看一下Intra16x16中的4种帧内预测模式的C语言版本，作为对比再看一下Intra16x16中Vertical模式的X86汇编版本和NEON汇编版本。

x264_predict_16x16_v_c()

x264_predict_16x16_v_c()是Intra16x16帧内预测Vertical模式的C语言版本函数。该函数的定义位于common\predict.c，如下所示。

```cpp
//16x16帧内预测
//垂直预测（Vertical）
void x264_predict_16x16_v_c( pixel *src )
{
    /*
     * Vertical预测方式
     *   |X1 X2 X3 X4
     * --+-----------
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *
     */
    /*
     * 【展开宏定义】
     * uint32_t v0 = ((x264_union32_t*)(&src[ 0-FDEC_STRIDE]))->i;
     * uint32_t v1 = ((x264_union32_t*)(&src[ 4-FDEC_STRIDE]))->i;
     * uint32_t v2 = ((x264_union32_t*)(&src[ 8-FDEC_STRIDE]))->i;
     * uint32_t v3 = ((x264_union32_t*)(&src[12-FDEC_STRIDE]))->i;
     * 在这里，上述代码实际上相当于：
     * uint32_t v0 = *((uint32_t*)(&src[ 0-FDEC_STRIDE]));
     * uint32_t v1 = *((uint32_t*)(&src[ 4-FDEC_STRIDE]));
     * uint32_t v2 = *((uint32_t*)(&src[ 8-FDEC_STRIDE]));
     * uint32_t v3 = *((uint32_t*)(&src[12-FDEC_STRIDE]));
     * 即分成4次，每次取出4个像素（一共16个像素），分别赋值给v0，v1，v2，v3
     * 取出的值源自于16x16块上面的一行像素
     *    0|          4          8          12         16
     *    ||    v0    |    v1    |    v2    |    v3    |
     * ---++==========+==========+==========+==========+
     *    ||
     *    ||
     *    ||
     *    ||
     *    ||
     *    ||
     *
     */
    //pixel4实际上是uint32_t（占用32bit），存储4个像素的值（每个像素占用8bit）

    pixel4 v0 = MPIXEL_X4( &src[ 0-FDEC_STRIDE] );
    pixel4 v1 = MPIXEL_X4( &src[ 4-FDEC_STRIDE] );
    pixel4 v2 = MPIXEL_X4( &src[ 8-FDEC_STRIDE] );
    pixel4 v3 = MPIXEL_X4( &src[12-FDEC_STRIDE] );

    //循环赋值16行
    for( int i = 0; i < 16; i++ )
    {
        //【展开宏定义】
        //(((x264_union32_t*)(src+ 0))->i) = v0;
        //(((x264_union32_t*)(src+ 4))->i) = v1;
        //(((x264_union32_t*)(src+ 8))->i) = v2;
        //(((x264_union32_t*)(src+12))->i) = v3;
        //即分成4次，每次赋值4个像素
        //
        MPIXEL_X4( src+ 0 ) = v0;
        MPIXEL_X4( src+ 4 ) = v1;
        MPIXEL_X4( src+ 8 ) = v2;
        MPIXEL_X4( src+12 ) = v3;
        //下一行
        //FDEC_STRIDE=32,是重建宏块缓存fdec_buf一行的数据量
        src += FDEC_STRIDE;
    }
}
```

从源代码可以看出，x264_predict_16x16_v_c()首先取出16x16块上面一行像素值，依次存储在v0、v1、v2、v3，然后循环16次赋值给块中的16行像素。

x264_predict_16x16_h_c()

x264_predict_16x16_h_c()是Intra16x16帧内预测Horizontal模式的C语言版本函数。该函数的定义位于common\predict.c，如下所示。

```cpp
//16x16帧内预测
//水平预测（Horizontal）
void x264_predict_16x16_h_c( pixel *src )
{
    /*
     * Horizontal预测方式
     *    |
     * --+-----------
     * X5|X5 X5 X5 X5
     * X6|X6 X6 X6 X6
     * X7|X7 X7 X7 X7
     * X8|X8 X8 X8 X8
     *
     */
    /*
     * const pixel4 v = PIXEL_SPLAT_X4( src[-1] );
     * 宏定义展开后
     * const uint32_t v = (src[-1])*0x01010101U;
     *
     * PIXEL_SPLAT_X4()的作用应该是把最后一个像素（最后8位）拷贝给前面3个像素（前24位）
     * 即把0x0100009F变成0x9F9F9F9F
     * 推导：
     * 前提是x占8bit（对应1个像素）
     * y=x*0x01010101
     *  =x*(0x00000001+0x00000100+0x00010000+0x01000000)
     *  =x<<0+x<<8+x<<16+x<<24
     *
     * const uint32_t v = (src[-1])*0x01010101U含义：
     * 每行把src[-1]中像素值例如0x02赋值给v.v取值为0x02020202
     * src[-1]即16x16块左侧的值
     */
    //循环赋值16行
    for( int i = 0; i < 16; i++ )
    {
        const pixel4 v = PIXEL_SPLAT_X4( src[-1] );
        //宏定义展开后：
        //((x264_union32_t*)(src+ 0))->i=v;
        //((x264_union32_t*)(src+ 4))->i=v;
        //((x264_union32_t*)(src+ 8))->i=v;
        //((x264_union32_t*)(src+12))->i=v;
        //即分4次，每次赋值4个像素（一行一共16个像素，取值是一样的）
        //
        //   0|          4          8          12         16
        //   ||          |          |          |          |
        //---++==========+==========+==========+==========+
        //   ||
        // v ||    v     |    v     |    v     |    v     |
        //   ||
        //   ||
        //   ||
        //
        MPIXEL_X4( src+ 0 ) = v;
        MPIXEL_X4( src+ 4 ) = v;
        MPIXEL_X4( src+ 8 ) = v;
        MPIXEL_X4( src+12 ) = v;
        //下一行
        //FDEC_STRIDE=32,是重建宏块缓存fdec_buf一行的数据量
        src += FDEC_STRIDE;
    }
}
```

从源代码可以看出，x264_predict_16x16_h_c()首先取出16x16块每行左边的1个像素，复制4份后存储在v中，然后分成4次将v赋值给这一行像素。其中“PIXEL_SPLAT_X4()”的功能是取出变量低8位的数值复制4份到高24位，相关的推导功能已经记录在源代码中，不再重复叙述。

x264_predict_16x16_dc_c()

x264_predict_16x16_dc_c()是Intra16x16帧内预测DC模式的C语言版本函数。该函数的定义位于common\predict.c，如下所示。

[cpp]

```cpp
#define PREDICT_16x16_DC(v)\
    for( int i = 0; i < 16; i++ )\
    {\
        MPIXEL_X4( src+ 0 ) = v;\
        MPIXEL_X4( src+ 4 ) = v;\
        MPIXEL_X4( src+ 8 ) = v;\
        MPIXEL_X4( src+12 ) = v;\
        src += FDEC_STRIDE;\
    }

void x264_predict_16x16_dc_c( pixel *src )
{
    /*
     * DC预测方式
     *    |X1 X2 X3 X4
     * --+-----------
     * X5|
     * X6|     Y
     * X7|
     * X8|
     *
     * Y=(X1+X2+X3+X4+X5+X6+X7+X8)/8
     */

    int dc = 0;
    //把16x16块中所有像素的值加起来，存储在dc中
    for( int i = 0; i < 16; i++ )
    {
        //左侧的值
        dc += src[-1 + i * FDEC_STRIDE];
        //上方的值
        dc += src[i - FDEC_STRIDE];
    }
    //加起来的值除以32（一共16+16个点）
    //“+16”是为了四舍五入？
    //PIXEL_SPLAT_X4()的作用应该是把最后一个像素（最后8位）拷贝给前面3个像素（前24位）
    //即把0x0100009F变成0x9F9F9F9F
    pixel4 dcsplat = PIXEL_SPLAT_X4( ( dc + 16 ) >> 5 );
    //赋值到16x16块中的每个像素
    /*
     * 宏展开之后结果
     * for( int i = 0; i < 16; i++ )
     * {
     *  (((x264_union32_t*)(src+ 0))->i) = dcsplat;
     *  (((x264_union32_t*)(src+ 4))->i) = dcsplat;
     *  (((x264_union32_t*)(src+ 8))->i) = dcsplat;
     *  (((x264_union32_t*)(src+12))->i) = dcsplat;
     *  src += 32;
     * }
     */
    PREDICT_16x16_DC( dcsplat );
}
```

从源代码可以看出，x264_predict_16x16_dc_c()求出16x16块上面一行像素和左边一列像素的平均值，然后赋值给16x16块中的每一个像素。

X86以及ARM平台汇编函数

除了C语言版本的帧内预测函数之外，还包含了很多汇编语言版本的函数。下面以Intra16x16帧内预测Vertical模式为例，看一下该函数的X86平台汇编版本以及ARM平台汇编版本。

x264_predict_16x16_init_mmx()

x264_predict_16x16_init_mmx()用于初始化经过x86汇编优化过的Intra16x16的帧内预测函数。该函数的定义位于common\x86\predict-c.c（在“x86”子文件夹下），如下所示。

```cpp
//Intra16x16帧内预测汇编函数-MMX版本
void x264_predict_16x16_init_mmx( int cpu, x264_predict_t pf[7] )
{
    if( !(cpu&X264_CPU_MMX2) )
        return;
    pf[I_PRED_16x16_DC]      = x264_predict_16x16_dc_mmx2;
    pf[I_PRED_16x16_DC_TOP]  = x264_predict_16x16_dc_top_mmx2;
    pf[I_PRED_16x16_DC_LEFT] = x264_predict_16x16_dc_left_mmx2;
    pf[I_PRED_16x16_V]       = x264_predict_16x16_v_mmx2;
    pf[I_PRED_16x16_H]       = x264_predict_16x16_h_mmx2;
#if HIGH_BIT_DEPTH
    if( !(cpu&X264_CPU_SSE) )
        return;
    pf[I_PRED_16x16_V]       = x264_predict_16x16_v_sse;
    if( !(cpu&X264_CPU_SSE2) )
        return;
    pf[I_PRED_16x16_DC]      = x264_predict_16x16_dc_sse2;
    pf[I_PRED_16x16_DC_TOP]  = x264_predict_16x16_dc_top_sse2;
    pf[I_PRED_16x16_DC_LEFT] = x264_predict_16x16_dc_left_sse2;
    pf[I_PRED_16x16_H]       = x264_predict_16x16_h_sse2;
    pf[I_PRED_16x16_P]       = x264_predict_16x16_p_sse2;
    if( !(cpu&X264_CPU_AVX) )
        return;
    pf[I_PRED_16x16_V]       = x264_predict_16x16_v_avx;
    if( !(cpu&X264_CPU_AVX2) )
        return;
    pf[I_PRED_16x16_H]       = x264_predict_16x16_h_avx2;
#else
#if !ARCH_X86_64
    pf[I_PRED_16x16_P]       = x264_predict_16x16_p_mmx2;
#endif
    if( !(cpu&X264_CPU_SSE) )
        return;
    pf[I_PRED_16x16_V]       = x264_predict_16x16_v_sse;
    if( !(cpu&X264_CPU_SSE2) )
        return;
    pf[I_PRED_16x16_DC]      = x264_predict_16x16_dc_sse2;
    if( cpu&X264_CPU_SSE2_IS_SLOW )
        return;
    pf[I_PRED_16x16_DC_TOP]  = x264_predict_16x16_dc_top_sse2;
    pf[I_PRED_16x16_DC_LEFT] = x264_predict_16x16_dc_left_sse2;
    pf[I_PRED_16x16_P]       = x264_predict_16x16_p_sse2;
    if( !(cpu&X264_CPU_SSSE3) )
        return;
    if( !(cpu&X264_CPU_SLOW_PSHUFB) )
        pf[I_PRED_16x16_H]       = x264_predict_16x16_h_ssse3;
#if HAVE_X86_INLINE_ASM
    pf[I_PRED_16x16_P]       = x264_predict_16x16_p_ssse3;
#endif
    if( !(cpu&X264_CPU_AVX) )
        return;
    pf[I_PRED_16x16_P]       = x264_predict_16x16_p_avx;
#endif // HIGH_BIT_DEPTH

    if( cpu&X264_CPU_AVX2 )
    {
        pf[I_PRED_16x16_P]       = x264_predict_16x16_p_avx2;
        pf[I_PRED_16x16_DC]      = x264_predict_16x16_dc_avx2;
        pf[I_PRED_16x16_DC_TOP]  = x264_predict_16x16_dc_top_avx2;
        pf[I_PRED_16x16_DC_LEFT] = x264_predict_16x16_dc_left_avx2;
    }
}
```

可以看出，针对Intra16x16的Vertical帧内预测模式，x264_predict_16x16_init_mmx()会根据系统的特型初始化2个函数：如果系统仅支持MMX指令集，就会初始化x264_predict_16x16_v_mmx2()；如果系统还支持SSE指令集，就会初始化x264_predict_16x16_v_sse()。下面看一下这2个函数的代码。

x264_predict_16x16_v_mmx2()
x264_predict_16x16_v_sse()

在x264中，x264_predict_16x16_v_mmx2()和x264_predict_16x16_v_sse()这两个函数的定义是写到一起的。它们的定义位于common\x86\predict-a.asm，如下所示。

[cpp]

```
;-----------------------------------------------------------------------------
; void predict_16x16_v( pixel *src )
; Intra16x16帧内预测Vertical模式
;-----------------------------------------------------------------------------
;SIZEOF_PIXEL取值为1
;FDEC_STRIDEB为重建宏块缓存fdec_buf一行像素的大小，取值为32
;
;平台相关的信息位于x86inc.asm
;INIT_MMX中
;  mmsize为8
;  mova为movq
;INIT_XMM中：
;  mmsize为16
;  mova为movdqa
;
;STORE16的定义在前面，用于循环16行存储数据

%macro PREDICT_16x16_V 0
cglobal predict_16x16_v, 1,2
%assign %%i 0
%rep 16*SIZEOF_PIXEL/mmsize                          ;rep循环执行，拷贝16x16块上方的1行像素数据至m0,m1...
                                                     ;mmssize为指令1次处理比特数
    mova m %+ %%i, [r0-FDEC_STRIDEB+%%i*mmsize]      ;移入m0,m1...
%assign %%i %%i+1
%endrep
%if 16*SIZEOF_PIXEL/mmsize == 4                      ;1行需要处理4次
    STORE16 m0, m1, m2, m3                           ;循环存储16行，每次存储4个寄存器
%elif 16*SIZEOF_PIXEL/mmsize == 2                    ;1行需要处理2次
    STORE16 m0, m1                                   ;循环存储16行，每次存储2个寄存器
%else                                                ;1行需要处理1次
    STORE16 m0                                       ;循环存储16行，每次存储1个寄存器
%endif
    RET
%endmacro

INIT_MMX mmx2
PREDICT_16x16_V
INIT_XMM sse
PREDICT_16x16_V
```

从汇编代码可以看出，x264_predict_16x16_v_mmx2()和x264_predict_16x16_v_sse()的逻辑是一模一样的。它们之间的不同主要在于一条指令处理的数据量：MMX指令的MOVA对应的是MOVQ，一次处理8Byte（8个像素）；SSE指令的MOVA对应的是MOVDQA，一次处理16Byte（16个像素，正好是16x16块中的一行像素）。
作为对比，我们可以看一下ARM平台下汇编优化过的Intra16x16的帧内预测函数。这些汇编函数的初始化函数是x264_predict_16x16_init_arm()。

x264_predict_16x16_init_arm()

x264_predict_16x16_init_arm()用于初始化ARM平台下汇编优化过的Intra16x16的帧内预测函数。该函数的定义位于common\arm\predict-c.c（“arm”文件夹下），如下所示。

[cpp]

```
void x264_predict_16x16_init_arm( int cpu, x264_predict_t pf[7] )
{
    if (!(cpu&X264_CPU_NEON))
        return;

#if !HIGH_BIT_DEPTH
    pf[I_PRED_16x16_DC ]    = x264_predict_16x16_dc_neon;
    pf[I_PRED_16x16_DC_TOP] = x264_predict_16x16_dc_top_neon;
    pf[I_PRED_16x16_DC_LEFT]= x264_predict_16x16_dc_left_neon;
    pf[I_PRED_16x16_H ]     = x264_predict_16x16_h_neon;
    pf[I_PRED_16x16_V ]     = x264_predict_16x16_v_neon;
    pf[I_PRED_16x16_P ]     = x264_predict_16x16_p_neon;
#endif // !HIGH_BIT_DEPTH
}
```

从源代码可以看出，针对Vertical预测模式，x264_predict_16x16_init_arm()初始化了经过NEON指令集优化的函数x264_predict_16x16_v_neon()。

x264_predict_16x16_v_neon()

x264_predict_16x16_v_neon()的定义位于common\arm\predict-a.S，如下所示。

[cpp]

```
/*
 * Intra16x16帧内预测Vertical模式-NEON
 *
 */
 /* FDEC_STRIDE=32Bytes，为重建宏块一行像素的大小 */
 /* R0存储16x16像素块地址 */
function x264_predict_16x16_v_neon
    sub         r0, r0, #FDEC_STRIDE     /* r0=r0-FDEC_STRIDE */
    mov         ip, #FDEC_STRIDE         /* ip=32 */
                                         /* VLD向量加载: 内存->NEON寄存器 */
                                         /* d0,d1为64bit双字寄存器，共16Byte，在这里存储16x16块上方一行像素 */
    vld1.64     {d0-d1}, [r0,:128], ip   /* 将R0指向的数据从内存加载到d0和d1寄存器（64bit） */
                                         /* r0=r0+ip */
.rept 16                                 /* 循环16次，一次处理1行 */
                                         /* VST向量存储: NEON寄存器->内存 */
    vst1.64     {d0-d1}, [r0,:128], ip   /* 将d0和d1寄存器中的数据传递给R0指向的内存 */
                                         /* r0=r0+ip */
.endr
    bx          lr                       /* 子程序返回 */
endfunc
```

可以看出，x264_predict_16x16_v_neon()使用vld1.64指令载入16x16块上方的一行像素，然后在一个16次的循环中，使用vst1.64指令将该行像素值赋值给16x16块的每一行。
至此有关Intra16x16的Vertical帧内预测方式的源代码就分析完了。

Intra4x4帧内预测源代码

Intra4x4帧内预测模块的初始化函数是x264_predict_4x4_init()。该函数对x264_predict_t结构体中的函数指针进行了赋值。X264运行的过程中只要调用x264_predict_t的函数指针就可以完成相应的功能。

x264_predict_4x4_init()

x264_predict_4x4_init()用于初始化Intra4x4帧内预测汇编函数。该函数的定义位于common\predict.c，如下所示。

[cpp]

```cpp
//Intra4x4帧内预测汇编函数初始化
void x264_predict_4x4_init( int cpu, x264_predict_t pf[12] )
{
    //9种Intra4x4预测方式
    pf[I_PRED_4x4_V]      = x264_predict_4x4_v_c;
    pf[I_PRED_4x4_H]      = x264_predict_4x4_h_c;
    pf[I_PRED_4x4_DC]     = x264_predict_4x4_dc_c;
    pf[I_PRED_4x4_DDL]    = x264_predict_4x4_ddl_c;
    pf[I_PRED_4x4_DDR]    = x264_predict_4x4_ddr_c;
    pf[I_PRED_4x4_VR]     = x264_predict_4x4_vr_c;
    pf[I_PRED_4x4_HD]     = x264_predict_4x4_hd_c;
    pf[I_PRED_4x4_VL]     = x264_predict_4x4_vl_c;
    pf[I_PRED_4x4_HU]     = x264_predict_4x4_hu_c;
    //这些是？
    pf[I_PRED_4x4_DC_LEFT]= x264_predict_4x4_dc_left_c;
    pf[I_PRED_4x4_DC_TOP] = x264_predict_4x4_dc_top_c;
    pf[I_PRED_4x4_DC_128] = x264_predict_4x4_dc_128_c;

#if HAVE_MMX
    x264_predict_4x4_init_mmx( cpu, pf );
#endif

#if HAVE_ARMV6
    x264_predict_4x4_init_arm( cpu, pf );
#endif

#if ARCH_AARCH64
    x264_predict_4x4_init_aarch64( cpu, pf );
#endif
}
```

从源代码可看出，x264_predict_4x4_init()首先对帧内预测函数指针数组x264_predict_t[]中的元素赋值了C语言版本的函数x264_predict_4x4_v_c()，x264_predict_4x4_h_c()，x264_predict_4x4_dc_c()，x264_predict_4x4_p_c()等一系列函数（Intra4x4有9种，后面那几种是怎么回事？）；然后会判断系统平台的特性，如果平台支持的话，会调用x264_predict_4x4_init_mmx()，x264_predict_4x4_init_arm()等给x264_predict_t[]中的元素赋值经过汇编优化的函数。下面看一下Intra4x4帧内预测中Vertical、Horizontal、DC模式的C语言版本函数。

x264_predict_4x4_v_c()

x264_predict_4x4_v_c()实现了Intra4x4帧内预测Vertical模式。该函数的定义位于common\predict.c，如下所示。

[cpp]

```cpp
void x264_predict_4x4_v_c( pixel *src )
{
    /*
     * Vertical预测方式
     *   |X1 X2 X3 X4
     * --+-----------
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *   |X1 X2 X3 X4
     *
     */

    /*
     * 宏展开后的结果如下所示
     * 注：重建宏块缓存fdec_buf一行的数据量为32Byte
     *
     * (((x264_union32_t*)(&src[(0)+(0)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(1)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(2)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(3)*32]))->i) = (((x264_union32_t*)(&src[(0)+(-1)*32]))->i);
     */
    PREDICT_4x4_DC(SRC_X4(0,-1));
}
```

x264_predict_4x4_v_c()函数的函数体极其简单，只有一个宏定义“PREDICT_4x4_DC(SRC_X4(0,-1));”。如果把该宏展开后，可以看出它取了4x4块上面一行4个像素的值，然后分别赋值给4x4块的4行像素。

x264_predict_4x4_h_c()

x264_predict_4x4_h_c()实现了Intra4x4帧内预测Horizontal模式。该函数的定义位于common\predict.c，如下所示。

[cpp]

```cpp
void x264_predict_4x4_h_c( pixel *src )
{
    /*
     * Horizontal预测方式
     *   |
     * --+-----------
     * X5|X5 X5 X5 X5
     * X6|X6 X6 X6 X6
     * X7|X7 X7 X7 X7
     * X8|X8 X8 X8 X8
     *
     */

    /*
     * 宏展开后的结果如下所示
     * 注：重建宏块缓存fdec_buf一行的数据量为32Byte
     *
     * 该代码就是把每行左边的值赋值给该行像素，一次赋值一行
     *
     * (((x264_union32_t*)(&src[(0)+(0)*32]))->i)=((src[(-1)+(0)*32])*0x01010101U);
     * (((x264_union32_t*)(&src[(0)+(1)*32]))->i)=((src[(-1)+(1)*32])*0x01010101U);
     * (((x264_union32_t*)(&src[(0)+(2)*32]))->i)=((src[(-1)+(2)*32])*0x01010101U);
     * (((x264_union32_t*)(&src[(0)+(3)*32]))->i)=((src[(-1)+(3)*32])*0x01010101U);
     *
     * PIXEL_SPLAT_X4()的作用应该是把最后一个像素（最后8位）拷贝给前面3个像素（前24位）
     * 即把0x0100009F变成0x9F9F9F9F
     * 推导：
     * 前提是x占8bit（对应1个像素）
     * y=x*0x01010101
     *  =x*(0x00000001+0x00000100+0x00010000+0x01000000)
     *  =x<<0+x<<8+x<<16+x<<24
     *
     * const uint32_t v = (src[-1])*0x01010101U含义：
     * 每行把src[-1]中像素值例如0x02赋值给v.v取值为0x02020202
     * src[-1]即16x16块左侧的值
     *
     */

    SRC_X4(0,0) = PIXEL_SPLAT_X4( SRC(-1,0) );
    SRC_X4(0,1) = PIXEL_SPLAT_X4( SRC(-1,1) );
    SRC_X4(0,2) = PIXEL_SPLAT_X4( SRC(-1,2) );
    SRC_X4(0,3) = PIXEL_SPLAT_X4( SRC(-1,3) );
}
```

从源代码可以看出，x264_predict_4x4_h_c()首先取出4x4块每行左边的1个像素，复制4份后赋值给这一行像素。其中“PIXEL_SPLAT_X4()”的功能是取出变量低8位的数值复制4份到高24位。

x264_predict_4x4_dc_c()

x264_predict_4x4_dc_c()实现了Intra4x4帧内预测DC模式。该函数的定义位于common\predict.c，如下所示。

[cpp]

```cpp
void x264_predict_4x4_dc_c( pixel *src )
{
    /*
     * DC预测方式
     *   |X1 X2 X3 X4
     * --+-----------
     * X5|
     * X6|     Y
     * X7|
     * X8|
     *
     * Y=(X1+X2+X3+X4+X5+X6+X7+X8)/8
     */

    /*
     * 宏展开后的结果如下所示
     * 注：重建宏块缓存fdec_buf一行的数据量为32Byte
     * 注2："+4"是为了四舍五入
     *
     * uint32_t dc=(((src[(-1)+(0)*32] + src[(-1)+(1)*32] + src[(-1)+(2)*32] + src[(-1)+(3)*32] +
     *     src[(0)+(-1)*32] + src[(1)+(-1)*32] + src[(2)+(-1)*32] + src[(3)+(-1)*32] + 4) >> 3)*0x01010101U)
     *
     * 一次赋值一行
     * (((x264_union32_t*)(&src[(0)+(0)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(1)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(2)*32]))->i) =
     * (((x264_union32_t*)(&src[(0)+(3)*32]))->i) = dc;
     *
     */
    pixel4 dc = PIXEL_SPLAT_X4( (SRC(-1,0) + SRC(-1,1) + SRC(-1,2) + SRC(-1,3) +
                                 SRC(0,-1) + SRC(1,-1) + SRC(2,-1) + SRC(3,-1) + 4) >> 3 );
    PREDICT_4x4_DC( dc );
}
```

从源代码可以看出，x264_predict_4x4_dc_c()取出了4x4块左边和上边的8个像素，将它们的平均值赋值给4x4块中的每个像素。

像素计算源代码

像素计算模块的初始化函数是x264_pixel_init()。该函数对x264_pixel_function_t结构体中的函数指针进行了赋值。X264运行的过程中只要调用x264_pixel_function_t的函数指针就可以完成相应的功能。

x264_pixel_init()

x264_pixel_init()初始化像素值计算相关的汇编函数（包括SAD、SATD、SSD等）。该函数的定义位于common\pixel.c，如下所示。

[cpp]

```cpp
/****************************************************************************
 * x264_pixel_init:
 ****************************************************************************/
//SAD等和像素计算有关的函数
void x264_pixel_init( int cpu, x264_pixel_function_t *pixf )
{
    memset( pixf, 0, sizeof(*pixf) );

    //初始化2个函数-16x16,16x8
#define INIT2_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_16x16] = x264_pixel_##name2##_16x16##cpu;\
    pixf->name1[PIXEL_16x8]  = x264_pixel_##name2##_16x8##cpu;
    //初始化4个函数-(16x16,16x8),8x16,8x8
#define INIT4_NAME( name1, name2, cpu ) \
    INIT2_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_8x16]  = x264_pixel_##name2##_8x16##cpu;\
    pixf->name1[PIXEL_8x8]   = x264_pixel_##name2##_8x8##cpu;
    //初始化5个函数-(16x16,16x8,8x16,8x8),8x4
#define INIT5_NAME( name1, name2, cpu ) \
    INIT4_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_8x4]   = x264_pixel_##name2##_8x4##cpu;
    //初始化6个函数-(16x16,16x8,8x16,8x8,8x4),4x8
#define INIT6_NAME( name1, name2, cpu ) \
    INIT5_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_4x8]   = x264_pixel_##name2##_4x8##cpu;
    //初始化7个函数-(16x16,16x8,8x16,8x8,8x4,4x8),4x4
#define INIT7_NAME( name1, name2, cpu ) \
    INIT6_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_4x4]   = x264_pixel_##name2##_4x4##cpu;
#define INIT8_NAME( name1, name2, cpu ) \
    INIT7_NAME( name1, name2, cpu ) \
    pixf->name1[PIXEL_4x16]  = x264_pixel_##name2##_4x16##cpu;
```

```
    //重新起个名字
#define INIT2( name, cpu ) INIT2_NAME( name, name, cpu )
#define INIT4( name, cpu ) INIT4_NAME( name, name, cpu )
#define INIT5( name, cpu ) INIT5_NAME( name, name, cpu )
#define INIT6( name, cpu ) INIT6_NAME( name, name, cpu )
#define INIT7( name, cpu ) INIT7_NAME( name, name, cpu )
#define INIT8( name, cpu ) INIT8_NAME( name, name, cpu )

#define INIT_ADS( cpu ) \
    pixf->ads[PIXEL_16x16] = x264_pixel_ads4##cpu;\
    pixf->ads[PIXEL_16x8] = x264_pixel_ads2##cpu;\
    pixf->ads[PIXEL_8x8] = x264_pixel_ads1##cpu;
    //8个sad函数
    INIT8( sad, );
    INIT8_NAME( sad_aligned, sad, );
    //7个sad函数-一次性计算3次
    INIT7( sad_x3, );
    //7个sad函数-一次性计算4次
    INIT7( sad_x4, );
    //8个ssd函数
    //ssd可以用来计算PSNR
    INIT8( ssd, );
    //8个satd函数
    //satd计算的是经过Hadamard变换后的值
    INIT8( satd, );
    //8个satd函数-一次性计算3次
    INIT7( satd_x3, );
    //8个satd函数-一次性计算4次
    INIT7( satd_x4, );
    INIT4( hadamard_ac, );
    INIT_ADS( );

    pixf->sa8d[PIXEL_16x16] = x264_pixel_sa8d_16x16;
    pixf->sa8d[PIXEL_8x8]   = x264_pixel_sa8d_8x8;
    pixf->var[PIXEL_16x16] = x264_pixel_var_16x16;
    pixf->var[PIXEL_8x16]  = x264_pixel_var_8x16;
    pixf->var[PIXEL_8x8]   = x264_pixel_var_8x8;
    pixf->var2[PIXEL_8x16]  = x264_pixel_var2_8x16;
    pixf->var2[PIXEL_8x8]   = x264_pixel_var2_8x8;
    //计算UV的
    pixf->ssd_nv12_core = pixel_ssd_nv12_core;
    //计算SSIM
    pixf->ssim_4x4x2_core = ssim_4x4x2_core;
    pixf->ssim_end4 = ssim_end4;
    pixf->vsad = pixel_vsad;
    pixf->asd8 = pixel_asd8;

    pixf->intra_sad_x3_4x4    = x264_intra_sad_x3_4x4;
    pixf->intra_satd_x3_4x4   = x264_intra_satd_x3_4x4;
    pixf->intra_sad_x3_8x8    = x264_intra_sad_x3_8x8;
    pixf->intra_sa8d_x3_8x8   = x264_intra_sa8d_x3_8x8;
    pixf->intra_sad_x3_8x8c   = x264_intra_sad_x3_8x8c;
    pixf->intra_satd_x3_8x8c  = x264_intra_satd_x3_8x8c;
    pixf->intra_sad_x3_8x16c  = x264_intra_sad_x3_8x16c;
    pixf->intra_satd_x3_8x16c = x264_intra_satd_x3_8x16c;
    pixf->intra_sad_x3_16x16  = x264_intra_sad_x3_16x16;
    pixf->intra_satd_x3_16x16 = x264_intra_satd_x3_16x16;

    //后面的初始化基本上都是汇编优化过的函数

#if HIGH_BIT_DEPTH
#if HAVE_MMX
    if( cpu&X264_CPU_MMX2 )
    {
        INIT7( sad, _mmx2 );
        INIT7_NAME( sad_aligned, sad, _mmx2 );
        INIT7( sad_x3, _mmx2 );
        INIT7( sad_x4, _mmx2 );
        INIT8( satd, _mmx2 );
        INIT7( satd_x3, _mmx2 );
        INIT7( satd_x4, _mmx2 );
        INIT4( hadamard_ac, _mmx2 );
        INIT8( ssd, _mmx2 );
        INIT_ADS( _mmx2 );

        pixf->ssd_nv12_core = x264_pixel_ssd_nv12_core_mmx2;
        pixf->var[PIXEL_16x16] = x264_pixel_var_16x16_mmx2;
        pixf->var[PIXEL_8x8]   = x264_pixel_var_8x8_mmx2;
#if ARCH_X86
        pixf->var2[PIXEL_8x8]  = x264_pixel_var2_8x8_mmx2;
        pixf->var2[PIXEL_8x16] = x264_pixel_var2_8x16_mmx2;
#endif

        pixf->intra_sad_x3_4x4    = x264_intra_sad_x3_4x4_mmx2;
        pixf->intra_satd_x3_4x4   = x264_intra_satd_x3_4x4_mmx2;
        pixf->intra_sad_x3_8x8    = x264_intra_sad_x3_8x8_mmx2;
        pixf->intra_sad_x3_8x8c   = x264_intra_sad_x3_8x8c_mmx2;
        pixf->intra_satd_x3_8x8c  = x264_intra_satd_x3_8x8c_mmx2;
        pixf->intra_sad_x3_8x16c  = x264_intra_sad_x3_8x16c_mmx2;
        pixf->intra_satd_x3_8x16c = x264_intra_satd_x3_8x16c_mmx2;
        pixf->intra_sad_x3_16x16  = x264_intra_sad_x3_16x16_mmx2;
```

```
        pixf->intra_satd_x3_16x16 = x264_intra_satd_x3_16x16_mmx2;
    }
    if( cpu&X264_CPU_SSE2 )
    {
        INIT4_NAME( sad_aligned, sad, _sse2_aligned );
        INIT5( ssd, _sse2 );
        INIT6( satd, _sse2 );
        pixf->satd[PIXEL_4x16] = x264_pixel_satd_4x16_sse2;

        pixf->sa8d[PIXEL_16x16] = x264_pixel_sa8d_16x16_sse2;
        pixf->sa8d[PIXEL_8x8]   = x264_pixel_sa8d_8x8_sse2;
#if ARCH_X86_64
        pixf->intra_sa8d_x3_8x8 = x264_intra_sa8d_x3_8x8_sse2;
        pixf->sa8d_satd[PIXEL_16x16] = x264_pixel_sa8d_satd_16x16_sse2;
#endif
        pixf->intra_sad_x3_4x4  = x264_intra_sad_x3_4x4_sse2;
        pixf->ssd_nv12_core = x264_pixel_ssd_nv12_core_sse2;
        pixf->ssim_4x4x2_core  = x264_pixel_ssim_4x4x2_core_sse2;
        pixf->ssim_end4        = x264_pixel_ssim_end4_sse2;
        pixf->var[PIXEL_16x16] = x264_pixel_var_16x16_sse2;
        pixf->var[PIXEL_8x8]   = x264_pixel_var_8x8_sse2;
        pixf->var2[PIXEL_8x8]  = x264_pixel_var2_8x8_sse2;
        pixf->var2[PIXEL_8x16] = x264_pixel_var2_8x16_sse2;
        pixf->intra_sad_x3_8x8 = x264_intra_sad_x3_8x8_sse2;
}
//此处省略大量的X86、ARM等平台的汇编函数初始化代码
}
```

x264_pixel_init()的源代码非常的长，主要原因在于它把C语言版本的函数以及各种平台的汇编函数都写到一块了（不知道现在最新的版本是不是还是这样）。x264_pixel_init()包含了大量和像素计算有关的函数，包括SAD、SATD、SSD、SSIM等等。它的输入参数x264_pixel_function_t是一个结构体，其中包含了各种像素计算的函数接口。x264_pixel_function_t的定义如下所示。

[cpp]

```cpp
typedef struct
{
    x264_pixel_cmp_t  sad[8];
    x264_pixel_cmp_t  ssd[8];
    x264_pixel_cmp_t satd[8];
    x264_pixel_cmp_t ssim[7];
    x264_pixel_cmp_t sa8d[4];
    x264_pixel_cmp_t mbcmp[8]; /* either satd or sad for subpel refine and mode decision */
    x264_pixel_cmp_t mbcmp_unaligned[8]; /* unaligned mbcmp for subpel */
    x264_pixel_cmp_t fpelcmp[8]; /* either satd or sad for fullpel motion search */
    x264_pixel_cmp_x3_t fpelcmp_x3[7];
    x264_pixel_cmp_x4_t fpelcmp_x4[7];
    x264_pixel_cmp_t sad_aligned[8]; /* Aligned SAD for mbcmp */
    int (*vsad)( pixel *, intptr_t, int );
    int (*asd8)( pixel *pix1, intptr_t stride1, pixel *pix2, intptr_t stride2, int height );
    uint64_t (*sa8d_satd[1])( pixel *pix1, intptr_t stride1, pixel *pix2, intptr_t stride2 );

    uint64_t (*var[4])( pixel *pix, intptr_t stride );
    int (*var2[4])( pixel *pix1, intptr_t stride1,
                    pixel *pix2, intptr_t stride2, int *ssd );
    uint64_t (*hadamard_ac[4])( pixel *pix, intptr_t stride );

    void (*ssd_nv12_core)( pixel *pixuv1, intptr_t stride1,
                           pixel *pixuv2, intptr_t stride2, int width, int height,
                           uint64_t *ssd_u, uint64_t *ssd_v );
    void (*ssim_4x4x2_core)( const pixel *pix1, intptr_t stride1,
                             const pixel *pix2, intptr_t stride2, int sums[2][4] );
    float (*ssim_end4)( int sum0[5][4], int sum1[5][4], int width );

    /* multiple parallel calls to cmp. */
    x264_pixel_cmp_x3_t sad_x3[7];
    x264_pixel_cmp_x4_t sad_x4[7];
    x264_pixel_cmp_x3_t satd_x3[7];
    x264_pixel_cmp_x4_t satd_x4[7];

    /* abs-diff-sum for successive elimination.
     * may round width up to a multiple of 16. */
    int (*ads[7])( int enc_dc[4], uint16_t *sums, int delta,
                   uint16_t *cost_mvx, int16_t *mvs, int width, int thresh );

    /* calculate satd or sad of V, H, and DC modes. */
    void (*intra_mbcmp_x3_16x16)( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_satd_x3_16x16) ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_sad_x3_16x16)  ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_mbcmp_x3_4x4)  ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_satd_x3_4x4)   ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_sad_x3_4x4)    ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_mbcmp_x3_chroma)( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_satd_x3_chroma) ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_sad_x3_chroma)  ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_mbcmp_x3_8x16c) ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_satd_x3_8x16c)  ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_sad_x3_8x16c)   ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_mbcmp_x3_8x8c)  ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_satd_x3_8x8c)   ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_sad_x3_8x8c)    ( pixel *fenc, pixel *fdec, int res[3] );
    void (*intra_mbcmp_x3_8x8)  ( pixel *fenc, pixel edge[36], int res[3] );
    void (*intra_sa8d_x3_8x8)   ( pixel *fenc, pixel edge[36], int res[3] );
    void (*intra_sad_x3_8x8)    ( pixel *fenc, pixel edge[36], int res[3] );
    /* find minimum satd or sad of all modes, and set fdec.
     * may be NULL, in which case just use pred+satd instead. */
    int (*intra_mbcmp_x9_4x4)( pixel *fenc, pixel *fdec, uint16_t *bitcosts );
    int (*intra_satd_x9_4x4) ( pixel *fenc, pixel *fdec, uint16_t *bitcosts );
    int (*intra_sad_x9_4x4)  ( pixel *fenc, pixel *fdec, uint16_t *bitcosts );
    int (*intra_mbcmp_x9_8x8)( pixel *fenc, pixel *fdec, pixel edge[36], uint16_t *bitcosts, uint16_t *satds );
    int (*intra_sa8d_x9_8x8) ( pixel *fenc, pixel *fdec, pixel edge[36], uint16_t *bitcosts, uint16_t *satds );
    int (*intra_sad_x9_8x8)  ( pixel *fenc, pixel *fdec, pixel edge[36], uint16_t *bitcosts, uint16_t *satds );
} x264_pixel_function_t;
```

在x264_pixel_init()中定义了好几个宏，用于给x264_pixel_function_t结构体中的函数接口赋值。例如“INIT8(sad,)”用于给x264_pixel_function_t中的sad[8]赋值。该宏展开后的代码如下。

[cpp]

```cpp
pixf->sad[PIXEL_16x16] = x264_pixel_sad_16x16;
pixf->sad[PIXEL_16x8]  = x264_pixel_sad_16x8;
pixf->sad[PIXEL_8x16]  = x264_pixel_sad_8x16;
pixf->sad[PIXEL_8x8]   = x264_pixel_sad_8x8;
pixf->sad[PIXEL_8x4]   = x264_pixel_sad_8x4;
pixf->sad[PIXEL_4x8]   = x264_pixel_sad_4x8;
pixf->sad[PIXEL_4x4]   = x264_pixel_sad_4x4;
pixf->sad[PIXEL_4x16]  = x264_pixel_sad_4x16;
```

“INIT8(ssd,)” 用于给x264_pixel_function_t中的ssd[8]赋值。该宏展开后的代码如下。

[cpp]

```cpp
pixf->ssd[PIXEL_16x16] = x264_pixel_ssd_16x16;
pixf->ssd[PIXEL_16x8]  = x264_pixel_ssd_16x8;
pixf->ssd[PIXEL_8x16]  = x264_pixel_ssd_8x16;
pixf->ssd[PIXEL_8x8]   = x264_pixel_ssd_8x8;
pixf->ssd[PIXEL_8x4]   = x264_pixel_ssd_8x4;
pixf->ssd[PIXEL_4x8]   = x264_pixel_ssd_4x8;
pixf->ssd[PIXEL_4x4]   = x264_pixel_ssd_4x4;
pixf->ssd[PIXEL_4x16]  = x264_pixel_ssd_4x16;
```

“INIT8(satd,)” 用于给x264_pixel_function_t中的satd[8]赋值。该宏展开后的代码如下。

[cpp]

```cpp
pixf->satd[PIXEL_16x16] = x264_pixel_satd_16x16;
pixf->satd[PIXEL_16x8]  = x264_pixel_satd_16x8;
pixf->satd[PIXEL_8x16]  = x264_pixel_satd_8x16;
pixf->satd[PIXEL_8x8]   = x264_pixel_satd_8x8;
pixf->satd[PIXEL_8x4]   = x264_pixel_satd_8x4;
pixf->satd[PIXEL_4x8]   = x264_pixel_satd_4x8;
pixf->satd[PIXEL_4x4]   = x264_pixel_satd_4x4;
pixf->satd[PIXEL_4x16]  = x264_pixel_satd_4x16;
```

下文打算分别记录SAD、SSD和SATD计算的函数x264_pixel_sad_4x4()，x264_pixel_ssd_4x4()，和x264_pixel_satd_4x4()。此外再记录一个一次性“批量”计算4个点的函数x264_pixel_sad_x4_4x4()。

x264_pixel_sad_4x4()

x264_pixel_sad_4x4()用于计算4x4块的SAD。该函数的定义位于common\pixel.c，如下所示。

[cpp]

```cpp
  static int x264_pixel_sad_4x4( pixel *pix1, intptr_t i_stride_pix1,
                 pixel *pix2, intptr_t i_stride_pix2 )
{
    int i_sum = 0;
    for( int y = 0; y < 4; y++ ) //4个像素
    {
        for( int x = 0; x < 4; x++ ) //4个像素
        {
            i_sum += abs( pix1[x] - pix2[x] );//相减之后求绝对值，然后累加
        }
        pix1 += i_stride_pix1;
        pix2 += i_stride_pix2;
    }
    return i_sum;
}
```

可以看出x264_pixel_sad_4x4()将两个4x4图像块对应点相减之后，调用abs()求出绝对值，然后累加到i_sum变量上。

x264_pixel_sad_x4_4x4()

x264_pixel_sad_4x4()用于计算4个4x4块的SAD。该函数的定义位于common\pixel.c，如下所示。

[cpp]

```cpp
static void x264_pixel_sad_x4_4x4( pixel *fenc, pixel *pix0, pixel *pix1,pixel *pix2, pixel *pix3,
                                   intptr_t i_stride, int scores[4] )
{
    scores[0] = x264_pixel_sad_4x4( fenc, 16, pix0, i_stride );
    scores[1] = x264_pixel_sad_4x4( fenc, 16, pix1, i_stride );
    scores[2] = x264_pixel_sad_4x4( fenc, 16, pix2, i_stride );
    scores[3] = x264_pixel_sad_4x4( fenc, 16, pix3, i_stride );
}
```

可以看出，x264_pixel_sad_4x4()计算了起始点在pix0，pix1，pix2，pix3四个4x4的图像块和fenc之间的SAD，并将结果存储于scores[4]数组中。

x264_pixel_ssd_4x4()

x264_pixel_ssd_4x4()用于计算4x4块的SSD。该函数的定义位于common\pixel.c，如下所示。

```cpp
static int x264_pixel_ssd_4x4( pixel *pix1, intptr_t i_stride_pix1,
                 pixel *pix2, intptr_t i_stride_pix2 )
{
    int i_sum = 0;
    for( int y = 0; y < 4; y++ ) //4个像素
    {
        for( int x = 0; x < 4; x++ ) //4个像素
        {
            int d = pix1[x] - pix2[x]; //相减
            i_sum += d*d;              //平方之后，累加
        }
        pix1 += i_stride_pix1;
        pix2 += i_stride_pix2;
    }
    return i_sum;
}
```

可以看出x264_pixel_ssd_4x4()将两个4x4图像块对应点相减之后，取了平方值，然后累加到i_sum变量上。

x264_pixel_satd_4x4()

x264_pixel_satd_4x4()用于计算4x4块的SATD。该函数的定义位于common\pixel.c，如下所示。

```cpp
//SAD（Sum of Absolute Difference）=SAE（Sum of Absolute Error)即绝对误差和
//SATD（Sum of Absolute Transformed Difference）即hadamard变换后再绝对值求和
//
//为什么帧内模式选择要用SATD？
//SAD即绝对误差和，仅反映残差时域差异，影响PSNR值，不能有效反映码流的大小。
//SATD即将残差经哈德曼变换的4x4块的预测残差绝对值总和，可以将其看作简单的时频变换，其值在一定程度上可以反映生成码流的大小。
//4x4的SATD
static NOINLINE int x264_pixel_satd_4x4( pixel *pix1, intptr_t i_pix1, pixel *pix2, intptr_t i_pix2 )
{
    sum2_t tmp[4][2];
    sum2_t a0, a1, a2, a3, b0, b1;
    sum2_t sum = 0;

    for( int i = 0; i < 4; i++, pix1 += i_pix1, pix2 += i_pix2 )
    {
        a0 = pix1[0] - pix2[0];
        a1 = pix1[1] - pix2[1];
        b0 = (a0+a1) + ((a0-a1)<<BITS_PER_SUM);
        a2 = pix1[2] - pix2[2];
        a3 = pix1[3] - pix2[3];
        b1 = (a2+a3) + ((a2-a3)<<BITS_PER_SUM);
        tmp[i][0] = b0 + b1;
        tmp[i][1] = b0 - b1;
    }
    for( int i = 0; i < 2; i++ )
    {
        HADAMARD4( a0, a1, a2, a3, tmp[0][i], tmp[1][i], tmp[2][i], tmp[3][i] );
        a0 = abs2(a0) + abs2(a1) + abs2(a2) + abs2(a3);
        sum += ((sum_t)a0) + (a0>>BITS_PER_SUM);
    }
    return sum >> 1;
}
```

可以看出x264_pixel_satd_4x4()调用了一个宏HADAMARD4()用于Hadamard变换的计算，并最终将两个像素块Hadamard变换后对应元素求差的绝对值之后，累加到sum变量上。

mbcmp_init()

Intra宏块帧内预测模式的分析函数x264_mb_analyse_intra()中并没有直接调用x264_pixel_function_t 中sad[]/satd[]的函数，而是调用了x264_pixel_function_t的mbcmp[]中的函数。mbcmp[]中实际上就是存储的sad[]/satd[]中的函数。mbcmp_init()函数通过参数决定了mbcmp[]使用sad[]还是satd[]。该函数的定义位于encoder\encoder.c，如下所示。

[cpp]

```cpp
//决定了像素比较的时候用SAD还是SATD
static void mbcmp_init( x264_t *h )
{
    //b_lossless一般为0
    //主要看i_subpel_refine，大于1的话就使用SATD
    int satd = !h->mb.b_lossless && h->param.analyse.i_subpel_refine > 1;

    //sad或者satd赋值给mbcmp
    memcpy( h->pixf.mbcmp, satd ? h->pixf.satd : h->pixf.sad_aligned, sizeof(h->pixf.mbcmp) );
    memcpy( h->pixf.mbcmp_unaligned, satd ? h->pixf.satd : h->pixf.sad, sizeof(h->pixf.mbcmp_unaligned) );
    h->pixf.intra_mbcmp_x3_16x16 = satd ? h->pixf.intra_satd_x3_16x16 : h->pixf.intra_sad_x3_16x16;
    h->pixf.intra_mbcmp_x3_8x16c = satd ? h->pixf.intra_satd_x3_8x16c : h->pixf.intra_sad_x3_8x16c;
    h->pixf.intra_mbcmp_x3_8x8c  = satd ? h->pixf.intra_satd_x3_8x8c  : h->pixf.intra_sad_x3_8x8c;
    h->pixf.intra_mbcmp_x3_8x8 = satd ? h->pixf.intra_sa8d_x3_8x8 : h->pixf.intra_sad_x3_8x8;
    h->pixf.intra_mbcmp_x3_4x4 = satd ? h->pixf.intra_satd_x3_4x4 : h->pixf.intra_sad_x3_4x4;
    h->pixf.intra_mbcmp_x9_4x4 = h->param.b_cpu_independent || h->mb.b_lossless ? NULL
                               : satd ? h->pixf.intra_satd_x9_4x4 : h->pixf.intra_sad_x9_4x4;
    h->pixf.intra_mbcmp_x9_8x8 = h->param.b_cpu_independent || h->mb.b_lossless ? NULL
                               : satd ? h->pixf.intra_sa8d_x9_8x8 : h->pixf.intra_sad_x9_8x8;
    satd &= h->param.analyse.i_me_method == X264_ME_TESA;
    memcpy( h->pixf.fpelcmp, satd ? h->pixf.satd : h->pixf.sad, sizeof(h->pixf.fpelcmp) );
    memcpy( h->pixf.fpelcmp_x3, satd ? h->pixf.satd_x3 : h->pixf.sad_x3, sizeof(h->pixf.fpelcmp_x3) );
    memcpy( h->pixf.fpelcmp_x4, satd ? h->pixf.satd_x4 : h->pixf.sad_x4, sizeof(h->pixf.fpelcmp_x4) );
}
```

从mbcmp_init()的源代码可以看出，当i_subpel_refine取值大于1的时候，satd变量为1，此时后续代码中赋值给mbcmp[]相关的一系列函数指针的函数就是SATD函数；当i_subpel_refine取值小于等于1的时候，satd变量为0，此时后续代码中赋值给mbcmp[]相关的一系列函数指针的函数就是SAD函数。

至此有关x264中的Intra宏块分析模块的源代码就分析完毕了。

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