原 FFmpeg的HEVC解码器源代码简单分析：解码器主干部分

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HEVC源代码分析文章列表：

【解码 -libavcodec HEVC 解码器】

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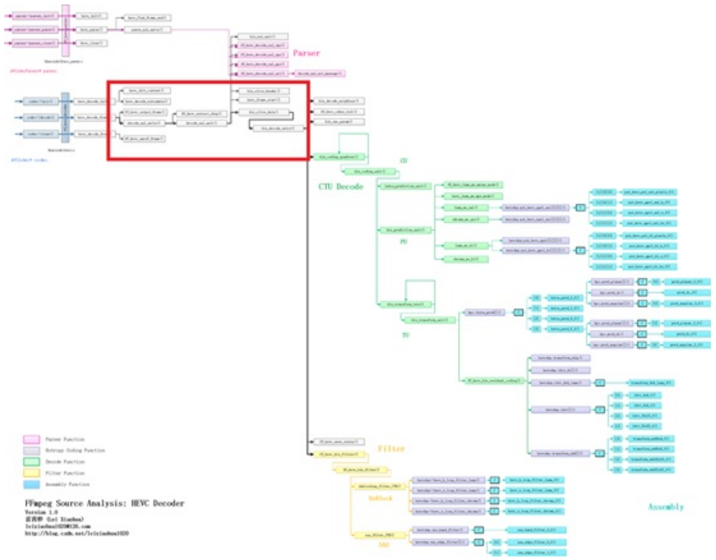
本文分析FFmpeg的libavcodec中的HEVC解码器的主干部分。“主干部分”是相对于“CTU解码”、 “环路滤波”这些细节部分而言的。它包含了HEVC解码器直到hls_decode_entry()前面的函数调用关系（hls_decode_entry()后面就是HEVC解码器的细节部分，主要包含了“CTU解码”、 “环路滤波”2个部分）。

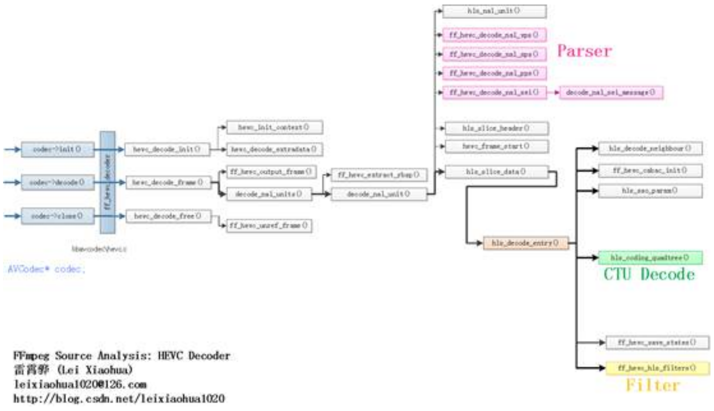
函数调用关系图

FFmpeg HEVC解码器主干部分在整个HEVC解码器中的位置如下图所示。



单击查看更清晰的大图

HEVC解码器主干部分的源代码的调用关系如下图所示。



单击查看更清晰的大图

从图中可以看出，HEVC解码器初始化函数是hevc_decode_init()，解码函数是hevc_decode_frame()，关闭函数是hevc_decode_free()。其中hevc_decode_frame()调用了decode_nal_units()进行一帧NALU的解码，decode_nal_units()又调用了decode_nal_unit()进行一个NALU的解码。

decode_nal_unit()一方面调用解析函数ff_hevc_decode_nal_vps()，ff_hevc_decode_nal_sps()，ff_hevc_decode_nal_pps()等对VPS、SPS、PPS进行解析；另一方面调用了hls_slice_header()和hls_slice_data()对Slice数据进行解码。

hls_slice_data()中调用了hls_decode_entry()，在其中完成了Slice Data解码的流程。该流程包含了CU、PU、TU解码，环路滤波、SAO滤波等环节。

ff_hevc_decoder

ff_hevc_decoder是HEVC解码器对应的AVCodec结构体。该结构体的定义位于libavcodec\hevc.c，如下所示。

[cpp]

```cpp
AVCodec ff_hevc_decoder = {
    .name                  = "hevc",
    .long_name             = NULL_IF_CONFIG_SMALL("HEVC (High Efficiency Video Coding)"),
    .type                  = AVMEDIA_TYPE_VIDEO,
    .id                    = AV_CODEC_ID_HEVC,
    .priv_data_size        = sizeof(HEVCContext),
    .priv_class            = &hevc_decoder_class,
    .init                  = hevc_decode_init,
    .close                 = hevc_decode_free,
    .decode                = hevc_decode_frame,
    .flush                 = hevc_decode_flush,
    .update_thread_context = hevc_update_thread_context,
    .init_thread_copy      = hevc_init_thread_copy,
    .capabilities          = CODEC_CAP_DR1 | CODEC_CAP_DELAY |
                             CODEC_CAP_SLICE_THREADS | CODEC_CAP_FRAME_THREADS,
    .profiles              = NULL_IF_CONFIG_SMALL(profiles),
};
```

从源代码可以看出，HEVC解码器初始化函数是hevc_decode_init()，解码函数是hevc_decode_frame()，关闭函数是hevc_decode_free()。

hevc_decode_init()

hevc_decode_init()用于初始化HEVC解码器。该函数的定义如下。

[cpp]

```cpp
//初始化HEVC解码器
static av_cold int hevc_decode_init(AVCodecContext *avctx)
{
    HEVCContext *s = avctx->priv_data;
    int ret;

    //初始化CABAC
    ff_init_cabac_states();

    avctx->internal->allocate_progress = 1;

    //为HEVCContext中的变量分配内存空间
    ret = hevc_init_context(avctx);
    if (ret < 0)
        return ret;

    s->enable_parallel_tiles = 0;
    s->picture_struct = 0;

    if(avctx->active_thread_type & FF_THREAD_SLICE)
        s->threads_number = avctx->thread_count;
    else
        s->threads_number = 1;

    //如果AVCodecContext中包含extradata，则解码之
    if (avctx->extradata_size > 0 && avctx->extradata) {
        ret = hevc_decode_extradata(s);
        if (ret < 0) {
            hevc_decode_free(avctx);
            return ret;
        }
    }

    if((avctx->active_thread_type & FF_THREAD_FRAME) && avctx->thread_count > 1)
            s->threads_type = FF_THREAD_FRAME;
        else
            s->threads_type = FF_THREAD_SLICE;

    return 0;
}
```

从源代码中可以看出，hevc_decode_init()对HEVCContext中的变量做了一些初始化工作。其中调用了一个函数hevc_init_context()用于给HEVCContext中的变量分配内存空间。

hevc_init_context()

hevc_init_context()用于给HEVCContext中的变量分配内存空间。该函数的定义如下所示。

```cpp
//为HEVCContext中的变量分配内存空间
static av_cold int hevc_init_context(AVCodecContext *avctx)
{
    HEVCContext *s = avctx->priv_data;
    int i;

    s->avctx = avctx;

    s->HEVClc = av_mallocz(sizeof(HEVCLocalContext));
    if (!s->HEVClc)
        goto fail;
    s->HEVClcList[0] = s->HEVClc;
    s->sList[0] = s;

    s->cabac_state = av_malloc(HEVC_CONTEXTS);
    if (!s->cabac_state)
        goto fail;

    s->tmp_frame = av_frame_alloc();
    if (!s->tmp_frame)
        goto fail;

    s->output_frame = av_frame_alloc();
    if (!s->output_frame)
        goto fail;

    for (i = 0; i < FF_ARRAY_ELEMS(s->DPB); i++) {
        s->DPB[i].frame = av_frame_alloc();
        if (!s->DPB[i].frame)
            goto fail;
        s->DPB[i].tf.f = s->DPB[i].frame;
    }

    s->max_ra = INT_MAX;

    s->md5_ctx = av_md5_alloc();
    if (!s->md5_ctx)
        goto fail;

    ff_bswapdsp_init(&s->bdsp);

    s->context_initialized = 1;
    s->eos = 0;

    return 0;

fail:
    hevc_decode_free(avctx);
    return AVERROR(ENOMEM);
}
```

hevc_decode_free()

hevc_decode_free()用于关闭HEVC解码器。该函数的定义如下所示。

[cpp]

```cpp
//关闭HEVC解码器
static av_cold int hevc_decode_free(AVCodecContext *avctx)
{
    HEVCContext       *s = avctx->priv_data;
    int i;

    pic_arrays_free(s);

    av_freep(&s->md5_ctx);

    for(i=0; i < s->nals_allocated; i++) {
        av_freep(&s->skipped_bytes_pos_nal[i]);
    }
    av_freep(&s->skipped_bytes_pos_size_nal);
    av_freep(&s->skipped_bytes_nal);
    av_freep(&s->skipped_bytes_pos_nal);

    av_freep(&s->cabac_state);

    av_frame_free(&s->tmp_frame);
    av_frame_free(&s->output_frame);

    for (i = 0; i < FF_ARRAY_ELEMS(s->DPB); i++) {
        ff_hevc_unref_frame(s, &s->DPB[i], ~0);
        av_frame_free(&s->DPB[i].frame);
    }

    for (i = 0; i < FF_ARRAY_ELEMS(s->vps_list); i++)
        av_buffer_unref(&s->vps_list[i]);
    for (i = 0; i < FF_ARRAY_ELEMS(s->sps_list); i++)
        av_buffer_unref(&s->sps_list[i]);
    for (i = 0; i < FF_ARRAY_ELEMS(s->pps_list); i++)
        av_buffer_unref(&s->pps_list[i]);
    s->sps = NULL;
    s->pps = NULL;
    s->vps = NULL;

    av_buffer_unref(&s->current_sps);

    av_freep(&s->sh.entry_point_offset);
    av_freep(&s->sh.offset);
    av_freep(&s->sh.size);

    for (i = 1; i < s->threads_number; i++) {
        HEVCLocalContext *lc = s->HEVClcList[i];
        if (lc) {
            av_freep(&s->HEVClcList[i]);
            av_freep(&s->sList[i]);
        }
    }
    if (s->HEVClc == s->HEVClcList[0])
        s->HEVClc = NULL;
    av_freep(&s->HEVClcList[0]);

    for (i = 0; i < s->nals_allocated; i++)
        av_freep(&s->nals[i].rbsp_buffer);
    av_freep(&s->nals);
    s->nals_allocated = 0;

    return 0;
}
```

从源代码可以看出，hevc_decode_free()释放了HEVCContext中的内存。

hevc_decode_frame()

hevc_decode_frame()是HEVC解码器中最关键的函数，用于解码一帧数据。该函数的定义如下所示。

[cpp]

```cpp
/*
 * 解码一帧数据
 *
 * 注释：雷霄骅
 * leixiaohua1020@126.com
 * http://blog.csdn.net/leixiaohua1020
 *
 */
static int hevc_decode_frame(AVCodecContext *avctx, void *data, int *got_output,
                             AVPacket *avpkt)
{
    int ret;
    HEVCContext *s = avctx->priv_data;
    //没有输入码流的时候，输出解码器中剩余数据
    //对应“Flush Decoder”功能
    if (!avpkt->size) {
        //第3个参数flush取值为1
        ret = ff_hevc_output_frame(s, data, 1);
        if (ret < 0)
            return ret;

        *got_output = ret;
        return 0;
    }

    s->ref = NULL;
    //解码一帧数据
    ret    = decode_nal_units(s, avpkt->data, avpkt->size);
    if (ret < 0)
        return ret;

    /* verify the SEI checksum */
    if (avctx->err_recognition & AV_EF_CRCCHECK && s->is_decoded &&
        s->is_md5) {
        ret = verify_md5(s, s->ref->frame);
        if (ret < 0 && avctx->err_recognition & AV_EF_EXPLODE) {
            ff_hevc_unref_frame(s, s->ref, ~0);
            return ret;
        }
    }
    s->is_md5 = 0;

    if (s->is_decoded) {
        av_log(avctx, AV_LOG_DEBUG, "Decoded frame with POC %d.\n", s->poc);
        s->is_decoded = 0;
    }

    if (s->output_frame->buf[0]) {
        //输出解码后数据
        av_frame_move_ref(data, s->output_frame);
        *got_output = 1;
    }

    return avpkt->size;
}
```

从源代码可以看出，hevc_decode_frame()根据输入的AVPacket的data是否为NULL分成两个情况：

（1）AVPacket的data为NULL的时候，代表没有输入码流，这时候直接调用ff_hevc_output_frame()输出解码器中缓存的帧。

（2）AVPacket的data不为NULL的时候，调用decode_nal_units()解码输入的一帧数据的NALU。

下面看一下一帧NALU的解码函数decode_nal_units()。

decode_nal_units()

decode_nal_units()用于解码一帧NALU。该函数的定义如下所示。

[cpp]

```cpp
//解码一帧数据
static int decode_nal_units(HEVCContext *s, const uint8_t *buf, int length)
{
    int i, consumed, ret = 0;

    s->ref = NULL;
    s->last_eos = s->eos;
    s->eos = 0;

    /* split the input packet into NAL units, so we know the upper bound on the
     * number of slices in the frame */
    s->nb_nals = 0;
    while (length >= 4) {
        HEVCNAL *nal;
        int extract_length = 0;

        if (s->is_nalff) {
            int i;
            for (i = 0; i < s->nal_length_size; i++)
```

```
            for (i = 0; i < s->nal_length_size; i++)
                extract_length = (extract_length << 8) | buf[i];
            buf    += s->nal_length_size;
            length -= s->nal_length_size;

            if (extract_length > length) {
                av_log(s->avctx, AV_LOG_ERROR, "Invalid NAL unit size.\n");
                ret = AVERROR_INVALIDDATA;
                goto fail;
            }
        } else {
            /* search start code */
            //查找起始码0x000001
            while (buf[0] != 0 || buf[1] != 0 || buf[2] != 1) {
                ++buf;
                --length;
                if (length < 4) {
                    av_log(s->avctx, AV_LOG_ERROR, "No start code is found.\n");
                    ret = AVERROR_INVALIDDATA;
                    goto fail;
                }
            }
            //找到后，跳过起始码（3Byte）
            buf           += 3;
            length        -= 3;
        }

        if (!s->is_nalff)
            extract_length = length;

        if (s->nals_allocated < s->nb_nals + 1) {
            int new_size = s->nals_allocated + 1;
            HEVCNAL *tmp = av_realloc_array(s->nals, new_size, sizeof(*tmp));
            if (!tmp) {
                ret = AVERROR(ENOMEM);
                goto fail;
            }
            s->nals = tmp;
            memset(s->nals + s->nals_allocated, 0,
                   (new_size - s->nals_allocated) * sizeof(*tmp));
            av_reallocp_array(&s->skipped_bytes_nal, new_size, sizeof(*s->skipped_bytes_nal));
            av_reallocp_array(&s->skipped_bytes_pos_size_nal, new_size, sizeof(*s->skipped_bytes_pos_size_nal));
            av_reallocp_array(&s->skipped_bytes_pos_nal, new_size, sizeof(*s->skipped_bytes_pos_nal));
            s->skipped_bytes_pos_size_nal[s->nals_allocated] = 1024; // initial buffer size
            s->skipped_bytes_pos_nal[s->nals_allocated] = av_malloc_array(s->skipped_bytes_pos_size_nal[s->nals_allocated], sizeof(*s->skipped_bytes_pos));
            s->nals_allocated = new_size;
        }
        s->skipped_bytes_pos_size = s->skipped_bytes_pos_size_nal[s->nb_nals];
        s->skipped_bytes_pos = s->skipped_bytes_pos_nal[s->nb_nals];
        nal = &s->nals[s->nb_nals];

        consumed = ff_hevc_extract_rbsp(s, buf, extract_length, nal);

        s->skipped_bytes_nal[s->nb_nals] = s->skipped_bytes;
        s->skipped_bytes_pos_size_nal[s->nb_nals] = s->skipped_bytes_pos_size;
        s->skipped_bytes_pos_nal[s->nb_nals++] = s->skipped_bytes_pos;


        if (consumed < 0) {
            ret = consumed;
            goto fail;
        }

        ret = init_get_bits8(&s->HEVClc->gb, nal->data, nal->size);
        if (ret < 0)
            goto fail;
        hls_nal_unit(s);

        if (s->nal_unit_type == NAL_EOB_NUT ||
            s->nal_unit_type == NAL_EOS_NUT)
            s->eos = 1;

        buf    += consumed;
        length -= consumed;
    }

    /* parse the NAL units */
    for (i = 0; i < s->nb_nals; i++) {
        int ret;
        s->skipped_bytes = s->skipped_bytes_nal[i];
        s->skipped_bytes_pos = s->skipped_bytes_pos_nal[i];
        //解码NALU
        ret = decode_nal_unit(s, s->nals[i].data, s->nals[i].size);
        if (ret < 0) {
            av_log(s->avctx, AV_LOG_WARNING,
                   "Error parsing NAL unit #%d.\n", i);
            goto fail;
        }
    }

fail:
```

```
    if (s->ref && s->threads_type == FF_THREAD_FRAME)
        ff_thread_report_progress(&s->ref->tf, INT_MAX, 0);

    return ret;
}
```

从源代码可以看出，decode_nal_units()中又调用了另一个函数decode_nal_unit()，两者的名字只相差一个“s”。由此可以看出decode_nal_unit()作用是解码一个NALU。

decode_nal_unit()

decode_nal_unit()用于解码一个NALU。该函数的定义如下所示。

[cpp]

```cpp
//解码一个NALU
static int decode_nal_unit(HEVCContext *s, const uint8_t *nal, int length)
{
    HEVCLocalContext *lc = s->HEVClc;
    GetBitContext *gb    = &lc->gb;
    int ctb_addr_ts, ret;

    ret = init_get_bits8(gb, nal, length);
    if (ret < 0)
        return ret;

    ret = hls_nal_unit(s);
    if (ret < 0) {
        av_log(s->avctx, AV_LOG_ERROR, "Invalid NAL unit %d, skipping.\n",
               s->nal_unit_type);
        goto fail;
    } else if (!ret)
        return 0;

    switch (s->nal_unit_type) {
    case NAL_VPS:
        //解析VPS
        ret = ff_hevc_decode_nal_vps(s);
        if (ret < 0)
            goto fail;
        break;
    case NAL_SPS:
        //解析SPS
        ret = ff_hevc_decode_nal_sps(s);
        if (ret < 0)
            goto fail;
        break;
    case NAL_PPS:
        //解析PPS
        ret = ff_hevc_decode_nal_pps(s);
        if (ret < 0)
            goto fail;
        break;
    case NAL_SEI_PREFIX:
    case NAL_SEI_SUFFIX:
        //解析SEI
        ret = ff_hevc_decode_nal_sei(s);
        if (ret < 0)
            goto fail;
        break;
    case NAL_TRAIL_R:
    case NAL_TRAIL_N:
    case NAL_TSA_N:
    case NAL_TSA_R:
    case NAL_STSA_N:
    case NAL_STSA_R:
    case NAL_BLA_W_LP:
    case NAL_BLA_W_RADL:
    case NAL_BLA_N_LP:
    case NAL_IDR_W_RADL:
    case NAL_IDR_N_LP:
    case NAL_CRA_NUT:
    case NAL_RADL_N:
    case NAL_RADL_R:
    case NAL_RASL_N:
    case NAL_RASL_R:
        //解析Slice
        //解析Slice Header
        ret = hls_slice_header(s);
        if (ret < 0)
            return ret;

        if (s->max_ra == INT_MAX) {
            if (s->nal_unit_type == NAL_CRA_NUT || IS_BLA(s)) {
                s->max_ra = s->poc;
            } else {
                if (IS_IDR(s))
                    s->max_ra = INT_MIN;
            }
```

```
        }

        if ((s->nal_unit_type == NAL_RASL_R || s->nal_unit_type == NAL_RASL_N) &&
            s->poc <= s->max_ra) {
            s->is_decoded = 0;
            break;
        } else {
            if (s->nal_unit_type == NAL_RASL_R && s->poc > s->max_ra)
                s->max_ra = INT_MIN;
        }

        if (s->sh.first_slice_in_pic_flag) {
            ret = hevc_frame_start(s);
            if (ret < 0)
                return ret;
        } else if (!s->ref) {
            av_log(s->avctx, AV_LOG_ERROR, "First slice in a frame missing.\n");
            goto fail;
        }

        if (s->nal_unit_type != s->first_nal_type) {
            av_log(s->avctx, AV_LOG_ERROR,
                   "Non-matching NAL types of the VCL NALUs: %d %d\n",
                   s->first_nal_type, s->nal_unit_type);
            return AVERROR_INVALIDDATA;
        }

        if (!s->sh.dependent_slice_segment_flag &&
            s->sh.slice_type != I_SLICE) {
            ret = ff_hevc_slice_rpl(s);
            if (ret < 0) {
                av_log(s->avctx, AV_LOG_WARNING,
                       "Error constructing the reference lists for the current slice.\n");
                goto fail;
            }
        }
        //解码 Slice Data
        if (s->threads_number > 1 && s->sh.num_entry_point_offsets > 0)
            ctb_addr_ts = hls_slice_data_wpp(s, nal, length);
        else
            ctb_addr_ts = hls_slice_data(s);
        if (ctb_addr_ts >= (s->sps->ctb_width * s->sps->ctb_height)) {
            s->is_decoded = 1;
        }

        if (ctb_addr_ts < 0) {
            ret = ctb_addr_ts;
            goto fail;
        }
        break;
    case NAL_EOS_NUT:
    case NAL_EOB_NUT:
        s->seq_decode = (s->seq_decode + 1) & 0xff;
        s->max_ra     = INT_MAX;
        break;
    case NAL_AUD:
    case NAL_FD_NUT:
        break;
    default:
        av_log(s->avctx, AV_LOG_INFO,
               "Skipping NAL unit %d\n", s->nal_unit_type);
    }

    return 0;
fail:
    if (s->avctx->err_recognition & AV_EF_EXPLODE)
        return ret;
    return 0;
}
```

从源代码可以看出，decode_nal_unit()根据不同的NALU类型调用了不同的处理函数。这些处理函数可以分为两类——解析函数和解码函数，如下所示。

（1）解析函数（获取信息）：

ff_hevc_decode_nal_vps()：解析VPS。

ff_hevc_decode_nal_sps()：解析SPS。

ff_hevc_decode_nal_pps()：解析PPS。

ff_hevc_decode_nal_sei()：解析SEI。

hls_slice_header()：解析Slice Header。

（2）解码函数（解码得到图像）：

hls_slice_data()：解码Slice Data。

其中解析函数在文章《FFmpeg的HEVC解码器源代码简单分析：解析器（Parser）部分》已经有过介绍，就不再重复叙述了。解码函数hls_slice_data()完成了解码Slice Data的工作，下面看一下该函数的定义。

hls_slice_data()

hls_slice_data()用于解码Slice Data。该函数的定义如下所示。

```cpp
//解码Slice Data
static int hls_slice_data(HEVCContext *s)
{
    int arg[2];
    int ret[2];

    arg[0] = 0;
    arg[1] = 1;
    //解码入口函数
    s->avctx->execute(s->avctx, hls_decode_entry, arg, ret , 1, sizeof(int));
    return ret[0];
}
```

可以看出该函数的源代码很简单，调用了另一个函数hls_decode_entry()。

hls_decode_entry()

hls_decode_entry()是Slice Data解码的入口函数。该函数的定义如下所示。

```cpp
/*
 * 解码入口函数
 *
 * 注释：雷霄骅
 * leixiaohua1020@126.com
 * http://blog.csdn.net/leixiaohua1020
 *
 */
static int hls_decode_entry(AVCodecContext *avctxt, void *isFilterThread)
{
    HEVCContext *s  = avctxt->priv_data;
    //CTB尺寸
    int ctb_size    = 1 << s->sps->log2_ctb_size;
    int more_data   = 1;
    int x_ctb       = 0;
    int y_ctb       = 0;
    int ctb_addr_ts = s->pps->ctb_addr_rs_to_ts[s->sh.slice_ctb_addr_rs];

    if (!ctb_addr_ts && s->sh.dependent_slice_segment_flag) {
        av_log(s->avctx, AV_LOG_ERROR, "Impossible initial tile.\n");
        return AVERROR_INVALIDDATA;
    }

    if (s->sh.dependent_slice_segment_flag) {
        int prev_rs = s->pps->ctb_addr_ts_to_rs[ctb_addr_ts - 1];
        if (s->tab_slice_address[prev_rs] != s->sh.slice_addr) {
            av_log(s->avctx, AV_LOG_ERROR, "Previous slice segment missing\n");
            return AVERROR_INVALIDDATA;
        }
    }

    while (more_data && ctb_addr_ts < s->sps->ctb_size) {
        int ctb_addr_rs = s->pps->ctb_addr_ts_to_rs[ctb_addr_ts];
        //CTB的位置x和y
        x_ctb = (ctb_addr_rs % ((s->sps->width + ctb_size - 1) >> s->sps->log2_ctb_size)) << s->sps->log2_ctb_size;
        y_ctb = (ctb_addr_rs / ((s->sps->width + ctb_size - 1) >> s->sps->log2_ctb_size)) << s->sps->log2_ctb_size;
        //初始化周围的参数
        hls_decode_neighbour(s, x_ctb, y_ctb, ctb_addr_ts);
        //初始化CABAC
        ff_hevc_cabac_init(s, ctb_addr_ts);
        //样点自适应补偿参数
        hls_sao_param(s, x_ctb >> s->sps->log2_ctb_size, y_ctb >> s->sps->log2_ctb_size);

        s->deblock[ctb_addr_rs].beta_offset = s->sh.beta_offset;
        s->deblock[ctb_addr_rs].tc_offset   = s->sh.tc_offset;
        s->filter_slice_edges[ctb_addr_rs]  = s->sh.slice_loop_filter_across_slices_enabled_flag;
        /*
         * CU示意图
         *
         * 64x64块
         *
         * 深度d=0
         * split_flag=1时候划分为4个32x32
         *
         * +--------+--------+--------+--------+--------+--------+--------+--------+
         * |                                                                       |
         * |                                   |                                   |
         * |                                                                       |
         * +                                   |                                   +
         * |                                                                       |
         * |                                   |                                   |
         * |                                                                       |
         * +                                   |                                   +
         * |                                                                       |
```

```
         * |                                   |                                   |
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         * + --  --  --  --  --  --  --  --  --+ --  --  --  --  --  --  --  --  --+
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         * |                                                                       |
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         * |                                   |                                   |
         * +                                                                       +
         * |                                   |                                   |
         * |                                                                       |
         * |                                   |                                   |
         * +--------+--------+--------+--------+--------+--------+--------+--------+
         *
         *
         * 32x32 块
         * 深度d=1
         * split_flag=1时候划分为4个16x16
         *
         * +--------+--------+--------+--------+
         * |                                   |
         * |                 |                 |
         * |                                   |
         * +                 |                 +
         * |                                   |
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         * |                                   |
         * + --  --  --  --  + --  --  --  --  +
         * |                                   |
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         * |                                   |
         * +                 |                 +
         * |                                   |
         * |                 |                 |
         * |                                   |
         * +--------+--------+--------+--------+
         *
         *
         * 16x16 块
         * 深度d=2
         * split_flag=1时候划分为4个8x8
         *
         * +--------+--------+
         * |                 |
         * |        |        |
         * |                 |
         * +  --  --+ --  -- +
         * |                 |
         * |        |        |
         * |                 |
         * +--------+--------+
         *
         *
         * 8x8块
         * 深度d=3
         * split_flag=1时候划分为4个4x4
         *
         * +----+----+
         * |    |    |
         * + -- + -- +
         * |    |    |
         * +----+----+
         *
         */
        /*
         * 解析四叉树结构，并且解码
         *
         * hls_coding_quadtree(HEVCContext *s, int x0, int y0, int log2_cb_size, int cb_depth)中：
         * s：HEVCContext上下文结构体
         * x_ctb：CB位置的x坐标
         * y_ctb：CB位置的y坐标
         * log2_cb_size：CB大小取log2之后的值
         * cb_depth：深度
         *
         */
        more_data = hls_coding_quadtree(s, x_ctb, y_ctb, s->sps->log2_ctb_size, 0);
        if (more_data < 0) {
            s->tab_slice_address[ctb_addr_rs] = -1;
            return more_data;
        }
```
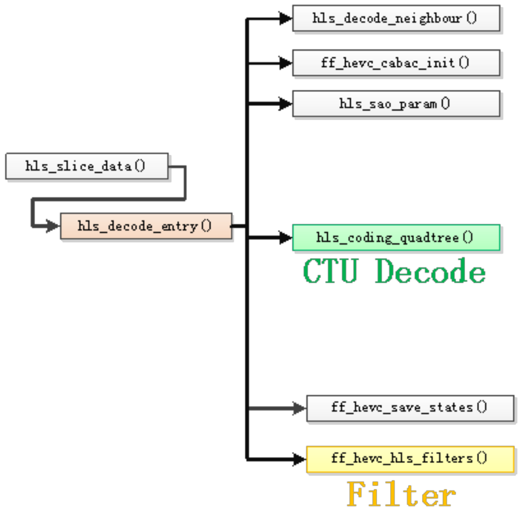

```
        ctb_addr_ts++;
        //保存解码信息以供下次使用
        ff_hevc_save_states(s, ctb_addr_ts);
        //去块效应滤波
        ff_hevc_hls_filters(s, x_ctb, y_ctb, ctb_size);
    }

    if (x_ctb + ctb_size >= s->sps->width &&
        y_ctb + ctb_size >= s->sps->height)
        ff_hevc_hls_filter(s, x_ctb, y_ctb, ctb_size);

    return ctb_addr_ts;
}
```

从源代码可以看出，hls_decode_entry()以CTB为单位处理输入的视频流。每个CTB的压缩数据经过下面两个基本步骤进行处理：

（1）调用hls_coding_quadtree()对CTB解码。其中包括了CU、PU、TU的解码。

（2）调用ff_hevc_hls_filters()进行滤波。其中包括去块效应滤波和SAO滤波。

hls_decode_entry()的函数调用关系如下图所示。后续的几篇文章将会对其调用的函数进行分析。



至此，FFmpeg HEVC解码器的主干部分的源代码就分析完毕了。

雷霄骅
leixiaohua1020@126.com
http://blog.csdn.net/leixiaohua1020

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