sshmount ソースリスト

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1　メインモジュール　main.rs

```rust
mod cmdline_opt;
mod fuse_util;
mod ssh_connect;
mod ssh_filesystem;

use anyhow::{Context, Result};
use clap::Parser;
use cmdline_opt::Opt;
use daemonize::Daemonize;
use fuse_util::{make_full_path, make_mount_option, make_remote_path};
use ssh_connect::make_ssh_session;
//use log::debug;

fn main() -> Result<()> {
    env_logger::init();
    let opt = Opt::parse();

    let ssh = make_ssh_session(&opt).context("Failed to generate ssh session.")?;

    let path = make_remote_path(&opt, &ssh).context("Failed to generate remote path.")?;
    let options = make_mount_option(&opt);
    let mount_point = make_full_path(&opt.mount_point)?;

    // プロセスのデーモン化
    if opt.daemon {
        let daemonize = Daemonize::new();
        if let Err(e) = daemonize.start() {
            eprintln!("daemonization filed.(error: {})", e);
        }
    }
    // ファイルシステムへのマウント実行
    let fs = ssh_filesystem::Sshfs::new(ssh, &path)?;
    fuser::mount2(fs, mount_point, &options).context("Failed to mount FUSE.")?;
    Ok(())
}
```

2　コマンドラインオプションの定義 cmdline_opt.rs

```rust
use anyhow::{anyhow, Context};
use clap::Parser;
use std::path::PathBuf;

/// コマンドラインオプション
#[derive(Parser)]
#[command(author, version, about)]
pub struct Opt {
    /// Distination [user@]host:[path]
    pub remote: RemoteName,
    /// Path to mount
    #[arg(value_parser = exist_dir)]
    pub mount_point: String,
    /// Path to config file
    #[arg(short = 'F', long)]
    pub config_file: Option<PathBuf>,
    /// Login name
    #[arg(short, long)]
    pub login_name: Option<String>,
    /// File name of secret key file
    #[arg(short, long)]
    pub identity: Option<PathBuf>,
    /// Port no
    #[arg(short, long, default_value_t = 22)]
    pub port: u16,
    /// Read only
    #[arg(short, long)]
    pub readonly: bool,
    /// Not executable
    #[arg(long)]
    pub no_exec: bool,
    /// Do not change access date and time(atime)
    #[arg(long)]
    pub no_atime: bool,
    /// run in daemon mode
    #[arg(short, long)]
    pub daemon: bool,
}

/// 指定されたディレクトリが存在し、中にファイルがないことを確認する。
fn exist_dir(s: &str) -> anyhow::Result<String> {
    match std::fs::read_dir(s) {
        Ok(mut dir) => match dir.next() {
```

```
            None => Ok(s.to_string()),
            Some(_) => Err(anyhow!("Mount destination directory is not empty.")),
        },
        Err(e) => match e.kind() {
            std::io::ErrorKind::NotFound => Err(anyhow!("The mount directory does not exist.")),
            std::io::ErrorKind::NotConnected => Err(anyhow!(
                "The network of the mount directory is disconnected. (Did you forget to umount?)."
            )),
            _ => Err(e).context("Unexpected error.(check mount directory)"),
        },
    }
}

/// コマンドラインの接続先ホスト情報
#[derive(Clone, Debug, PartialEq)]
pub struct RemoteName {
    /// ユーザー名
    pub user: Option<String>,
    /// ホスト名　または　IPアドレス
    pub host: String,
    /// 接続先パス
    pub path: Option<std::path::PathBuf>,
}

impl std::fmt::Display for RemoteName {
    fn fmt(&self, f: &mut std::fmt::Formatter<'_>) -> std::fmt::Result {
        let s = format!("<{:?}><{:?}><{:?}>", &self.user, &self.host, &self.path);
        s.fmt(f)
    }
}

impl std::str::FromStr for RemoteName {
    type Err = ErrorRemoteName;
    fn from_str(s: &str) -> Result<Self, Self::Err> {
        let mut rest_str = s;
        let user = match rest_str.split_once('@') {
            Some((u, r)) => {
                rest_str = r;
                if !u.trim().is_empty() {
                    Some(u.trim().to_string())
                } else {
                    None
                }
            }
            None => None,
        };
```

```
        let (host, path) = match rest_str.split_once(':') {
            Some((h, p)) => (
                if !h.trim().is_empty() {
                    h.trim().to_string()
                } else {
                    return Err(ErrorRemoteName);
                },
                if !p.trim().is_empty() {
                    Some(std::path::PathBuf::from(p.trim().to_string()))
                } else {
                    None
                },
            ),
            None => return Err(ErrorRemoteName),
        };
        Ok(Self { user, host, path })
    }
}

#[derive(thiserror::Error, Debug, PartialEq, Eq)]
#[error("The format of the host to connect to is \"[user@]host:[path]\".")]
pub struct ErrorRemoteName;

#[cfg(test)]
mod test {
    use super::*;
    #[test]
    fn verify_cli() {
        use clap::CommandFactory;
        Opt::command().debug_assert()
    }

    #[test]
    fn test_from_str_remotename() {
        use std::path::Path;
        let s = "mito@reterminal.local:/home/mito";
        let r: RemoteName = s.parse().unwrap();
        let k = RemoteName {
            user: Some("mito".to_string()),
            host: "reterminal.local".to_string(),
            path: Some(Path::new("/home/mito").into()),
        };
        assert_eq!(r, k);

        let s = "mito@reterminal.local:/home/mito/";
        let r: RemoteName = s.parse().unwrap();
```

```
136         let k = RemoteName {
137             user: Some("mito".to_string()),
138             host: "reterminal.local".to_string(),
139             path: Some(Path::new("/home/mito").into()),
140         };
141         assert_eq!(r, k);
142 
143         let s = "reterminal.local:";
144         let r: RemoteName = s.parse().unwrap();
145         let k = RemoteName {
146             user: None,
147             host: "reterminal.local".to_string(),
148             path: None,
149         };
150         assert_eq!(r, k);
151 
152         let s = " mito @reterminal.local: ";
153         let r: RemoteName = s.parse().unwrap();
154         let k = RemoteName {
155             user: Some("mito".to_string()),
156             host: "reterminal.local".to_string(),
157             path: None,
158         };
159         assert_eq!(r, k);
160 
161         let s = "reterminal.local";
162         let r: Result<RemoteName, ErrorRemoteName> = s.parse();
163         assert_eq!(r, Err(ErrorRemoteName));
164 
165         let s = "mito@reterminal.local";
166         let r: Result<RemoteName, ErrorRemoteName> = s.parse();
167         assert_eq!(r, Err(ErrorRemoteName));
168 
169         let s = " mito @: ";
170         let r: Result<RemoteName, ErrorRemoteName> = s.parse();
171         assert_eq!(r, Err(ErrorRemoteName));
172     }
173 }
```

3　ssh2 ログイン処理モジュール ssh_connect.rs

```rust
//! ssh 接続関連関数モジュール

use crate::cmdline_opt::Opt;
use anyhow::{anyhow, Context, Result};
use dialoguer::Password;
use dns_lookup::lookup_host;
use log::{debug, error};
use ssh2::Session;
use ssh2_config::{HostParams, ParseRule, SshConfig};
use std::{
    fs::File,
    io::BufReader,
    net::TcpStream,
    path::{Path, PathBuf},
    str,
};

/// セッションを生成する。
pub fn make_ssh_session(opt: &Opt) -> Result<Session> {
    let host_params = get_ssh_config(&opt.config_file).query(&opt.remote.host);
    let address = get_address(opt, &host_params).context("Failed to get host address")?;
    let username = get_username(opt, &host_params).context("Failed to get user name.")?;
    debug!(
        "[main] 接続先情報-> ユーザー:\"{}\", ip address:{:?}",
        &username, &address
    );
    let identity_file = get_identity_file(opt, &host_params)?;

    let ssh = connect_ssh(address).context("The ssh connection failed.")?;
    userauth(&ssh, &username, &identity_file).context("User authentication failed.")?;
    Ok(ssh)
}

/// ホストの ip アドレス解決
fn get_address(opt: &Opt, host_params: &HostParams) -> Result<std::net::SocketAddr> {
    let dns = host_params.host_name.as_deref().unwrap_or(&opt.remote.host);
    let addr = lookup_host(dns)
        .inspect_err(|e| error!("get_address : Failed lookup_host[{}]", e))
        .context("Cannot find host to connect to.")?
        .collect::<Vec<_>>();
    let addr = addr
        .first()
        .ok_or(anyhow!("Unable to obtain DNS address."))
```

```
44          .inspect_err(|e| error!("get_address : {}", e))?;
45      Ok(std::net::SocketAddr::from((*addr, opt.port)))
46  }
47
48  /// ssh-config の取得と解析
49  /// ファイル名が指定されていない場合は"~/.ssh/config"を使用
50  /// config ファイルのエラー及びファイルがない場合、デフォルト値を返す。
51  fn get_ssh_config(file_opt: &Option<PathBuf>) -> SshConfig {
52      get_config_file(file_opt)
53          .map(BufReader::new)
54          .map_or(SshConfig::default(), |mut f| {
55              SshConfig::default()
56                  .parse(&mut f, ParseRule::ALLOW_UNKNOWN_FIELDS)
57                  .unwrap_or_else(|e| {
58                      eprintln!("警告:config ファイル内にエラー -- {e}");
59                      SshConfig::default()
60                  })
61          })
62  }
63
64  /// ssh_config ファイルがあれば、オープンする。
65  /// ファイル名の指定がなければ、$Home/.ssh/config を想定する。
66  fn get_config_file(file_name: &Option<PathBuf>) -> Option<std::fs::File> {
67      let file_name = file_name.clone().or_else(|| {
68          home::home_dir().map(|p| {
69              let mut p = p;
70              p.push(".ssh/config");
71              p
72          })
73      });
74
75      file_name.and_then(|p| File::open(p).ok())
76  }
77
78  /// ログイン名を確定し、取得する。
79  /// ログイン名指定の優先順位は、1. -u 引数指定, 2.remote 引数, 3.ssh_config 指定, 4. 現在のユーザー名
80  fn get_username(opt: &Opt, params: &HostParams) -> Result<String> {
81      if let Some(n) = &opt.login_name {
82          Ok(n.clone())
83      } else if let Some(n) = &opt.remote.user {
84          Ok(n.clone())
85      } else if let Some(n) = &params.user {
86          Ok(n.clone())
87      } else if let Some(n) = users::get_current_username() {
88          n.to_str()
89              .map(|s| s.to_string())
```

```
            .ok_or(anyhow!("Invalid login user name. -- {n:?}"))
    } else {
        Err(anyhow!("Could not obtain user name."))
    }
}

/// 秘密キーファイルのパスを取得する
fn get_identity_file(opt: &Opt, host_params: &HostParams) -> Result<Option<PathBuf>> {
    if let Some(n) = &opt.identity {
        std::fs::File::open(n).with_context(|| {
            format!(
                "Unable to access the secret key file specified by the \"-i\" option. [{:?}]",
                &n
            )
        })?;
        Ok(Some(n.clone()))
    } else {
        let name = host_params.identity_file.as_ref().map(|p| p[0].clone());
        if let Some(ref n) = name {
            std::fs::File::open(n).with_context(|| {
                format!(
                    "Unnable to access the secret file specified by the ssh-config. [{:?}]",
                    &n
                )
            })?;
        }
        Ok(name)
    }
}

/// リモートの ssh に接続し、セッションを生成する。
fn connect_ssh<A: std::net::ToSocketAddrs>(address: A) -> Result<Session> {
    let tcp = TcpStream::connect(address).context("Failed to connect to TCP/IP.")?;
    let mut ssh = Session::new().context("Failed to connect to ssh.")?;
    ssh.set_tcp_stream(tcp);
    ssh.handshake().context("Failed to hanshake ssh.")?;
    Ok(ssh)
}

/// ssh 認証を実施する。
fn userauth(sess: &Session, username: &str, identity: &Option<PathBuf>) -> Result<()> {
    if user_auth_agent(sess, username).is_ok() {
        return Ok(());
    }
    if let Some(f) = identity {
        if user_auth_identity(sess, username, f).is_ok() {
```

```
136             return Ok(());
137         }
138     }
139     user_auth_password(sess, username)
140         .map_err(|_| anyhow!("All user authentication methods failed."))
141 }
142 
143 /// agent 認証
144 fn user_auth_agent(sess: &Session, username: &str) -> Result<(), ssh2::Error> {
145     let ret = sess.userauth_agent(username);
146     if ret.is_err() {
147         debug!("認証失敗 (agent)->{:?}", ret.as_ref().unwrap_err());
148     };
149     ret
150 }
151 
152 /// 公開キー認証
153 fn user_auth_identity(sess: &Session, username: &str, key_file: &Path) -> Result<(), String> {
154     let mut ret = sess.userauth_pubkey_file(username, None, key_file, None);
155     if ret.is_ok() {
156         return Ok(());
157     };
158     if let ssh2::ErrorCode::Session(-16) = ret.as_ref().unwrap_err().code() {
159         // error_code -16 ->
160         // LIBSSH2_ERROR_FILE:PUBLIC_KEY の取得失敗。多分、秘密キーのパスフレーズ
161         for _i in 0..3 {
162             let password = Password::new()
163                 .with_prompt("Enter the passphrase for the secret key.")
164                 .allow_empty_password(true)
165                 .interact()
166                 .map_err(|e| e.to_string())?;
167             ret = sess.userauth_pubkey_file(username, None, key_file, Some(&password));
168             if ret.is_ok() {
169                 return Ok(());
170             }
171             eprintln!("The passphrase is different.");
172         }
173     }
174     debug!("認証失敗 (pubkey)->{:?}", ret.as_ref().unwrap_err());
175     Err("公開キー認証失敗".to_string())
176 }
177 
178 /// パスワード認証
179 fn user_auth_password(sess: &Session, username: &str) -> Result<(), String> {
180     for _i in 0..3 {
181         let password = Password::new()
```

```
182                 .with_prompt("Enter your login password.")
183                 .allow_empty_password(true)
184                 .interact()
185                 .map_err(|e| e.to_string())?;
186             let ret = sess.userauth_password(username, &password);
187             if ret.is_ok() {
188                 return Ok(());
189             }
190             let ssh2::ErrorCode::Session(-18) = ret.as_ref().unwrap_err().code() else {
191                 break;
192             };
193             // ssh2エラーコード  -18 ->
194             // LIBSSH2_ERROR_AUTHENTICATION_FAILED: パスワードが違うんでしょう。
195             eprintln!("The password is different.");
196             debug!("認証失敗(password)->{:?}", ret.unwrap_err());
197         }
198         Err("パスワード認証失敗".to_string())
199     }
```

4　FUSE 接続オプション生成モジュール fuse_util.rs

```rust
//! FUSE パラメータ関係　ユーティリティ

use crate::cmdline_opt::Opt;
use anyhow::{ensure, Context, Result};
use ssh2::Session;
use std::env::current_dir;
use std::{
    io::Read,
    path::{Path, PathBuf},
    str,
};

/// マウントポイントのフルパスを生成する
pub fn make_full_path<P: AsRef<Path>>(path: P) -> Result<PathBuf> {
    if path.as_ref().is_absolute() {
        Ok(path.as_ref().to_path_buf())
    } else {
        let mut full_path = current_dir().context("cannot access current directory.")?;
        full_path.push(path);
        Ok(full_path)
    }
}

/// リモート接続先の path の生成
pub fn make_remote_path(opt: &Opt, session: &Session) -> Result<PathBuf> {
    // パスの生成
    const MSG_ERRORHOME: &str = "Fail to generate path name.";
    let mut path = match opt.remote.path {
        Some(ref p) => {
            if p.is_absolute() {
                p.clone()
            } else {
                let mut h = get_home_on_remote(session).context(MSG_ERRORHOME)?;
                h.push(p);
                h
            }
        }
        None => get_home_on_remote(session).context(MSG_ERRORHOME)?,
    };
    // 生成したパスが実在するかを確認する
    let sftp = session
        .sftp()
        .context("Connection to SFTP failed when checking for existence of a path.")?;
```

```
44      let file_stat = sftp
45          .stat(&path)
46          .with_context(|| format!("Cannot find path to connect to. path={:?}", &path))?;
47      ensure!(
48          file_stat.is_dir(),
49          "The path to connect to is not a directory."
50      );
51      // 生成したパスがシンボリックリンクのときは、リンク先を解決する
52      let file_stat = sftp
53          .lstat(&path)
54          .context("Failed to obtain the attributes of the destination directory.")?;
55      if file_stat.file_type().is_symlink() {
56          path = sftp
57              .readlink(&path)
58              .context("Failed to resolve symbolic link to connect to.")?;
59          if !path.is_absolute() {
60              let tmp = path;
61              path = get_home_on_remote(session)
62                  .context("Failed to complete the symbolic link to connect to.")?;
63              path.push(tmp);
64          };
65      };
66
67      Ok(path)
68  }
69
70  /// FUSE の接続時オプションを生成する
71  pub fn make_mount_option(cmd_opt: &Opt) -> Vec<fuser::MountOption> {
72      use fuser::MountOption;
73
74      let mut options = vec![MountOption::FSName("sshfs".to_string())];
75      options.push(MountOption::NoDev);
76      options.push(MountOption::DirSync);
77      options.push(MountOption::Sync);
78      match cmd_opt.readonly {
79          true => options.push(MountOption::RO),
80          false => options.push(MountOption::RW),
81      }
82      match cmd_opt.no_exec {
83          true => options.push(MountOption::NoExec),
84          false => options.push(MountOption::Exec),
85      }
86      match cmd_opt.no_atime {
87          true => options.push(MountOption::NoAtime),
88          false => options.push(MountOption::Atime),
89      }
```

```rust
    options
}

/// ssh 接続先のカレントディレクトリを取得する
fn get_home_on_remote(session: &Session) -> Result<PathBuf> {
    let mut channel = session
        .channel_session()
        .context("Fail to build ssh channel.")?;
    channel
        .exec("pwd")
        .context("Fail to execute \"pwd\" command.")?;
    let mut buf = Vec::<u8>::new();
    channel
        .read_to_end(&mut buf)
        .context("Fail to get response for \"pwd\" command.")?;
    channel.close().context("Fail to close ssh channel.")?;
    str::from_utf8(&buf)
        .context("The pwd result contains non-utf8 characters.")?
        .trim()
        .parse::<PathBuf>()
        .context("Fail to build path name.")
}
```

5　ファイルシステムモジュール ssh_filesystem.rs

```rust
mod bi_hash_map;
mod file_handle;
mod inode;

use file_handle::Fhandles;
use inode::Inodes;

use anyhow::Context;
use fuser::{FileAttr, Filesystem, ReplyAttr, ReplyData, ReplyDirectory, ReplyEntry, Request};
use libc::ENOENT;
use log::{debug, error, warn};
use ssh2::{ErrorCode, OpenFlags, OpenType, Session, Sftp};
use std::{
    ffi::OsStr,
    io::{Read, Seek, Write},
    path::{Path, PathBuf},
    time::{Duration, SystemTime, UNIX_EPOCH},
};

/// FUSE ファイルシステム実装
pub struct Sshfs {
    _session: Session,
    sftp: Sftp,
    inodes: Inodes,
    fhandls: Fhandles,
    _top_path: PathBuf,
}

impl Sshfs {
    pub fn new(session: Session, path: &Path) -> anyhow::Result<Self> {
        let mut inodes = Inodes::new();
        let top_path: PathBuf = path.into();
        inodes.add(&top_path);
        let sftp = session
            .sftp()
            .inspect_err(|_| {
                error!("Failed to create sftp from session.");
            })
            .context("Failed to create sftp from session.(Sshfs::new)")?;
        debug!(
            "[Sshfs::new] connect path: <{:?}>, inodes=<{:?}>",
            &top_path, &inodes
        );
```

```
        Ok(Self {
            _session: session,
            sftp,
            inodes,
            fhandls: Fhandles::new(),
            _top_path: top_path,
        })
    }

    /// ssh2経由でファイルのステータスを取得する。
    /// 副作用: 取得に成功した場合、inodesにパスを登録する。
    fn getattr_from_ssh2(&mut self, path: &Path, uid: u32, gid: u32) -> Result<FileAttr, Error> {
        let attr_ssh2 = self.sftp.lstat(path)?;
        let kind = Self::conv_file_kind_ssh2fuser(&attr_ssh2.file_type())?;
        let ino = self.inodes.add(path);
        Ok(FileAttr {
            ino,
            size: attr_ssh2.size.unwrap_or(0),
            blocks: attr_ssh2.size.unwrap_or(0) / 512 + 1,
            atime: UNIX_EPOCH + Duration::from_secs(attr_ssh2.atime.unwrap_or(0)),
            mtime: UNIX_EPOCH + Duration::from_secs(attr_ssh2.mtime.unwrap_or(0)),
            ctime: UNIX_EPOCH + Duration::from_secs(attr_ssh2.mtime.unwrap_or(0)),
            crtime: UNIX_EPOCH,
            kind,
            perm: attr_ssh2.perm.unwrap_or(0o666) as u16,
            nlink: 1,
            uid,
            gid,
            rdev: 0,
            blksize: 512,
            flags: 0,
        })
    }

    fn conv_file_kind_ssh2fuser(filetype: &ssh2::FileType) -> Result<fuser::FileType, Error> {
        match filetype {
            ssh2::FileType::NamedPipe => Ok(fuser::FileType::NamedPipe),
            ssh2::FileType::CharDevice => Ok(fuser::FileType::CharDevice),
            ssh2::FileType::BlockDevice => Ok(fuser::FileType::BlockDevice),
            ssh2::FileType::Directory => Ok(fuser::FileType::Directory),
            ssh2::FileType::RegularFile => Ok(fuser::FileType::RegularFile),
            ssh2::FileType::Symlink => Ok(fuser::FileType::Symlink),
            ssh2::FileType::Socket => Ok(fuser::FileType::Socket),
            ssh2::FileType::Other(_) => Err(Error(libc::EBADF)),
        }
    }
```

```
90
91      fn conv_timeornow2systemtime(time: &fuser::TimeOrNow) -> SystemTime {
92          match time {
93              fuser::TimeOrNow::SpecificTime(t) => *t,
94              fuser::TimeOrNow::Now => SystemTime::now(),
95          }
96      }
97  }
98
99  impl Filesystem for Sshfs {
100     fn lookup(&mut self, req: &Request, parent: u64, name: &OsStr, reply: ReplyEntry) {
101         let Some(mut path) = self.inodes.get_path(parent) else {
102             debug!("[lookup] 親ディレクトリの検索に失敗 inode={}", parent);
103             reply.error(ENOENT);
104             return;
105         };
106         path.push(Path::new(name));
107         match self.getattr_from_ssh2(&path, req.uid(), req.gid()) {
108             Ok(attr) => reply.entry(&Duration::from_secs(1), &attr, 0),
109             Err(e) => {
110                 reply.error(e.0);
111             }
112         };
113     }
114
115     fn getattr(&mut self, req: &Request, ino: u64, _fh: Option<u64>, reply: ReplyAttr) {
116         let Some(path) = self.inodes.get_path(ino) else {
117             debug!("[getattr] path 取得失敗: inode={}", ino);
118             reply.error(ENOENT);
119             return;
120         };
121         match self.getattr_from_ssh2(&path, req.uid(), req.gid()) {
122             Ok(attr) => {
123                 //debug!("[getattr]retrun attr: {:?}", &attr);
124                 reply.attr(&Duration::from_secs(1), &attr);
125             }
126             Err(e) => {
127                 warn!("[getattr] getattr_from_ssh2 エラー: {:?}", &e);
128                 reply.error(e.0)
129             }
130         };
131     }
132
133     fn readdir(
134         &mut self,
135         _req: &Request,
```

```
        ino: u64,
        _fh: u64,
        offset: i64,
        mut reply: ReplyDirectory,
    ) {
        let Some(path) = self.inodes.get_path(ino) else {
            reply.error(libc::ENOENT);
            return;
        };
        match self.sftp.readdir(&path) {
            Ok(mut dir) => {
                let cur_file_attr = ssh2::FileStat {
                    size: None,
                    uid: None,
                    gid: None,
                    perm: Some(libc::S_IFDIR),
                    atime: None,
                    mtime: None,
                }; // "." ".."の解決用。 attr ディレクトリであることのみを示す。
                dir.insert(0, (Path::new("..").into(), cur_file_attr.clone()));
                dir.insert(0, (Path::new(".").into(), cur_file_attr));
                let mut i = offset + 1;
                for f in dir.iter().skip(offset as usize) {
                    let ino = if f.0 == Path::new("..") || f.0 == Path::new(".") {
                        1
                    } else {
                        self.inodes.add(&f.0)
                    };
                    let name = match f.0.file_name() {
                        Some(n) => n,
                        None => f.0.as_os_str(),
                    };
                    let filetype = &f.1.file_type();
                    let filetype = match Self::conv_file_kind_ssh2fuser(filetype) {
                        Ok(t) => t,
                        Err(e) => {
                            warn!(
                                "[readdir] ファイルタイプ解析失敗: inode={}, name={:?}",
                                ino, name
                            );
                            reply.error(e.0);
                            return;
                        }
                    };
                    if reply.add(ino, i, filetype, name) {
                        break;
```

```
                    }
                    i += 1;
                }
                reply.ok();
            }
            Err(e) => {
                warn!("[readdir]ssh2::readdir 内でエラー発生-- {:?}", e);
                reply.error(Error::from(e).0);
            }
        };
    }

    fn readlink(&mut self, _req: &Request<'_>, ino: u64, reply: ReplyData) {
        let Some(path) = self.inodes.get_path(ino) else {
            error!("[readlink] 親ディレクトリの検索に失敗 {ino}");
            reply.error(libc::ENOENT);
            return;
        };
        match self.sftp.readlink(&path) {
            Ok(p) => {
                //debug!("[readlink] ret_path => {:?}", &p);
                reply.data(p.as_os_str().to_string_lossy().as_bytes());
            }
            Err(e) => {
                //debug!("[readlink] ssh2::readlink error => {e:?}");
                reply.error(Error::from(e).0);
            }
        }
    }

    fn open(&mut self, _req: &Request<'_>, ino: u64, flags: i32, reply: fuser::ReplyOpen) {
        let Some(file_name) = self.inodes.get_path(ino) else {
            reply.error(libc::ENOENT);
            return;
        };

        let mut flags_ssh2 = OpenFlags::empty();
        if flags & libc::O_WRONLY != 0 {
            flags_ssh2.insert(OpenFlags::WRITE);
        } else if flags & libc::O_RDWR != 0 {
            flags_ssh2.insert(OpenFlags::READ);
            flags_ssh2.insert(OpenFlags::WRITE);
        } else {
            flags_ssh2.insert(OpenFlags::READ);
        }
        if flags & libc::O_APPEND != 0 {
```

```
            flags_ssh2.insert(OpenFlags::APPEND);
        }
        if flags & libc::O_CREAT != 0 {
            flags_ssh2.insert(OpenFlags::CREATE);
        }
        if flags & libc::O_TRUNC != 0 {
            flags_ssh2.insert(OpenFlags::TRUNCATE);
        }
        if flags & libc::O_EXCL != 0 {
            flags_ssh2.insert(OpenFlags::EXCLUSIVE);
        }

        debug!(
            "[open] filename='{:?}', openflag = {:?}, bit = {:x}",
            &file_name,
            &flags_ssh2,
            flags_ssh2.bits()
        );
        match self
            .sftp
            .open_mode(&file_name, flags_ssh2, 0o777, ssh2::OpenType::File)
        {
            Ok(file) => {
                let fh = self.fhandls.add_file(file);
                reply.opened(fh, flags as u32);
            }
            Err(e) => {
                log::error!(
                    "file-open error: filename='{:?}', mode={:?}, err={}",
                    &file_name,
                    &flags_ssh2,
                    &e
                );
                reply.error(Error::from(e).0);
            }
        }
    }

    fn release(
        &mut self,
        _req: &Request<'_>,
        _ino: u64,
        fh: u64,
        _flags: i32,
        _lock_owner: Option<u64>,
        _flush: bool,
```

```
        reply: fuser::ReplyEmpty,
    ) {
        self.fhandls.del_file(fh);
        reply.ok();
    }

    fn read(
        &mut self,
        _req: &Request,
        _ino: u64,
        fh: u64,
        offset: i64,
        size: u32,
        _flags: i32,
        _lock_owner: Option<u64>,
        reply: ReplyData,
    ) {
        let Some(file) = self.fhandls.get_file(fh) else {
            reply.error(libc::EINVAL);
            return;
        };

        if let Err(e) = file.seek(std::io::SeekFrom::Start(offset as u64)) {
            reply.error(Error::from(e).0);
            return;
        }
        let mut buff = vec![0; size as usize];
        let mut read_size: usize = 0;
        while read_size < size as usize {
            match file.read(&mut buff[read_size..]) {
                Ok(s) => {
                    if s == 0 {
                        break;
                    };
                    read_size += s;
                }
                Err(e) => {
                    reply.error(Error::from(e).0);
                    return;
                }
            }
        }
        buff.resize(read_size, 0u8);
        reply.data(&buff);
    }

```

```rust
    fn write(
        &mut self,
        _req: &Request<'_>,
        _ino: u64,
        fh: u64,
        offset: i64,
        data: &[u8],
        _write_flags: u32,
        _flags: i32,
        _lock_owner: Option<u64>,
        reply: fuser::ReplyWrite,
    ) {
        let Some(file) = self.fhandls.get_file(fh) else {
            reply.error(libc::EINVAL);
            return;
        };

        if let Err(e) = file.seek(std::io::SeekFrom::Start(offset as u64)) {
            reply.error(Error::from(e).0);
            return;
        }
        let mut buf = data;
        while !buf.is_empty() {
            let cnt = match file.write(buf) {
                Ok(cnt) => cnt,
                Err(e) => {
                    reply.error(Error::from(e).0);
                    return;
                }
            };
            buf = &buf[cnt..];
        }
        reply.written(data.len() as u32);
    }

    fn mknod(
        &mut self,
        req: &Request<'_>,
        parent: u64,
        name: &OsStr,
        mode: u32,
        umask: u32,
        _rdev: u32,
        reply: ReplyEntry,
    ) {
        if mode & libc::S_IFMT != libc::S_IFREG {
```

```
366             reply.error(libc::EPERM);
367             return;
368         }
369         let mode = mode & (!umask | libc::S_IFMT);
370         let Some(mut new_name) = self.inodes.get_path(parent) else {
371             reply.error(libc::ENOENT);
372             return;
373         };
374         new_name.push(name);
375         if let Err(e) =
376             self.sftp
377                 .open_mode(&new_name, OpenFlags::CREATE, mode as i32, OpenType::File)
378         {
379             reply.error(Error::from(e).0);
380             return;
381         }
382         let new_attr = match self.getattr_from_ssh2(&new_name, req.uid(), req.gid()) {
383             Ok(a) => a,
384             Err(e) => {
385                 reply.error(e.0);
386                 return;
387             }
388         };
389         reply.entry(&Duration::from_secs(1), &new_attr, 0);
390     }
391
392     fn unlink(&mut self, _req: &Request<'_>, parent: u64, name: &OsStr, reply: fuser::ReplyEmpty) {
393         let Some(mut path) = self.inodes.get_path(parent) else {
394             reply.error(libc::ENOENT);
395             return;
396         };
397         path.push(name);
398         match self.sftp.unlink(&path) {
399             Ok(_) => {
400                 self.inodes.del_inode_with_path(&path);
401                 reply.ok();
402             }
403             Err(e) => reply.error(Error::from(e).0),
404         }
405     }
406
407     fn mkdir(
408         &mut self,
409         req: &Request<'_>,
410         parent: u64,
411         name: &OsStr,
```

```
412             mode: u32,
413             umask: u32,
414             reply: ReplyEntry,
415         ) {
416             let Some(mut path) = self.inodes.get_path(parent) else {
417                 reply.error(libc::ENOENT);
418                 return;
419             };
420             path.push(name);
421 
422             let mode = (mode & (!umask) & 0o777) as i32;
423 
424             match self.sftp.mkdir(&path, mode) {
425                 Ok(_) => match self.getattr_from_ssh2(&path, req.uid(), req.gid()) {
426                     Ok(attr) => reply.entry(&Duration::from_secs(1), &attr, 0),
427                     Err(e) => reply.error(e.0),
428                 },
429                 Err(e) => reply.error(Error::from(e).0),
430             }
431         }
432 
433         fn rmdir(&mut self, _req: &Request<'_>, parent: u64, name: &OsStr, reply: fuser::ReplyEmpty) {
434             let Some(mut path) = self.inodes.get_path(parent) else {
435                 reply.error(libc::ENOENT);
436                 return;
437             };
438             path.push(name);
439             match self.sftp.rmdir(&path) {
440                 Ok(_) => {
441                     self.inodes.del_inode_with_path(&path);
442                     reply.ok()
443                 }
444                 Err(e) => {
445                     if e.code() == ErrorCode::Session(-31) {
446                         // ssh2ライブラリの返すエラーが妙。置換しておく。
447                         reply.error(libc::ENOTEMPTY);
448                     } else {
449                         reply.error(Error::from(e).0)
450                     }
451                 }
452             }
453         }
454 
455         fn symlink(
456             &mut self,
457             req: &Request<'_>,
```

```
458             parent: u64,
459             name: &OsStr,
460             link: &Path,
461             reply: ReplyEntry,
462         ) {
463             let Some(mut target) = self.inodes.get_path(parent) else {
464                 reply.error(libc::ENOENT);
465                 return;
466             };
467             target.push(name);
468             match self.sftp.symlink(link, &target) {
469                 Ok(_) => match self.getattr_from_ssh2(&target, req.uid(), req.gid()) {
470                     Ok(attr) => reply.entry(&Duration::from_secs(1), &attr, 0),
471                     Err(e) => reply.error(e.0),
472                 },
473                 Err(e) => reply.error(Error::from(e).0),
474             }
475         }
476 
477         fn setattr(
478             &mut self,
479             req: &Request<'_>,
480             ino: u64,
481             mode: Option<u32>,
482             _uid: Option<u32>,
483             _gid: Option<u32>,
484             size: Option<u64>,
485             atime: Option<fuser::TimeOrNow>,
486             mtime: Option<fuser::TimeOrNow>,
487             _ctime: Option<std::time::SystemTime>,
488             _fh: Option<u64>,
489             _crtime: Option<std::time::SystemTime>,
490             _chgtime: Option<std::time::SystemTime>,
491             _bkuptime: Option<std::time::SystemTime>,
492             _flags: Option<u32>,
493             reply: ReplyAttr,
494         ) {
495             let stat = ssh2::FileStat {
496                 size,
497                 uid: None,
498                 gid: None,
499                 perm: mode,
500                 atime: atime.map(|t| {
501                     Self::conv_timeornow2systemtime(&t)
502                         .duration_since(UNIX_EPOCH)
503                         .unwrap_or_default()
```

```
                    .as_secs()
            }),
            mtime: mtime.map(|t| {
                Self::conv_timeornow2systemtime(&t)
                    .duration_since(UNIX_EPOCH)
                    .unwrap_or_default()
                    .as_secs()
            }),
        };
        let Some(filename) = self.inodes.get_path(ino) else {
            reply.error(ENOENT);
            return;
        };
        match self.sftp.setstat(&filename, stat) {
            Ok(_) => {
                let stat = self.getattr_from_ssh2(&filename, req.uid(), req.gid());
                match stat {
                    Ok(s) => reply.attr(&Duration::from_secs(1), &s),
                    Err(e) => reply.error(e.0),
                }
            }
            Err(e) => reply.error(Error::from(e).0),
        }
    }

    fn rename(
        &mut self,
        _req: &Request<'_>,
        parent: u64,
        name: &OsStr,
        newparent: u64,
        newname: &OsStr,
        flags: u32,
        reply: fuser::ReplyEmpty,
    ) {
        let Some(mut old_path) = self.inodes.get_path(parent) else {
            reply.error(libc::ENOENT);
            return;
        };
        old_path.push(name);

        let Some(mut new_path) = self.inodes.get_path(newparent) else {
            reply.error(libc::ENOENT);
            return;
        };
        new_path.push(newname);
```

```
550
551         let mut rename_flag = ssh2::RenameFlags::NATIVE;
552         if flags & libc::RENAME_EXCHANGE != 0 {
553             rename_flag.insert(ssh2::RenameFlags::ATOMIC);
554         }
555         if flags & libc::RENAME_NOREPLACE == 0 {
556             // rename の OVERWRITE が効いてない。手動で消す。
557             if let Ok(stat) = self.sftp.lstat(&new_path) {
558                 if stat.is_dir() {
559                     if let Err(e) = self.sftp.rmdir(&new_path) {
560                         reply.error(Error::from(e).0);
561                         return;
562                     }
563                 } else if let Err(e) = self.sftp.unlink(&new_path) {
564                     reply.error(Error::from(e).0);
565                     return;
566                 }
567                 self.inodes.del_inode_with_path(&new_path);
568             }
569         }
570
571         match self.sftp.rename(&old_path, &new_path, Some(rename_flag)) {
572             Ok(_) => {
573                 self.inodes.rename(&old_path, &new_path);
574                 reply.ok();
575             }
576             Err(e) => reply.error(Error::from(e).0),
577         }
578     }
579 }
580
581 #[derive(Debug, Clone, Copy)]
582 struct Error(i32);
583
584 impl From<ssh2::Error> for Error {
585     fn from(value: ssh2::Error) -> Self {
586         let eno = match value.code() {
587             ssh2::ErrorCode::Session(_) => libc::ENXIO,
588             ssh2::ErrorCode::SFTP(i) => match i {
589                 // libssh2の libssh2_sftp.hにて定義されている。
590                 2 => libc::ENOENT,        // NO_SUCH_FILE
591                 3 => libc::EACCES,        // permission_denied
592                 4 => libc::EIO,           // failure
593                 5 => libc::ENODEV,        // bad message
594                 6 => libc::ENXIO,         // no connection
595                 7 => libc::ENETDOWN,      // connection lost
```

```
                8 => libc::ENODEV,        // unsported
                9 => libc::EBADF,         // invalid handle
                10 => libc::ENOENT,       //no such path
                11 => libc::EEXIST,       // file already exists
                12 => libc::EACCES,       // write protected
                13 => libc::ENXIO,        // no media
                14 => libc::ENOSPC,       // no space on filesystem
                15 => libc::EDQUOT,       // quota exceeded
                16 => libc::ENODEV,       // unknown principal
                17 => libc::ENOLCK,       // lock conflict
                18 => libc::ENOTEMPTY,    // dir not empty
                19 => libc::ENOTDIR,      // not a directory
                20 => libc::ENAMETOOLONG, // invalid file name
                21 => libc::ELOOP,        // link loop
                _ => {
                    error!("An unknown error occurred during SSH2.[{}]", i);
                    libc::EIO
                }
            },
        };
        Self(eno)
    }
}

impl From<std::io::Error> for Error {
    fn from(value: std::io::Error) -> Self {
        use std::io::ErrorKind::*;
        let eno = match value.kind() {
            NotFound => libc::ENOENT,
            PermissionDenied => libc::EACCES,
            ConnectionRefused => libc::ECONNREFUSED,
            ConnectionReset => libc::ECONNRESET,
            ConnectionAborted => libc::ECONNABORTED,
            NotConnected => libc::ENOTCONN,
            AddrInUse => libc::EADDRINUSE,
            AddrNotAvailable => libc::EADDRNOTAVAIL,
            BrokenPipe => libc::EPIPE,
            AlreadyExists => libc::EEXIST,
            WouldBlock => libc::EWOULDBLOCK,
            InvalidInput => libc::EINVAL,
            InvalidData => libc::EILSEQ,
            TimedOut => libc::ETIMEDOUT,
            WriteZero => libc::EIO,
            Interrupted => libc::EINTR,
            Unsupported => libc::ENOTSUP,
            UnexpectedEof => libc::EOF,
```

```
642                 OutOfMemory => libc::ENOMEM,
643                 _ => {
644                     error!(
645                         "An unknown error occurred during std::io.[{}]",
646                         value.kind()
647                     );
648                     libc::EIO
649                 }
650             };
651             Self(eno)
652         }
653     }
```

6　ファイルハンドル管理モジュール ssh_filesystem/file_handle.rs

```rust
//! ファイルハンドル管理モジュール

use std::collections::HashMap;

/// ファイルハンドル管理構造体
pub(super) struct Fhandles {
    list: HashMap<u64, ssh2::File>,
    next_handle: u64,
}

impl Fhandles {
    pub(super) fn new() -> Self {
        Self {
            list: HashMap::new(),
            next_handle: 0,
        }
    }

    pub(super) fn add_file(&mut self, file: ssh2::File) -> u64 {
        let handle = self.next_handle;
        self.list.insert(handle, file);
        self.next_handle += 1;
        handle
    }

    pub(super) fn get_file(&mut self, fh: u64) -> Option<&mut ssh2::File> {
        self.list.get_mut(&fh)
    }

    pub(super) fn del_file(&mut self, fh: u64) {
        self.list.remove(&fh); // 戻り値は捨てる。この時点でファイルはクローズ。
                               // ハンドルの再利用のため、次回ハンドルを調整
        match self.list.keys().max() {
            Some(&i) => self.next_handle = i + 1,
            None => self.next_handle = 0,
        }
    }
}
```

7 Inode 管理モジュール ssh_filesystem/inode.rs

```rust
//! Inode 管理モジュール

use super::bi_hash_map::BiHashMap;

use std::path::{Path, PathBuf};

/// Inode 管理構造体
#[derive(Debug, Default)]
pub(super) struct Inodes {
    list: BiHashMap<u64, PathBuf>,
    max_inode: u64,
}

impl Inodes {
    /// Inode を生成する
    pub(super) fn new() -> Self {
        Self {
            list: BiHashMap::new(),
            max_inode: 0,
        }
    }

    /// path で指定された inode を生成し、登録する。
    /// すでに path の登録が存在する場合、追加はせず、登録済みの inode を返す。
    pub(super) fn add<P: AsRef<Path>>(&mut self, path: P) -> u64 {
        match self.get_inode(&path) {
            Some(i) => i,
            None => {
                self.max_inode += 1;
                let path = PathBuf::from(path.as_ref());
                if self
                    .list
                    .insert_no_overwrite(self.max_inode, path.clone())
                    .is_err()
                {
                    unreachable!(
                        "Unexpected duplicate inode {} or path {:?}",
                        self.max_inode, path
                    ); // 既に重複がチェックされているので、ありえない。
                }
                self.max_inode
            }
        }
```

```
44      }
45
46      /// path から inode を取得する
47      pub(super) fn get_inode<P: AsRef<Path>>(&self, path: P) -> Option<u64> {
48          let path = PathBuf::from(path.as_ref());
49          self.list.get_left(&path).copied()
50      }
51
52      /// inode から path を取得する
53      pub(super) fn get_path(&self, inode: u64) -> Option<PathBuf> {
54          self.list.get_right(&inode).cloned()
55      }
56
57      /// inodes から、inode の登録を削除する
58      /// (主用途がなくなっちゃったけど、将来のために残しておく)
59      #[allow(dead_code)]
60      pub(super) fn del_inode(&mut self, inode: u64) -> Option<u64> {
61          self.list.remove_left(&inode).map(|_| inode)
62      }
63
64      /// path 名から iNode の登録を削除する
65      pub(super) fn del_inode_with_path<P: AsRef<Path>>(&mut self, path: P) -> Option<u64> {
66          let path = PathBuf::from(path.as_ref());
67          self.list.remove_right(&path)
68      }
69
70      /// 登録されている inode の path を変更する。
71      /// old_path が存在しなければ、なにもしない。
72      pub(super) fn rename<P: AsRef<Path>>(&mut self, old_path: P, new_path: P) {
73          let Some(ino) = self.get_inode(old_path) else {
74              return;
75          };
76          self.list.remove_left(&ino);
77          let new_path = PathBuf::from(new_path.as_ref());
78          self.list.insert(ino, new_path);
79      }
80  }
81
82  #[cfg(test)]
83  mod inode_test {
84      use super::Inodes;
85      use std::path::Path;
86
87      #[test]
88      fn inode_add_test() {
89          let mut inodes = Inodes::new();
```

```
90          assert_eq!(inodes.add(Path::new("")), 1);
91          assert_eq!(inodes.add(Path::new("test")), 2);
92          assert_eq!(inodes.add(Path::new("")), 1);
93          assert_eq!(inodes.add(Path::new("test")), 2);
94          assert_eq!(inodes.add(Path::new("test3")), 3);
95          assert_eq!(inodes.add(Path::new("/test")), 4);
96          assert_eq!(inodes.add(Path::new("test/")), 2);
97      }
98
99      fn make_inodes() -> Inodes {
100         let mut inodes = Inodes::new();
101         inodes.add(Path::new(""));
102         inodes.add(Path::new("test"));
103         inodes.add(Path::new("test2"));
104         inodes.add(Path::new("test3/"));
105         inodes
106     }
107
108     #[test]
109     fn inodes_get_inode_test() {
110         let inodes = make_inodes();
111         assert_eq!(inodes.get_inode(Path::new("")), Some(1));
112         assert_eq!(inodes.get_inode(Path::new("test4")), None);
113         assert_eq!(inodes.get_inode(Path::new("/test")), None);
114         assert_eq!(inodes.get_inode(Path::new("test3")), Some(4));
115     }
116
117     #[test]
118     fn inodes_get_path_test() {
119         let inodes = make_inodes();
120         assert_eq!(inodes.get_path(1), Some(Path::new("").into()));
121         assert_eq!(inodes.get_path(3), Some(Path::new("test2").into()));
122         assert_eq!(inodes.get_path(5), None);
123         assert_eq!(inodes.get_path(3), Some(Path::new("test2/").into()));
124     }
125
126     #[test]
127     fn inodes_rename() {
128         let mut inodes = make_inodes();
129         let old = Path::new("test2");
130         let new = Path::new("new_test");
131         let ino = inodes.get_inode(old).unwrap();
132         inodes.rename(old, new);
133         assert_eq!(inodes.get_path(ino), Some(new.into()));
134
135         let mut inodes = make_inodes();
```

```
136             let inodes2 = make_inodes();
137             inodes.rename(Path::new("nai"), Path::new("kawattenai"));
138             assert_eq!(inodes.list, inodes2.list);
139         }
140     }
```

8　双方向ハッシュマップモジュール ssh_filesystem/bi_hash_map.rs

```rust
//! bidirectional hash map
//! 双方向ハッシュマップ

use std::{collections::HashMap, hash::Hash, sync::Arc};

/// 双方向ハッシュマップ
#[derive(Debug, Default, PartialEq, Eq)]
pub(super) struct BiHashMap<L, R>
where
    L: Hash + Eq + Clone,
    R: Hash + Eq + Clone,
{
    left: HashMap<Arc<L>, Arc<R>>,
    right: HashMap<Arc<R>, Arc<L>>,
}

impl<L, R> BiHashMap<L, R>
where
    L: Hash + Eq + Clone,
    R: Hash + Eq + Clone,
{
    /// 新しい双方向ハッシュマップを生成する
    pub fn new() -> Self {
        BiHashMap {
            right: HashMap::new(),
            left: HashMap::new(),
        }
    }

    /// チェック無しで挿入する。
    /// この時点で与えられる引数は、R,L のいずれも既存のキーと重複しないことが保証されている必要がある。
    fn insert_no_check(&mut self, left: L, right: R) {
        let right = Arc::new(right);
        let left = Arc::new(left);
        self.right.insert(right.clone(), left.clone());
        self.left.insert(left, right);
    }

    /// マップに新しい要素を挿入する。
    /// 既存のキーと重複する場合、対応する値を上書きし、OverwriteResult で通知する。
    pub fn insert(&mut self, left: L, right: R) -> OverwriteResult<L, R> {
        let old_left = self.right.remove(&right);
        let old_right = self.left.remove(&left);
```

```
        let result = match (old_left, old_right) {
            (None, None) => OverwriteResult::NoOverwrite,
            (Some(old_l), None) => {
                self.left.remove(old_l.as_ref());
                OverwriteResult::OverwriteLeft((*old_l).clone())
            }
            (None, Some(old_r)) => {
                self.right.remove(old_r.as_ref());
                OverwriteResult::OverwriteRight((*old_r).clone())
            }
            (Some(old_l), Some(old_r)) => {
                self.left.remove(old_l.as_ref());
                self.right.remove(old_r.as_ref());
                OverwriteResult::OverwriteBoth(
                    (left.clone(), (*old_r).clone()),
                    ((*old_l).clone(), right.clone()),
                )
            }
        };
        self.insert_no_check(left, right);
        result
    }

    /// マップに新しい値を挿入する
    /// 既存のキーが存在する場合は、エラーを返す。
    pub fn insert_no_overwrite(&mut self, left: L, right: R) -> Result<(), ()> {
        if self.contains_left(&left) || self.contains_right(&right) {
            return Err(());
        }
        self.insert_no_check(left, right);
        Ok(())
    }

    /// 左側のキーから右側の値を取得する
    /// 存在しない場合は *None* を返す
    pub fn get_right(&self, left: &L) -> Option<&R> {
        self.left.get(left).map(|arc_r| arc_r.as_ref())
    }

    /// 右側のキーから左側の値を取得する
    /// 存在しない場合は *None* を返す
    pub fn get_left(&self, right: &R) -> Option<&L> {
        self.right.get(right).map(|arc_l| arc_l.as_ref())
    }

    /// 左側のキーが存在するかどうかを返す
```

```rust
    /// 存在する場合は true、存在しない場合は false を返す
    pub fn contains_left(&self, left: &L) -> bool {
        self.left.contains_key(left)
    }

    /// 右側のキーが存在するかどうかを返す
    /// 存在する場合は true、存在しない場合は false を返す
    pub fn contains_right(&self, right: &R) -> bool {
        self.right.contains_key(right)
    }

    /// 左側の値から、リストの項目を削除する
    /// 存在しない場合は、なにもしない。
    /// 以前の値を返す。(存在しない場合は None)
    pub fn remove_left(&mut self, left: &L) -> Option<R> {
        let result = self.left.remove(left).map(|arc_r| (*arc_r).clone());
        if let Some(right) = result.as_ref() {
            self.right.remove(right);
        };
        result
    }

    /// 右側の値から、リストの項目を削除する
    /// 存在しない場合は、なにもしない。
    /// 以前の値を返す。(存在しない場合は None)
    pub fn remove_right(&mut self, right: &R) -> Option<L> {
        let result = self.right.remove(right).map(|arc_l| (*arc_l).clone());
        if let Some(left) = result.as_ref() {
            self.left.remove(left);
        };
        result
    }
}

/// 挿入時の上書き結果
#[derive(Debug, PartialEq, Eq)]
pub enum OverwriteResult<L, R> {
    NoOverwrite,
    OverwriteRight(R),
    OverwriteLeft(L),
    OverwriteBoth((L, R), (L, R)),
}

#[cfg(test)]
mod tests {
    use super::*;
```

```rust

    #[test]
    /// 単純な挿入と、値の取得のテスト
    fn tanjyunna_insert() {
        let mut bimap = BiHashMap::new();
        assert_eq!(bimap.insert(1, "a"), OverwriteResult::NoOverwrite);
        assert_eq!(bimap.get_right(&1), Some(&"a"));
        assert_eq!(bimap.get_left(&"a"), Some(&1));
        assert_eq!(bimap.insert_no_overwrite(2, "b"), Ok(()));
        assert_eq!(bimap.get_right(&2), Some(&"b"));
        assert_eq!(bimap.get_left(&"b"), Some(&2));
        assert!(bimap.contains_left(&1));
        assert!(bimap.contains_right(&"b"));
    }

    #[test]
    /// 上書き挿入のテスト
    /// 左側、右側、両側の上書きのケースを確認する
    fn overwrite_insert() {
        let mut bimap = BiHashMap::new();
        assert_eq!(bimap.insert(1, "a"), OverwriteResult::NoOverwrite);
        print_hash_map(&bimap, "insert (1, 'a')");
        assert_eq!(bimap.insert(1, "b"), OverwriteResult::OverwriteRight("a"));
        print_hash_map(&bimap, "insert (1, 'b')");
        assert_eq!(bimap.get_right(&1), Some(&"b"));
        assert_eq!(bimap.insert(2, "b"), OverwriteResult::OverwriteLeft(1));
        print_hash_map(&bimap, "insert (2, 'b')");
        assert_eq!(bimap.get_left(&"b"), Some(&2));
        assert_eq!(bimap.get_right(&2), Some(&"b"));
        assert_eq!(bimap.insert_no_overwrite(3, "c"), Ok(()));
        print_hash_map(&bimap, "insert (3, 'c')");
        assert_eq!(
            bimap.insert(2, "b"),
            OverwriteResult::OverwriteBoth((2, "b"), (2, "b"))
        );
        print_hash_map(&bimap, "insert (2, 'b') again");
        assert_eq!(
            bimap.insert(3, "b"),
            OverwriteResult::OverwriteBoth((3, "c"), (2, "b"))
        );
        print_hash_map(&bimap, "insert (3, 'b')");
        assert_eq!(bimap.get_right(&3), Some(&"b"));
        assert_eq!(bimap.get_left(&"b"), Some(&3));
        assert_eq!(bimap.left.len(), bimap.right.len());
        assert_eq!(bimap.get_right(&2), None);
        assert_eq!(bimap.insert_no_overwrite(3, "d"), Err(()));
```

```
182             print_hash_map(&bimap, "insert_no_overwright (3, 'd') [fail]");
183             assert_eq!(bimap.insert_no_overwrite(5, "e"), Ok(()));
184             print_hash_map(&bimap, "insert_no_overwright (5, 'e') [ok]");
185             assert_eq!(bimap.insert_no_overwrite(5, "d"), Err(()));
186             print_hash_map(&bimap, "insert_no_overwright (5, 'd') [fail]");
187         }
188
189         /// 左右の削除のテスト
190         #[test]
191         fn remove_test() {
192             let mut bimap = BiHashMap::new();
193             bimap.insert_no_check(1, "a");
194             bimap.insert_no_check(2, "b");
195             bimap.insert_no_check(3, "c");
196             print_hash_map(&bimap, "initial map");
197             assert_eq!(bimap.remove_left(&2), Some("b"));
198             print_hash_map(&bimap, "after remove_left(2)");
199             assert_eq!(bimap.get_left(&"b"), None);
200             assert_eq!(bimap.get_right(&2), None);
201             assert_eq!(bimap.remove_right(&"c"), Some(3));
202             print_hash_map(&bimap, "after remove_right('c')");
203             assert_eq!(bimap.get_left(&"c"), None);
204             assert_eq!(bimap.get_right(&3), None);
205             assert_eq!(bimap.remove_left(&4), None);
206             print_hash_map(&bimap, "after remove_left(4) [no op]");
207             assert_eq!(bimap.remove_right(&"d"), None);
208             print_hash_map(&bimap, "after remove_right('d') [no op]");
209         }
210
211         use std::fmt::Debug;
212         fn print_hash_map<R, L>(bimap: &BiHashMap<R, L>, mes: &str)
213         where
214             R: Debug + Hash + Eq + Clone,
215             L: Debug + Hash + Eq + Clone,
216         {
217             println!("=== {} ===", mes);
218             println!("Left to Right:");
219             for (l, r) in &bimap.left {
220                 println!("  {:?} => {:?}", l, r);
221             }
222             println!("Right to Left:");
223             for (r, l) in &bimap.right {
224                 println!("  {:?} => {:?}", r, l);
225             }
226         }
227     }
```