2025.7.1-2025.7.7工作记录

工作进展

1. 尝试实现在rt-smart上静态链接rust程序生成的库。只成功兼容了链接工具链，并未实现rust调用rt-smart串口打印函数。
2. 构建一个到`riscv64-unknown-rtsmart`的Rust语言的编译目标，使得Rust编译器可以将程序编译成能够在riscv64 平台上的rt-smart操作系统上运行的指令序列。
3. 参考社区前人完成的 RUST support for rt-thread项目，希望复现APP项目运行，再推广。

资料收集

`rust`调用`rt-smart`的`rt_kprintf`函数：【完整版】使用 Rust 进行嵌入式开发*51CTO博客*rust嵌入式开发，博客构建的rust程序调用`rt_kprintf`函数，并生成库文件，随后静态链接入内核执行。

构建一个到`riscv64-unknown-rtsmart`的Rust语言的编译目标：https://github.com/diandianjunA/RT-Thread-Smart-Rust。

RUST support for rt-thread项目：RT-Thread-Mirror/rtt_rust

搭建开发环境

安装qemu-system-riscv64

目标平台为riscv64 ，因此我们首先需要安装qemu-system-riscv64，用于支持rt-smart内核

```
sudo apt install qemu-system-riscv64
```

安装musl gcc工具链

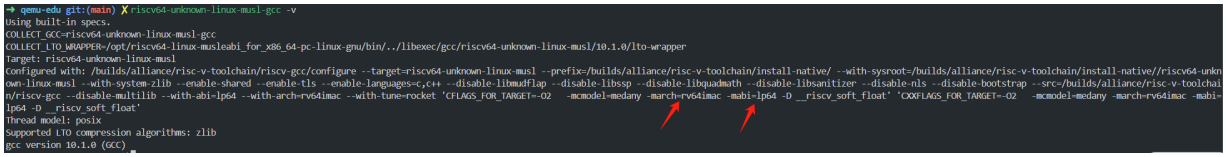
然后需要安装`musl gcc`工具链，下载地址为：https://download.rt-thread.org/download/rt-smart/toolchains/aarch64-linux-musleabi_for_x86_64-pc-linux-gnu_latest.tar.bz2

然后配置环境变量：

```
# riscv64 musl gcc

export RTT_CC=gcc
export RTT_EXEC_PATH=/opt/riscv64-linux-musleabi_for_x86_64-pc-linux-gnu/bin
export RTT_CC_PREFIX=riscv64-unknown-linux-musl-
export PATH=/opt/riscv64-linux-musleabi_for_x86_64-pc-linux-gnu/bin:$PATH
```

使用命令`source ~/.bashrc`刷新环境变量配置文件



重点需要注意 `-march=rv64imac`、 `-mabi=lp64`这两个配置。

安装xmake和scons工具

```
sudo add-apt-repository ppa:xmake-io/xmake
sudo apt update
sudo apt install xmake
sudo apt-get install scons
```

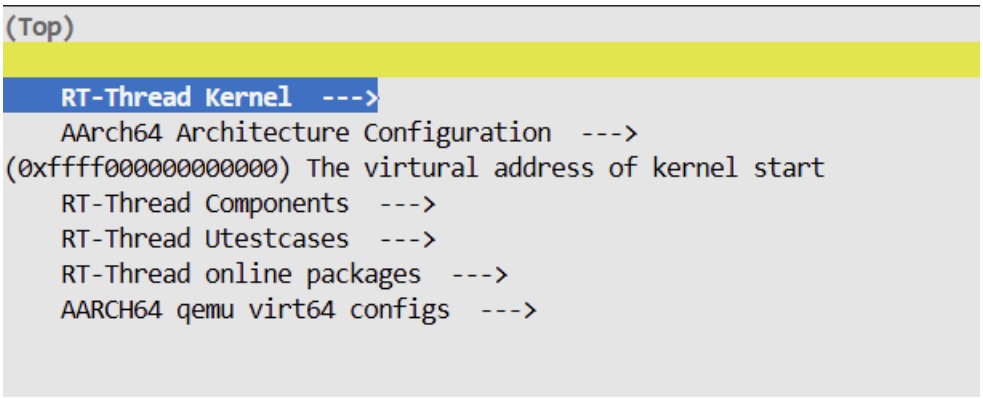
安装ncurses库

```
sudo apt-get install libncurses5-dev
```

构建内核镜像

进入到`machines/qemu-virt-aarch64`目录下

1. 选择RT-Thread Kernel选项



2. 使用Smart内核

```
(Top) → RT-Thread Kernel

    klibc options  --->
(16) The maximal size of kernel object name
[ ] Use the data types defined in ARCH_CPU
[ ] Enable RT-Thread Nano
[*] Enable RT-Thread Smart (microkernel on kernel/userland)
[ ] Enable AMP (Asymmetric Multi-Processing)
[*] Enable SMP (Symmetric multiprocessing)
(4) Number of CPUs
(8) Alignment size for CPU architecture data access
    The maximal level value of priority of thread (32)  --->
(100) Tick frequency, Hz
[*] Using stack overflow checking
-*- Enable system hook
[*]     Using function pointers as system hook
[ ] Enable hook list
-*- Enable IDLE Task hook
(4)     The max size of idle hook list
```

然后在该目录下执行`scons`命令开始编译内核

然后执行当前目录下的`run.sh`脚本即可运行rt-smart内核：

```
 \ | /
- RT -     Thread Smart Operating System
 / | \     5.2.0 build Jul  6 2025 14:36:07
 2006 - 2024 Copyright by RT-Thread team
lwIP-2.0.3 initialized!
[I/sal.skt] Socket Abstraction Layer initialize success.
[I/utest] utest is initialize success.
[I/utest] total utest testcase num: (1)
[I/drivers.serial] Using /dev/ttyS0 as default console
Hello RISC-V
msh />
```

编写rust程序

```
➜  rustapp git:(main) X tree
.
├── Cargo.lock
├── Cargo.toml
├── build.rs
└── src
    └── lib.rs
```

问题1（已解决）

rust提供平台有限：

```
riscv64-linux-android
riscv64-wrs-vxworks
riscv64gc-unknown-freebsd
riscv64gc-unknown-fuchsia
riscv64gc-unknown-hermit
riscv64gc-unknown-linux-gnu
riscv64gc-unknown-linux-musl
riscv64gc-unknown-netbsd
riscv64gc-unknown-none-elf
riscv64gc-unknown-nuttx-elf
riscv64gc-unknown-openbsd
riscv64imac-unknown-none-elf
riscv64imac-unknown-nuttx-elf
```

rust不提供rt-smart目标平台，所以尝试了`riscv64gc-unknown-linux-musl`和

`riscv64imac-unknown-none-elf`两个工具链。

先使用`riscv64gc-unknown-linux-musl`：

1. rt-smart平台不支持硬件浮点，所以会报错：`can't link double-float modules with soft-float modules`。更换`riscv64imac-unknown-none-elf`修复。
2. 由于**新版本的GCC编译器**根据SPEC做了更改，将csr相关指令从基本指令集当中挪了出去，变成了`zicsr`拓展。而RV Linux内核涉及很多csr的指令，如果在编译时没有体现`zicsr`拓展，在编译时便会报错：`-march=rv64i2p1_m2p0_a2p1_f2p2_d2p2_c2p0_zicsr2p0_zifencei2p0_zmmul1p0_zaamo1p0_zalrsc1p0: unsupported ISA subset z'`

   我查看了rust源码中`riscv64imac-unknown-none-elf`工具链的支持：

   ```
   options: TargetOptions {
       linker_flavor: LinkerFlavor::Gnu(Cc::No, Lld::Yes),
       linker: Some("rust-lld".into()),
       cpu: "generic-rv64".into(),
       max_atomic_width: Some(64),
       features: "+m,+a,+c".into(),
       llvm_abiname: "lp64".into(),
       panic_strategy: PanicStrategy::Abort,
       relocation_model: RelocModel::Static,
       code_model: Some(CodeModel::Medium),
       emit_debug_gdb_scripts: false,
   ```

   配置`./.cargo/config.toml`文件：

   ```
   [target.riscv64imac-unknown-none-elf]
   rustflags = [
       "-C", "target-feature=+i,-zaamo,-zalrsc,-zicsr,-zifencei,-zmmul",  # 禁用zicsr和zifencei扩展
       "-C", "link-arg=-march=rv64imac",          # 显式指定工具链支持的架构
       "-C", "link-arg=-mabi=lp64",               # 匹配工具链的ABI（lp64）
       "-C", "link-arg=-Wl,--no-relax"  # 禁用链接器自动放松优化
   ]
   ```

构建`rustapp`后，将生成的.a文件移到`/machines/qemu-virt-riscv64/applications`，修改`SConscript.py`添加链接，重新编译即可成功：

```
→ qemu-virt-riscv64 git:(main) X scons -j6
scons: Reading SConscript files ...
Musl version: unknown
scons: done reading SConscript files.
scons: Building targets ...
scons: building associated VariantDir targets: build
scons: `.' is up to date.
scons: done building targets.
```

问题2（未解决）

链接的库会使内核启动卡死：

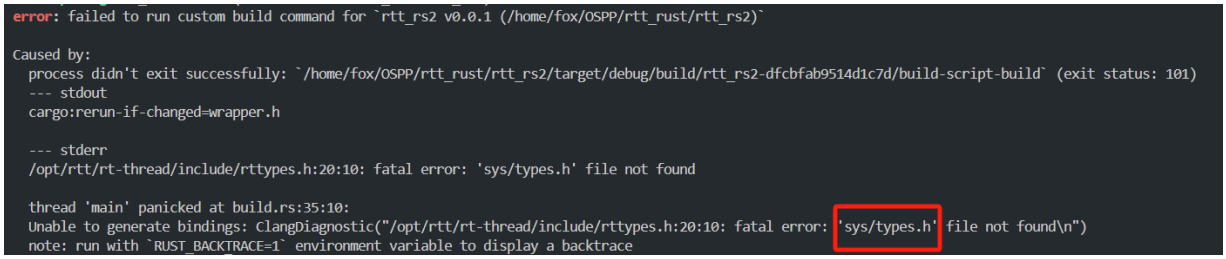
```
Boot HART ID              : 0
Boot HART Domain          : root
Boot HART Priv Version    : v1.12
Boot HART Base ISA        : rv64imafdch
Boot HART ISA Extensions  : time,sstc
Boot HART PMP Count       : 16
Boot HART PMP Granularity : 4
Boot HART PMP Address Bits: 54
Boot HART MHPM Count      : 16
Boot HART MIDELEG         : 0x0000000000001666
Boot HART MEDELEG         : 0x0000000000f0b509
q)q)q)q)q)q)q)q)q)QEMU: Terminated
```

猜测是build.rs写的有问题，所以参考已经实现的build.rs进行构建：

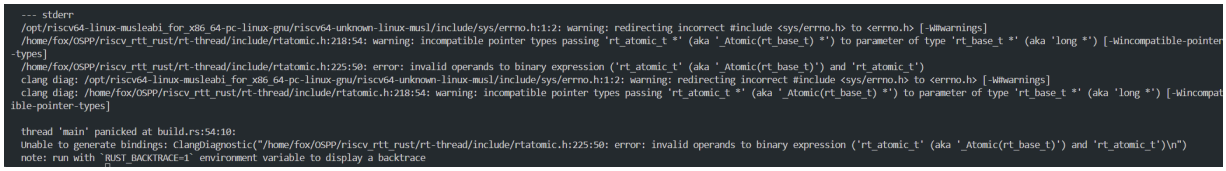
```
// 主要绑定头文件
  let bindings = bindgen::Builder::default()
        // 指定主头文件
        .header(format!("{}/include/rtthread.h", rtthread_path))
        // 使用 core 而非 std
        .use_core()
        // 合并 extern "C" 块
        .merge_extern_blocks(true)
        // 不在 enum 前面添加前缀
        .prepend_enum_name(false)
        // 关闭布局测试
        .layout_tests(false)
        // 添加额外的 clang 参数（include 路径）
        .clang_arg(format!("-I{}", hw_target_path))
        .clang_arg(format!("-I{}/include", rtthread_path))
        .clang_arg(format!("-I{}/components/legacy", rtthread_path))
        .clang_arg(format!("-I{}/components/drivers/include", rtthread_path))
        .clang_arg(format!("-I{}/components/finsh", rtthread_path))
        // .clang_arg(format!("-I{}/components/libc/compilers/common/extension",
rtthread_path))
        // .clang_arg(format!("-I{}/components/libc/compilers/common/include/sys/",
rtthread_path))
        .clang_arg("-I/home/fox/tools/gcc-arm-none-eabi-5_4-2016q3/arm-none-
eabi/include")
```

```
        .clang_arg("-I/home/fox/tools/gcc-arm-none-eabi-5_4-2016q3/arm-none-eabi/include/sys")
        .clang_arg(format!("-I{}", cpu_path))
        .clang_arg(format!("-I{}", cross_path))
        // 生成绑定
        .generate()
        .expect("Unable to generate bindings");
```

编译 `thumbv7em-none-eabihf` 平台成功，但是尝试 `riscv64imac-unknown-none-elf` 平台时失败：



我将工具链的库导入后，遇到了非常复杂的问题：



错误信息 `invalid operands to binary expression ('rt_atomic_t' and 'rt_atomic_t')` 表明编译器无法直接对原子类型（`rt_atomic_t`）进行标准运算符操作（如 `+`、`-` 等），后续需要查阅更多资料寻找解决方案。（`{RTT_ROOT}/libcpu/risc-v/` 下有很多架构，我都有尝试，但是最终都是以上的问题。）