FRC Design Patterns

Command-Based Programming in Java and WPILibJ

FRC Season 2024 Cresendo - GT Kickoff Software (Language) Workshop
Instructional Center 105, 9:30 - 10:15

RoboJackets - Competitive Robotics at Georgia Tech
Zimeng Chai
zimeng.chai@gatech.edu

About Me

Zimeng Chai

- Previous Team & Software Sub-team Lead of IronPulse Robotics (Team 6941)
- Current Freshman majoring in Computer Engineering at GT
- Member of RoboJackets, RoboRamblers, and The Laboratory for Intelligent Decision and Autonomous Robots

IRONPULSE

Robots that I Built and Programmed

Acetate - 2022 Rapid React

Hydrogen - 2023 Charged Up

Kyanite - 2023 Rapid React Replay

CONTENT

Introduction to Design Patterns

Introudction to Design Patterns

- Design Patterns are **typical solutions** to common software design problems.
- "How you **Organize** and **Write** your code following a certain **Paradigm**."
- Common design patterns include:
  - Creational: Factory, Singleton, Builder ...
  - Behavioral: State, Iterator, **Commands**, Observer(Subscriber) ...
  - Structural: Bridge, Proxy, Dectorator...
- Design patterns helps us to solve common software engineering problems under a framework of known-best-practices.

For a systematic guide / handy reference, please check Refactoring Guru ↗ or other books about design patterns and their applications.

From Plain Looper to Command-Based

From Plain Looper to Command-Based - Looper Review

Looper is one of the most common way we can write our FRC Robots - directly run all the methods via a update loop (no matter its at base level or divided into sections).

```java
public class Robot extends TimedRobot {
  // ...
  @Override
  public void robotPeriodic() {
    // run repeated since started
  }

  @Override
  public void disabledPeriodic() {
    // run repeated during disabled
  }

  @Override
  public void teleopPeriodic() {
    // run repeated during teleop
  }

  @Override
  public void testPeriodic() {
    // run repeated during test
  }
  // ...
}
```

```java
private final CrashTrackingRunnable runnable_
    = new CrashTrackingRunnable() {
    @Override
    public void runCrashTracked() {
        synchronized (mTaskRunningLock) {
            if (mRunning) {
                double now = Timer.getFPGATimestamp();

                for (Loop loop : mLoops) {
                    loop.onLoop(now);
                }

                mDT = now - mTimestamp;
                mTimestamp = now;
            }
        }
    }
};

public Looper(double period) {
    mNotifier = new Notifier(runnable_);
    mPeriod = period;
    mRunning = false;
    mLoops = new ArrayList<>();
}
```

Author: The Cheesy Poofs, Team 254, Code Link

From Looper to Command-Based - Pros and Cons

Pros

- Simple!
  - Thought Simplicity: direct call to methods, no mediator
  - Debug Simplicity: rather easy to find problems by directly looping and logging things out
- Can Reach High Level of Subsystem Autonomy
  - Periodic updates & response
  - Self-sustained, require less thoughts on the calling side

Cons

- Timed / Stepped Action is Hard to Write
  - e.g. Monkey Bar from Rapid React
  - Use clumsy `TimedBoolean`, `Timer` and status flags
- Coordination Complexity
  - "Super Cooridinator" for automation
  - Complex Cross-Subsystem actions (e.g. Autonomous)
- Command Conflicts
  - Have to judge and handle different commands from different sources, keeping only one
  - Huge amount of flags, if / else, debug and test
- Highly Coupled - Maintainence Difficulties

Structure of Command-Based Programs

Structure of Command-Based Programs - Commands

Commands are at the core of Command-Based Programming practices.
Commands are **actions** a robot can take to complete a certain task, combined in a certain way.

There a 4 core components of a command:

- Initialization - `initialize()`
- Execution - `execute()`
- End - `end(bool isInterrupted)`
- Judge Condition - `isFinished()`

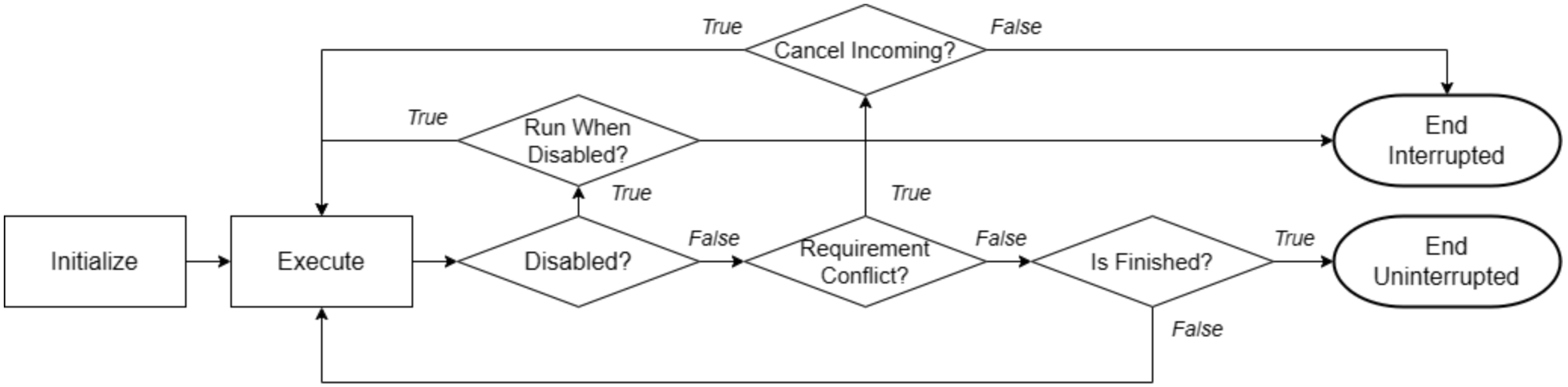
The 4 components make the command itself a small state-machine, giving it high flexibility.

```java
// commands can be created by extending CommandBase
public class ShooterCommand extends CommandBase {
    private DoubleSupplier controlTarget;
    private Shooter shooter;
    public ShooterCommand(Shooter shooter, DoubleSupplier controlTarget) {
        this.shooter = shooter;
        this.controlTarget = controlTarget;
        // add requirement to subsystem for exclusive access
        addRequirements(this.shooter);
    }

    @Override
    public void initialize() {
        shooter.setVolts(0.0);
    }

    @Override
    public void execute() {
        shooter.setVolts(controlTarget.getAsDouble());
    }

    @Override
    public void end(boolean interrupted) {
        shooter.setVolts(0.0);
    }

    @Override
    public boolean isFinished() {
        return false;
    }
}
```

Structure of Command-Based Programs - Commands (Cont)

Commands will be run repeated until `isFinished()` return true.

Command will always be run once after a successful scedule. (i.e. `initialize()`, `execute()`, `end()` will be invoked at least once, even `isFinished()` returned true initially.)

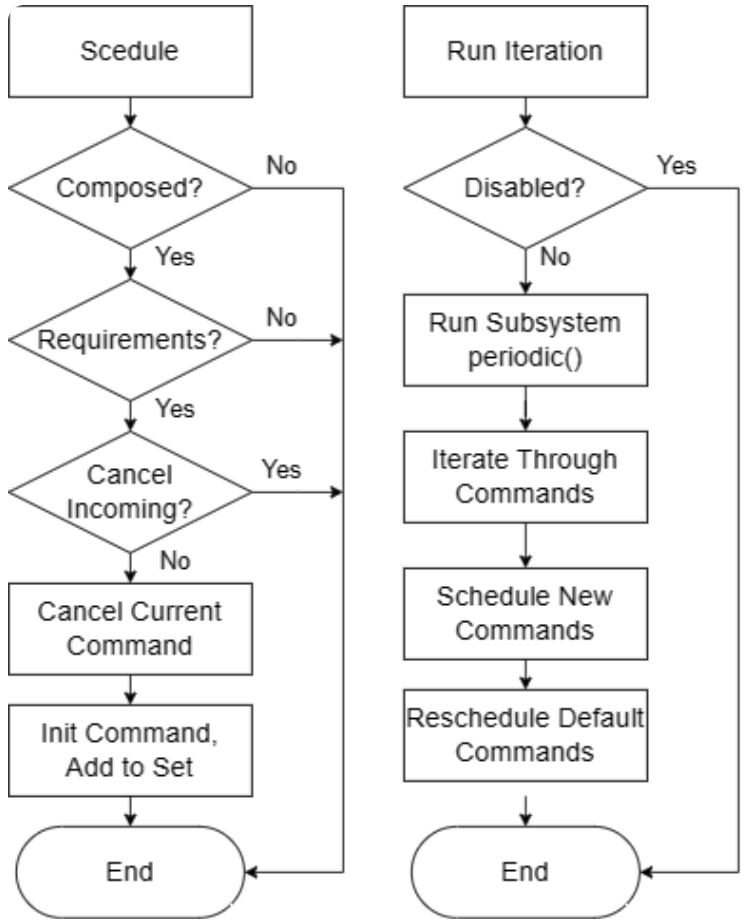


Structure of Command-Based Programs - Command Sceduler

Strictly speaking, Command-Based Programming is still "Looper". But it has more encapsulation, providing more convenience features, while solving the 3 problems mentioned before.

Singleton `CommandSceduler`'s `run` method is called on every iteration of `TimedRobot`.

```
public class Robot extends TimedRobot {
  // ...
  @Override
  public void robotPeriodic() {
    CommandScheduler.getInstance().run();
  }
  // ...
}
```



Creating Subsystems

Creating Subsystems - Basics

Subsystem extends `SubsystemBase` class. You can also create subsystems by implementing the `Subsystem` interface, but you have to register the subsystem yourself afterwards.

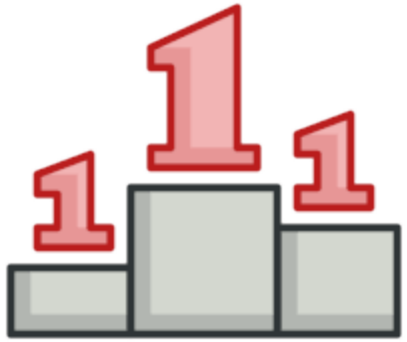
```
import edu.wpi.first.wpilibj2.command.SubsystemBase;

public class Shooter extends SubsystemBase {
    @Override
    public void periodic() {
        // periodic updates
    }
    @Override
    public void simulationPeriodic() {
        // periodic updates under simulation
    }
}
```

Creating Subsystems - Unique Access using Singleton

Subsystem Characteristics:

- Uniqueness - Acquire Hardware Resources
- Universal Access

Here, we can use **Singleton** - a design pattern to ensure **unique**, **global** access to subsystems.



```java
// singleton example
public class Shooter {
    private static Shooter instance; // static instance, allow access without instance
    private Shooter() {
        // private, prevent being called other than this class
    }

    public static Shooter getInstance() {
        // static method, access without a instance
        if(instance == null) {
            instance = new Shooter(); // create when no existing instance exists
        }
        return instance;
    }

    public void setRPM(double rpm) {}

    public void setVolts(double voltage) {}
}

// example usecase
private void test() {
    // all the getInstance() methods generate the same Shooter instance
    Shooter s = Shooter.getInstance();
    Shooter.getInstance().setRPM(100.0);
    s.setVolts(0.0);
}
```

Creating Subsystems - Seperating Responsibilities

The most important question to ask: **What should this Subsystem DO?**

- Problem of Scope and Control
  - What should be done by the commands? What should be done by the Subsystem?
  - How "high-level" should this Subsystem go?

📖 General Rules of Thumb

1: Subsystems should control the hardwares to directly reach a desired **state** you set as the target.

2: Anything that requires **coordination** should be handled by the Commands.

3: Anything that relates to **info publishing & state updating** should be handled by the Subsystems.

4: **Common parts** among a lot of commands should be taken out and encapsulated in the Subsystems.

5: If you are not sure, then generally leave things to new Commands (it's command-base programming!).

Creating Subsystems - Seperating Responsibilities (Cont)

```
public class Swerve extends SubsystemBase {
    private SwerveModuleState[] moduleStates;

    public void drive(ChassisSpeeds chassisSpeeds) {
        setModules(kinematics.toSwerveModuleStates(chassisSpeeds));
    }

    public void stop() {
        drive(new ChassisSpeeds());
    }

    public void setModules(SwerveModuleState... states) {
        if(states.length != moduleStates.length) return;
        System.arraycopy(states, 0, moduleStates, 0, states.length);
    }

    public Rotation2d getGyroAngle() {
        return gyroAngle;
    }

    @Override
    public void periodic() {
        for(int i = 0; i < moduleStates.length; ++i) {
            // control the motors to reach target states...
        }
    }
}
```

```
public class Swerve extends SubsystemBase {
    private SwerveDriveKinematics kinematics
            = Constants.SwerveConstants.KINEMATICS;
    private ChassisSpeeds speed = new ChassisSpeeds();
    private Rotation2d gyroAngle = new Rotation2d();
    private boolean orientMode = false;

    public void drive(ChassisSpeeds cs, boolean isFieldOriented) {
        speed = isFieldOriented
            ? ChassisSpeeds.fromFieldRelativeSpeeds(cs, gyroAngle)
            : cs;
    }

    public void stop() {
        drive(new ChassisSpeeds(), false);
    }

    public void orientModules(SwerveModuleStates... states) {
        // orient the modules
    }

    @Override
    public void periodic() {
        if(orientMode) {
            // control the motors for orientation...
        } else {
            for(SwerveModuleState s : kinematics.toSwerveModuleStates(speed)) {
                // control the motors to reach target states...
            }
        }
    }
```

Creating Subsystems - Seperating Responsibilities (Cont)

Other Common Dilemmas:

- Using a PIDCommand or a PIDController in the Subsystem?
- Using a SwerveControllerCommand or a TrajectoryFollower in the Subsystem?
- Using a Command to control joints of an arm, or only control the end-effector position while leaving the rest of the calculation to the Subsystem?
- ...

Set Your Standard!

Commands are powerful, as they are small state-machines that can even be combined. However, some of the common basic parts should be given to the subsystem to reduce verbosity of writing commands.

Set your standard, and follow it!

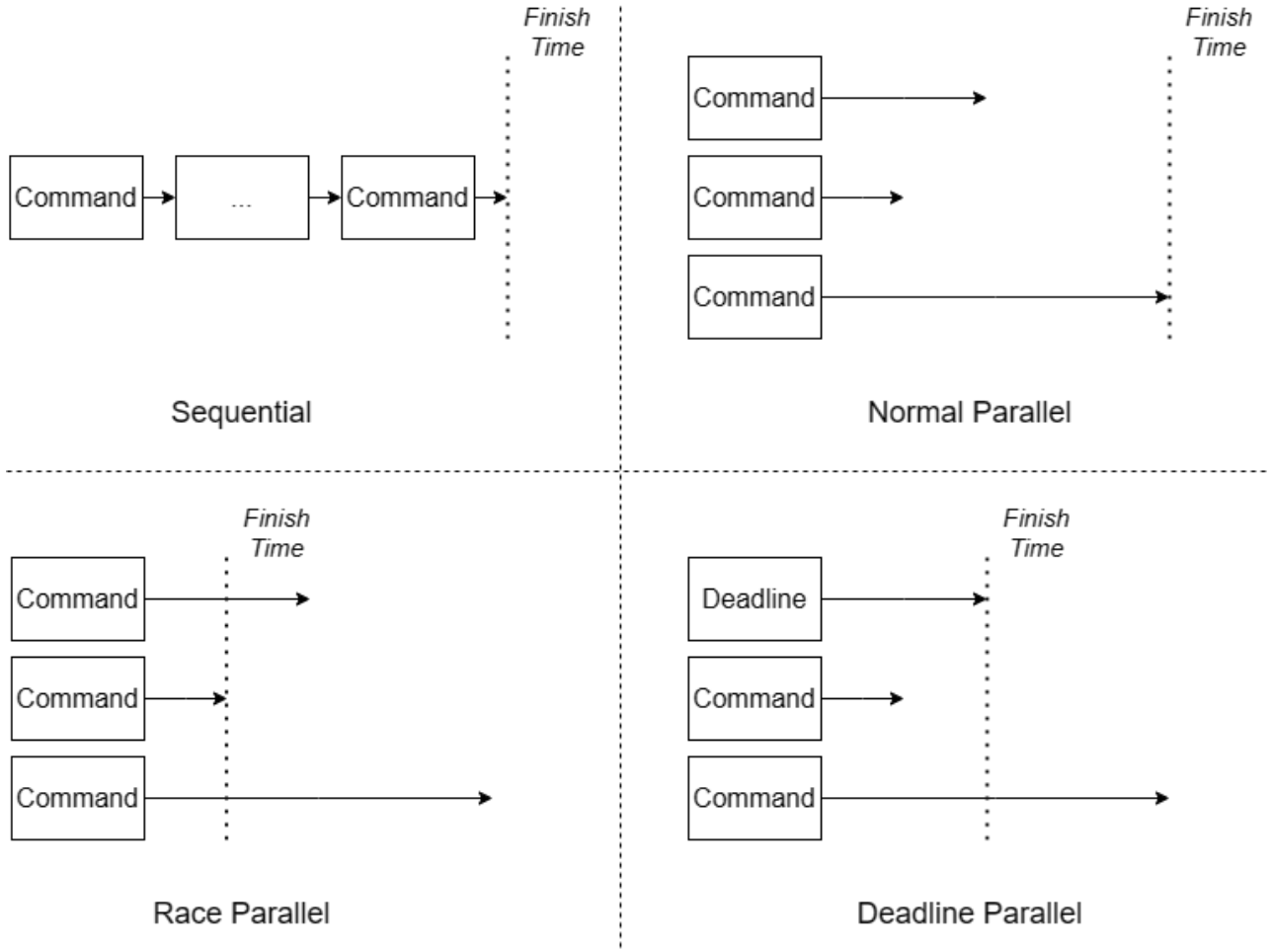
Creating Commands

Creating Commands - Command Grouping & Chaining

Commands can be grouped together using **Command Groups**.
Common Command groups includes:

- Sequential
- Parallel
  - Normal
  - Race
  - Deadline

Combining command groups can create complex commands.



Creating Commands - Using Command Factory & Decorators

There are command we repeatedly use:

- Run a single method
- Run in parallel / sequence / race / deadline
- Print debugging messages
- ...

We can use the **Factory** provided by WPILib - **Commands** class, to conveniently create them in a semantic and highly readable way.

To view all the things, check WPILib API Doc↗ .

```java
// trick to directly import all the static methods for Commands class, so saving a bunch of "Commands.xxx"
import static edu.wpi.first.wpilibj2.command.Commands.*;

// not use factory (at all)
public Command getAutonomousCommand() {
    return new ParallelCommandGroup(
        new SequentialCommandGroup(
            new PrintCommand("Prepare my best over-the-bump 3 game piece auton!!!!!"),
            new WaitCommand(1.0),
            new PrintCommand("whoops")),
        new SequentialCommandGroup(
            new ParallelRaceGroup(
                new RunCommand(() -> Shooter.getInstance().setRPM(100.0),
                    Shooter.getInstance()),
                new WaitCommand(0.5)),
            new InstantCommand(Shooter.getInstance()::stop, Shooter.getInstance())
        )
    );
}

// use factory
public Command getAutonomousCommand() {
    return parallel(
        sequence(
            print("Prepare my best over-the-bump 3 game piece auton!!!!!"),
            waitSeconds(1.0),
            print("whoops")),
        sequence(
            run(() -> Shooter.getInstance().setRPM(100.0), Shooter.getInstance()).withTimeout(0.5),
            runOnce(Shooter.getInstance()::stop, Shooter.getInstance())));
  }
```

Creating Commands - Use Command Factory Methods

Flow

- `RunCommand`, `StartEndCommand`, `RunEndCommand`
  - `run` - repeat one
  - `runOnce` - run one time
  - `startEnd` - run once, then another
  - `runEnd` - repeat one, then start another
- `SequentialCommandGroup`, `ParallelCommandGroup`
  - `sequence` - run in series
  - `parallel` - run group, finish when all finished
  - `race` - run group, finish when any is finished
  - `deadline` - run group, finish when ddl reached

Selection

- `ConditionalCommand`, `SelectCommand`
  - `either` - choose one from two
  - `select` - choose one from multiples

Time Related

- `WaitCommand`, `WaitUntilCommand`
  - `waitSeconds` - wait n seconds
  - `waitUntil` - wait for a condition

Utility

- `InstantCommand`, `PrintCommand`
  - `none` - do nothing, `print` - print message

Creating Commands - Factory of Factories

You can combine commands to create your own factory, then again combine those more high-level commands, finally creating very complex actions.

```
 /** Scores one game piece and balances from the center */
private Command centerScoreOneAndBalance(NodeLevel level, int position) {
    var objective = new Objective(position, level, ConeOrientation.UPRIGHT, false);
    var scoringSegment = driveAndScore(objective, false, true, false, startingLocations[position], false);
    return sequence(
        reset(startingLocations[position]),
        scoringSegment.command(),
        armToHome(),
        Commands.waitUntil(arm::isTrajectoryFinished),
        driveAndBalance(scoringSegment.pose()));
}
```

Author: Mechanical Advantage, Team 6328 Code Link

Creating Commands - Use Triggers

Finally, after creating all the Commands, they should be binded to a certain `Trigger` that starts them.

Triggers will be polled every iteration of the `EventLoop`. When condition is met, the trigger will scedule the command in a certain way (depending on the type of the `Trigger`).

Triggers can be directly created via `Trigger` class, or can be created by the factories inside `CommandGenericHID` for convenient binding.

```
// Bind via CommandGenericHID Factories
private void configureBindings() {
    controller.button(1)
    .onTrue(
        run(
            () -> Shooter.getInstance().setRPM(100.0),
            Shooter.getInstance()))
    .onFalse(
        runOnce(
            () -> Shooter.getInstance().stop(),
            Shooter.getInstance()
        )
    );
}
```

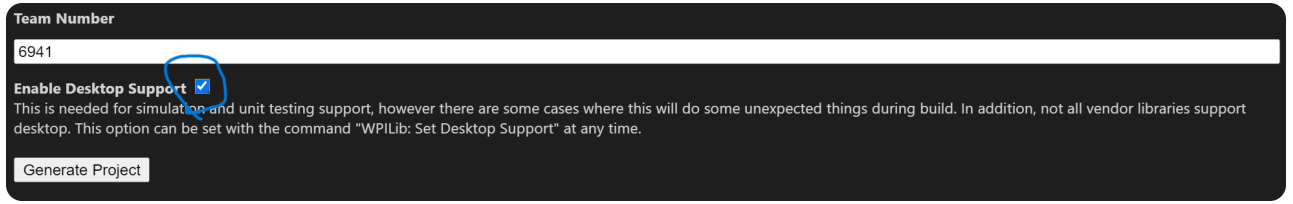
Writing Simulatable Code

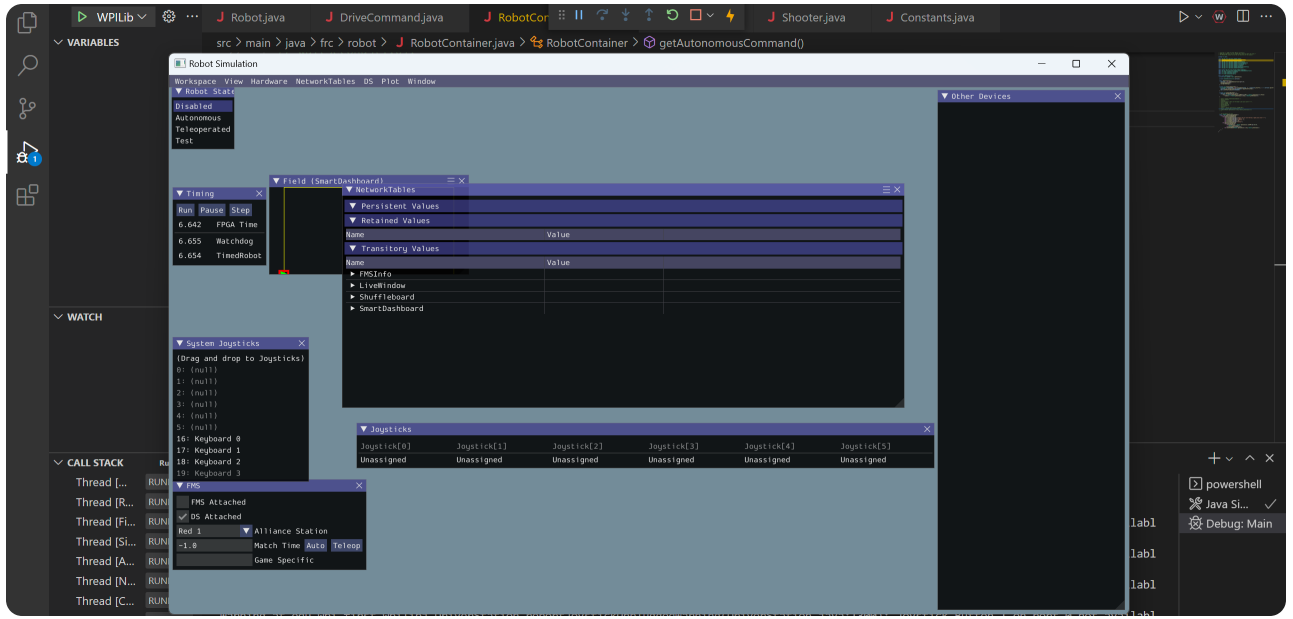
Use "Simulate Robot"

You can enable the "Desktop Support" feature when creating project, so you can use simulate your code.

During simulation, beside `periodic()` for each Subsystem, `simulationPeriodic()` will also be run. You can write code in that section for simulation updating logic.

```
public void run() { // inside CommandSceduler run()
    // ...
    for (Subsystem subsystem : m_subsystems.keySet()) {
        subsystem.periodic();
        if (RobotBase.isSimulation()) {
            subsystem.simulationPeriodic(); // additional
        }
    }
    // ...
}
```





Some Final Tips

- **KNOW YOUR LIMIT** – Time, Budget, and Human Resources.
- **KNOW YOUR HARDWARE**. If possible, IMPROVE YOUR HARDWARE. There are something that is just too hard to control, or the time spent is not worth of the return.
- **MAKE THINGS SIMPLE** (unless you have the resources and time to make it work). Do not overcomplicate things in the season. Utilize existing solutions.
- Write code that can be tested, debugged, and (potentially) simulated, so you can find problems faster. Finding problems means that you have the chance to fix, refactor and improve.
- Violent tests! There are things that will only break under field conditions.
- Keep calm, keep passionate and enjoy!

Thank You For Listening!

And Wish You a Great Kickoff to Cresendo!

The rest of the time is left for Q&As. Don't forget to check your belongings before you leave!

Opening Ceremony for Kickoff will be held at **Ferst Center for the Arts** at **11:00**. Doors will open at **10:30**. Take your time to be there!

Zimeng Chai
zimeng.chai@gatech.edu