SRI MUTHUKUMARAN INSTITUTE OF TECHNOLOGY

(Approved by AICTE, Accredited by NBA and Affiliated to Anna University, Chennai)
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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

YEAR/SEM: IV/VII
SUBJECT CODE & NAME: EC 8791 – EMBEDDED AND REAL TIME SYSTEMS

UNITI:-INTRODUCTION TO EMBEDDED SYSTEM DESIGN

PART – A

1. **What is an embedded computer system? (Nov/Dec-2012)**

It is defined as any device that includes a programmable computer but is not itself intended to be general-purpose computer. Thus, a PC is not itself an embedded computing system. But a fax machine or a clock built from a microprocessor is an embedded computing system.

2. **Why a programmable CPU is used rather than a hardwired unit?**

A programmable CPU is used rather than a hardwired unit for two reasons: first, it made the system easier to design and debug; and second, it allowed the possibility of upgrades and using the CPU for other purposes.

3. **List the characteristics of embedded computing applications. (Nov/Dec-2013)**

The characteristics of embedded computing applications are,

- Complex algorithms
- User interface
- Real time
- Multirate
- Manufacturing cost
- Power and energy

4. **Why use microprocessors?**

There are two reasons for using microprocessors in embedded computing applications.

- Microprocessors are very efficient way to implement digital systems.
- Microprocessors make it easier to design families of products that can be built to provide various feature sets at different price points and can be extended to provide new features to keep up with rapidly changing markets.

5. **Why not use PCs for all embedded computing? How many different hardware platforms do we need for embedded computing systems?**

PCs are widely used and provide a very flexible programming environment. Components of PCs are, in fact, used in many embedded computing systems. But several factors keep us from using the stock PC as the universal embedded computing platform.

6. **Define Cyber-physical systems. (Nov/Dec-2013)**

A cyber-physical system is one that combines physical devices, known as the plant, with computers that control the plant. The embedded computer is the cyber-part of the cyber-physical system. We can, in general, make certain trade-offs between the design of the control of the plant and the computational system that implements that control.

7. **List the challenges in embedded computing system design.**

The important problems that must be taken into account in embedded system design are,

- How much hardware do we need?
- How do we meet deadlines?
- How do we minimize power consumption?
- How do we design for upgradeability?
- Does it really work?

8. **What are the ways in which the nature of embedded computing machines makes their design more difficult? (Apr-2014)**

The nature of embedded computing machines makes their design more difficult in some ways. That are,

- Complex testing
- Limited observability and controllability
- Restricted development environments

9. What are the applications of an embedded system?

- Consumer electronics, e.g., cameras, camcorders, etc.,
- Consumer products, e.g., washers, microwave ovens, etc.,
- Automobiles (anti-lock braking, engine control, etc.,)
- Industrial process controllers & avionics/defense applications
- Computer/Communication products, e.g., printers, FAX machines, etc.

10. What are the objectives of embedded system design process?

There are two objectives for embedded system design process, that are,

- It will give us an introduction to the various steps in embedded system design before we delve into them in more detail.
- It will allow us to consider the design methodology itself.

11. Why the design methodology is so important? (Nov/Dec-2012)

A design methodology is important for three reasons,

- It allows us to keep a scorecard on a design to ensure that we have done everything we need to do, such as optimizing performance or performing functional tests.
- It allows us to develop computer-aided design tools.
- A design methodology makes it much easier for members of a design team to communicate.

12. What are the major level of abstraction in the design process?

The major level of abstraction in the Top-down design are,

- Requirements
- Specification
- Architecture
- Components
- System integration

The major level of abstraction in the Bottom-up design are,

- System integration
- Components
- Architecture
- Specification
- Requirements

13. What are all the major goals and the tasks we need to perform at every steps in the design process?

Goals:

- Manufacturing cost
- Performance

Tasks at every steps:

- We must analyze the design at each step to determine how we can meet the specifications.
- We must then refine the design to add detail.
- We must verify the design to ensure that it still meets all system goals, such as cost, speed, and so on.

14. What are all the non-functional requirements in embedded system design process? (Nov/Dec-2013)

The typical non-functional requirements includes,

- Performance
- Cost
- Physical size and weight
- Power consumption

15. List out the entries in the requirements form as a check list.

The entries in the requirement form are,

- Purpose
- Inputs
- Outputs
- Functions
- Performance
- Manufacturing cost
- Power
- Physical size and weight

16. Define Unified Modeling Language (UML).

The UML is an Object-Oriented modeling language. Object-oriented design emphasizes two concepts of importance:

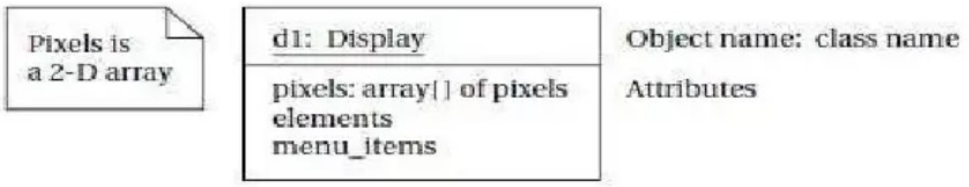
- It encourages the design to be described as a number of interaction objects, rather than a few large monolithic blocks of code.
- At least some of the objects will corresponds to real pieces of software or hardware in the system.

17. Give the steps in embedded system design process methodologies ?

- Requirements
- Specifications
- Architecture
- Components
- System integration

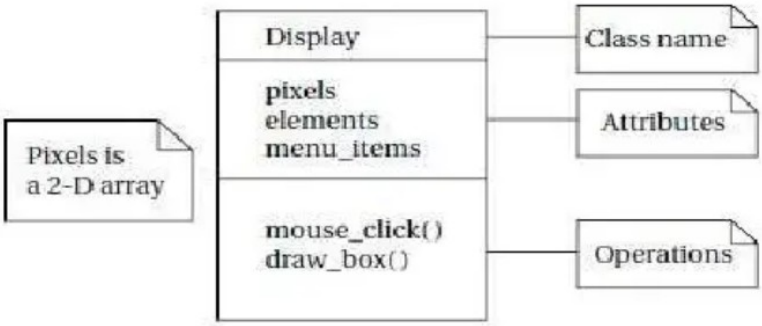
18. Figure an object describing a display in UML notation. (Nov/Dec-2014)

An object in UML notation



19. Figure out A class in UML notation.

An object in UML notation.



20. What are the types of relationships that can exist between objects and classes?

The types of relationships that can exist between objects and classes

- **Association** occurs between objects that communicate with each other but have no ownership relationship between them.
- **Aggregation** describes a complex object made of smaller objects.
- **Composition** is a type of aggregation in which the owner does not allow access to the component objects.
- **Generalization** allows us to define one class in terms of another.

21. What are the design metrics?

- Power
- Size
- NRE cost
- Performance

22. Give some examples for sophisticated embedded systems

- Embedded system for wireless LAN
- Embedded systems for real time video
- Security products
- ES for space lifeboat.

23. List the difference between soft and hard real time systems.

- **HardReal–timesystems:**Inthissystems,missingadeadlinemayleadtoacatastrophe(loss). [Missingdeadlinecauses failure.]
- **SoftReal–timesystems:**Inthesesystems,meetingthedeadlinesisimportantbutmissingthedeadlinewillnotlead to a catastrophe.[missingdeadlineresults in degraded performance]

24.

What are all the major hardware components included in a typical computing platform?

- CPU: provides basic computational facility
- RAM: used for program and data storage.
- ROM: holds the boot program and some permanent data.
- DMA controller: provides direct memory access capabilities.
- Timers: used by the operating system for variety of purpose.
- High speed bus: connect to the CPU bus through a bridge, allows fast devices to communicate efficiently with the rest of the system.
- Low speed bus: provides an inexpensive way to connect simpler devices and may be necessary for backward compatibility as well.

25.

Define CPU bus. (Nov/Dec-2014)

The bus is the mechanism by which the CPU communicates with memory and devices. A bus is, at a minimum, collection of wires but it also defines a protocol by which the CPU, memory, and devices communicate. One of the major roles of the bus is to provide an interface to memory.

PART -B

1.Explain about the embedded system design process with suitable diagrams.

THE EMBEDDED SYSTEM DESIGN PROCESS:

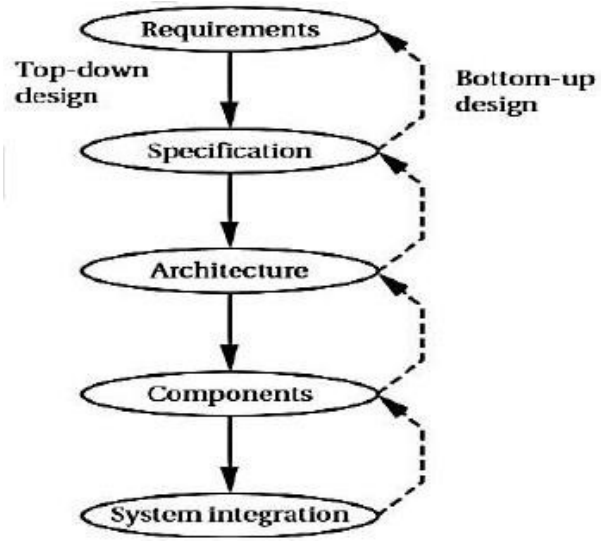


Fig1.2Majorlevels ofabstraction in thedesignprocess

Embedded system design process has two objectives.

- Introduction to thevariousstepsinembedded systemdesignbeforedevelopedindetaileddesign
- Design methodology

Adesign methodologyisimportantforfollowingreasons.

➢Designtoensure that we havedoneeverythingwe needto do.

➢Developcomputer-aideddesigntools.

➢Makesitmucheasierformembersofadesignteamtocommunicate.

Therearefivemajorlevelsofembeddedsystemdesignprocess.Beforegoingtodesignasystemthedesignersneedto fulfil theneeds to design such asystem. They are

REQUIREMENTS:

- **First**,thedesignermust**gatheraninformaldescriptionfromthecustomers**itisknownasrequirements.
- **Second**, then the**designer must know what weare designing andthento refinethe requirement intospecification** and to begin to designing the system architecture.
- Requirements**maybefunctionalornon-functional,**wemustofcoursecapturethebasicfunctionsoftheembeddedsystem, but functional description is oftennot sufficient.

Typicalnon-functional requirementsinclude:

Performance:

- Thespeedofthesystemisoftenamajorconsiderationbothfortheusabilityofthesystemandforitsultimatecost.

- Performancemay beacombinationofsoft performance metrics suchasapproximatetime to performa user-levelfunction and hard deadlines by which aparticularoperation must be completed.

Cost:

- Thetargetcostorpurchasepriceforthesystemisalmostalwaysaconsideration.Costtypicallyhastwomajorcomponents:

  - Manufacturingcostincludesthecostofcomponentsandassembly;

  - Nonrecurringengineering(NRE)costsincludethepersonnelandothercostsofdesigningthesystem.

Physicalsizeandweight:

- Thephysicalaspects ofthefinal systemcanvarygreatlydepending upontheapplication.
- Anindustrialcontrolsystemforanassemblylinemaybedesignedtofitintoastandard-sizerackwithnostrictlimitations on weight.
- A handheld device typically has tight requirements on both size and weight that can ripple through the entiresystem design.

Powerconsumption:

- Power,ofcourse,isimportantinbattery-poweredsystemsandisoftenimportantinotherapplicationsaswell.
- Powercanbespecifiedintherequirementsstageintermsofbatterylife.

Nowwewill listsome requirementsformcollected fromtheuser atthestartof theproject.

1. Name
2. Purpose
3. Inputs
4. Outputs
5. Functions
6. Performance
7. Manufacturingcost
8. Power
9. Physicalsizeandweight

SPECIFICATION:

- Thespecificationismoreprecise-itservesasthe**contractbetweenthecustomerandthearchitects**.Itmustbe**carefully written sothat itaccuratelyreflects thecustomer'srequirements**.
- Specificationisessentialto**creatingworkingsystems**witha**minimum ofdesignereffort**.
- Thespecification will**guidethedesigners what to build whenit build**.
- Thespecificationshouldbe**understandable**enoughsothat**someonecanverifythatitmeetssystemrequirements andoverall expectations of thecustomer.**

ARCHITECTUREDESIGN:

- Thespecification **doesnot sayhowthesystem doesthings,only whatthesystemdoes**.
- ***Thearchitectureis****aplanfortheoverallstructureofthesystemthatwillbeusedlatertodesignthecomponentsthat makeup the architecture****.***
- The**creation of thearchitecture** is the**first phase**of**what many designers thinkof as design**.
- Thearchitectureintheformof**ablockdiagramthatshowsmajoroperationsanddataflows**amongthem.
- Thisblockdiagramisstillquiteabstract-we**havenotyetspecifiedwhichoperationswillbeperformedbysoftwarerunning onaCPU, whatwill bedoneby special-purposehardware,** and soon.
- Architecturaldescriptionsmustbedesignedto**satisfybothfunctional andnon-functionalrequirements**.
- Notonlymustalltherequiredfunctionsbepresent,butwemust**meetcost,speed,power,andothernon-functionalconstraints.**
- Startingoutwithasystemarchitectureandrefiningthatto**hardwareandsoftwarearchitectures**isonegoodwayto ensurethat wemeet all specifications.
- Wecanconcentrateonthefunctionalelementsinthesystemblockdiagram,andthenconsiderthenon-functionalconstraints when creating the hardware and softwarearchitectures.

DESIGNINGHARDWAREANDSOFTWARECOMPONENTS:

- Thecomponentdesigneffort**buildsthosecomponentsinconformancetothearchitectureandspecification.**
- Thecomponentswillingeneralincludeboth**hardwarelikeFPGAs,boards**,andsoonand**softwaremodules.**
- Someofthe componentswill beready-made.
- The **CPU**, for example, will be a standard component in almost all cases, as well as memory chips and manyothercomponents.

SYSTEMINTEGRATION:

- **Onlyafterthecomponentsarebuiltdowehavethesatisfactionofputtingthemtogetherandseeingaworkingsystem.**
- Thisphaseusuallyconsists ofalotmorethanjust**pluggingeverything togetherand standing back**.
- **Bugs**aretypicallyfound**duringsystem integration**,and**goodplanning**canhelpus **findthebugs**quickly.
- Bybuildingupthesysteminphasesandrunning properlychosen tests,we canoftenfindbugsmoreeasily.
- Systemintegrationis **difficult**because**itusuallyuncoversproblems**.
    - ***Itisoften****hard toobservethe system in sufficient detailtodetermineexactlywhatis wrong****.***
- The**debuggingfacilities**forembeddedsystemsareusuallymuchmore**limited**than**whatyouwouldfindondesktop systems.**

2.Analyse the requirements for designing a GPS moving map in embedded system design process.

Requirementsanalysisof aGPS movingmap:

- Themovingmapisahandhelddevicethatdisplaysfortheuseramapoftheterrainaroundtheuser'scurrentposition ;themap displaychanges as theuserand the map devicechangeposition.
- Themoving map obtains its positionfrom theGPS, asatellite-based navigationsystem.
- Themovingmapdisplay mightlooksomething likethefollowingfunctions.

Functionality: Thissystemisdesignedforhighwaydrivingandsimilaruses,notnauticaloraviationusesthat require more specialized databases and functions. The system should show major roads and otherlandmarksavailablein standard topographic databases.

User interface: The screen should have at least 400 x 600 pixel resolution. The device should becontrolledbynomorethanthreebuttons.Amenusystemshouldpopuponthescreenwhenbuttonsarepressedtoallo w the user to makeselections to control thesystem.

Performance: Themapshouldscrollsmoothly.Uponpower-up,adisplayshouldtakenomorethanonesecondtoappear, andthesystemshouldbe ableto verifyitsposition anddisplay thecurrent mapwithin15 s.

Cost: The sellingcost(street price)ofthe unitshouldbenomorethan $100.

Physicalsizeandweight: Thedeviceshouldfitcomfortablyinthepalm ofthehand.
Powerconsumption: ThedeviceshouldrunforatleasteighthoursonfourAAbatteries.

Basedonthisdiscussion, let'swritearequirementschartfor ourmovingmapsystem:

Name	GPS moving map
Purpose	Consumer-grademovingmapfordrivinguse
Inputs	Powerbutton,two controlbuttons
Outputs	Back-litLCDdisplay 400x600
Functions	Uses5-receiverGPSsystem;threeuser-selectableresolutions;alwaysdisplays currentlatitudeandlongitude
Performance	Updatesscreenwithin 0.25seconds uponmovement
Manufacturingcost	$30
Power	100mW
Physicalsizeandweight	Nomorethan 2"x6,"12ounces

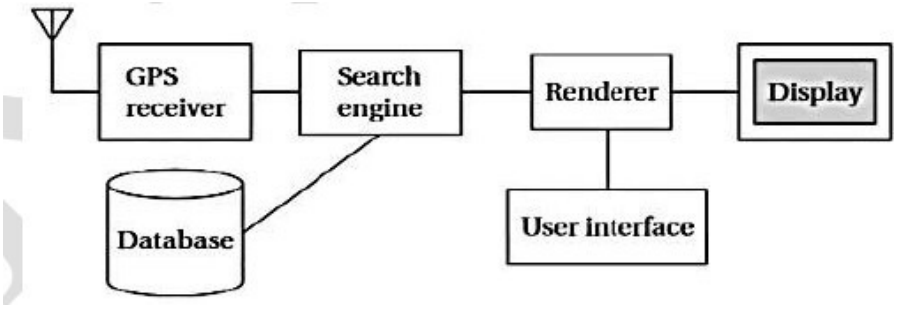


Fig1.3Blockdiagram forthe movingmap

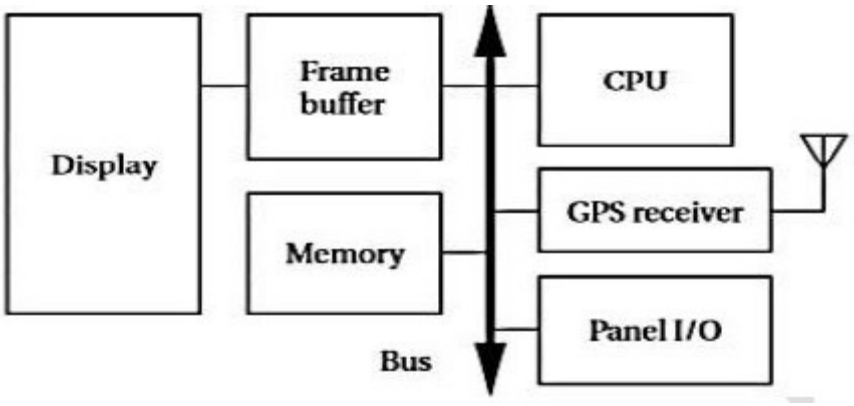


Fig1.3.1Hardwarearchitectureforthe movingmap

AspecificationoftheGPSsystemwouldincludeseveralcomponents:

- DatareceivedfromtheGPSsatelliteconstellation.
- Map data.
- Userinterface.
- Operationsthatmust beperformedtosatisfycustomerrequests.
- Backgroundactionsrequiredtokeepthesystemrunning,suchasoperatingtheGPSreceiver.

- TheGPSisagoodexampleofaspecializedcomponentinalmostthatwillnonethelessbepredesigned,standardcomponent.
- Wecanalso makeuseof standard softwaremodules onegood exampleis thattopographic database.

FORMALISMSFORSYSTEMDESIGN:

- ThereisavisuallanguagethatcanbeusedtocaptureallthesedesigntasksknownasUnifiedModelingLanguage (UML).
- UMLwasdesignedtobe usefulatmanylevelsofabstractioninthedesignprocess.
- UMLisusefulbecauseitencouragesdesignbysuccessiverefinementandprogressivelyaddingdetailtothedesign,ratherthanrethinking thedesign at each newlevel ofabstraction.
- UMLisanobject-orientedmodellinglanguage.
- Object-orienteddesignemphasizestwoconceptsofimportance:
  - Itencouragesthedesigntobedescribedasanumberofinteractingobjects,ratherthanafewlargemonolithicblocks of code.
  - Objectswillcorrespond torealpiecesofsoftwareorhardwareinthesystem.

Object-oriented(often abbreviatedOO)specificationcanbeseenintwocomplementaryways:

- Object-orientedspecificationallowsasystemtobedescribedinawaythatcloselymodelsreal-worldobjectsand their interactions.
- Object-orientedspecificationprovidesabasic setofprimitivesthatcanbeusedtodescribe systemswithparticularattributes,irrespectiveof therelationshipsof thosesystemscomponents toreal-worldobjects.

Therelationshipbetweenanobject-orientedspecificationandanobject-orientedprogramminglanguageisaspecificationlanguagemay not be executable.

- Butbothlanguagesprovidesimilarbasic methodsforstructuringlargesystems.
- UMLis alargeandrich,therearemanygraphical elementsinaUML diagram.
- Itisimportanttobecarefultousethecorrectdrawingtodescribesomethingforinstance;UMLdistinguishesbetween arrowswith openand filled-in arrowheads, andsolidand brokenlines.

StructuralDescription:

- Structuraldescription,givesbasiccomponentsof thesystem anddesigner canlearnhowtodescribehowthesecomponents.
- Theprincipalcomponentof anobject-orienteddesign is,theobject.
- Anobjectincludes aset ofattributesthat defineitsinternalstate.
- Anobject describingadisplay isshown inUML notationin Figure1.4.

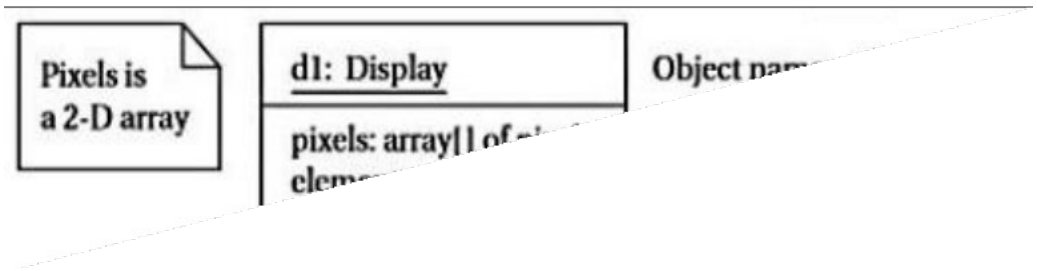


Fig1.4Anobjectin UMLnotation

- Theobjectisidentifiedintwoways:Ithasauniquename,anditisamemberofaclass.Thenameisunderlinedtoshow that this is adescription of an object and not ofaclass.
- Aclassisaformoftypedefinitionallobjectsderivedfromthesameclasshavethesamecharacteristics,althoughthei r attributes may havedifferent values.
- Aclassdefines theattributes thatanobject mayhave.
- Italsodefinestheoperations thatdeterminehowtheobjectinteractswiththe restofthe world.
- TheUML description oftheDisplay class isshown in Figure1.4.1.
- Aclass definesboth theinterfaceforaparticulartypeof objectand thatobject's implementation.
- When weuse anobject,wedonotdirectly manipulate itsattributes,wecanonlyreadormodify the object'sstatethrough the operations that define theinterfaceto theobject.
- Thechoiceofan interfaceisa veryimportant decision inobject-oriented design.
- Theproperinterfacemustprovidewaystoaccesstheobject'sstateaswellaswaystoupdatethestate.

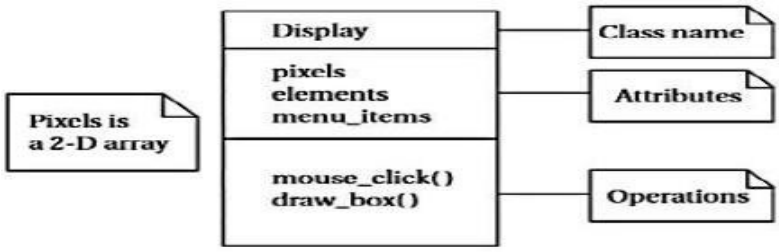


Fig1.4.1AnclassinUMLnotation

- Therearesevеraltypesof relationshipsthatcanexist betweenobjectsand classes:

  Associationoccursbetweenobjectsthatcommunicatewitheachotherbuthavenoownershiprelationshipbetweenthem.

  Aggregationdescribesacomplexobjectmadeofsmaller objects.

  Compositionisatypeofaggregationinwhichtheownerdoesnotallow accessto thecomponentobjects.

  Generalizationallowsustodefineoneclassintermsofanother.

- TheelementsofaUMLclassorobjectdonotnecessarilydirectlycorrespondtostatementsinaprogramminglanguage, if the UML is intended to describe something more abstract than a program, there may be a significantgapbetween the contentsof theUML andaprogramimplementing it.
- Anattributeissomevaluethatreflectsthecurrentstateoftheobject.
- The behaviours of the object must be in a higher-level specification, and contains basic things that can bedonewith an object.
- Likemostobject-orientedlanguages,UML also allowsustodefineoneclassintermsofanother.
- Aderivedclassinheritsalltheattributes andoperationsfromitsbaseclass.
- Aderivedclassisdefinedtoincludealltheattributesofitsbaseclass.

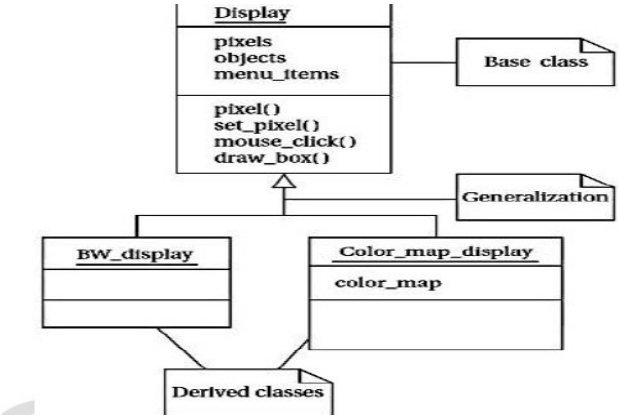


Fig1.4.2Derivedclassesasaform ofgeneralization in UML.

FromourexampledisplayisthebaseclassandBW_displayandColor_map_displayarethetwoderivedclasses.

- Here BW_display represents black and white display, now we can draw the diagram for base and derivedclasses.

Inheritance:

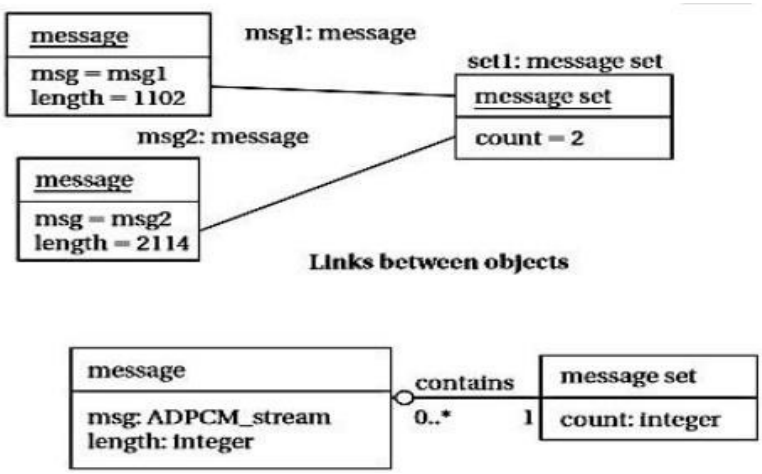


Fig1.4.3Associationbetweenclass es

UnifiedModelingLanguageconsiders inheritance tobeoneformofgeneralization.

- AgeneralizationrelationshipisshowninaUMLdiagramasanarrowwithanopen(unfilled)arrowheadisshown in fig 1.4.3.
- BothBW_displayandColor_map_displayarespecificversionsofDisplayUMLalsoallowsustodefinemultipleinheritance.
- Multipleinheritancemeanswhich aclassis derived frommorethanonebaseclass.
- Alinkdescribesa relationshipbetween objects;associationistolinkas classistoobject.

- Linkused to makeobjects tostand alone and association capturetypeinformation about theselinks.

BehavioralDescription:

- We have tospecify the behaviorof thesystemaswellasitsstructure.Onewaytospecify thebehavior of anoperationis astatemachine.

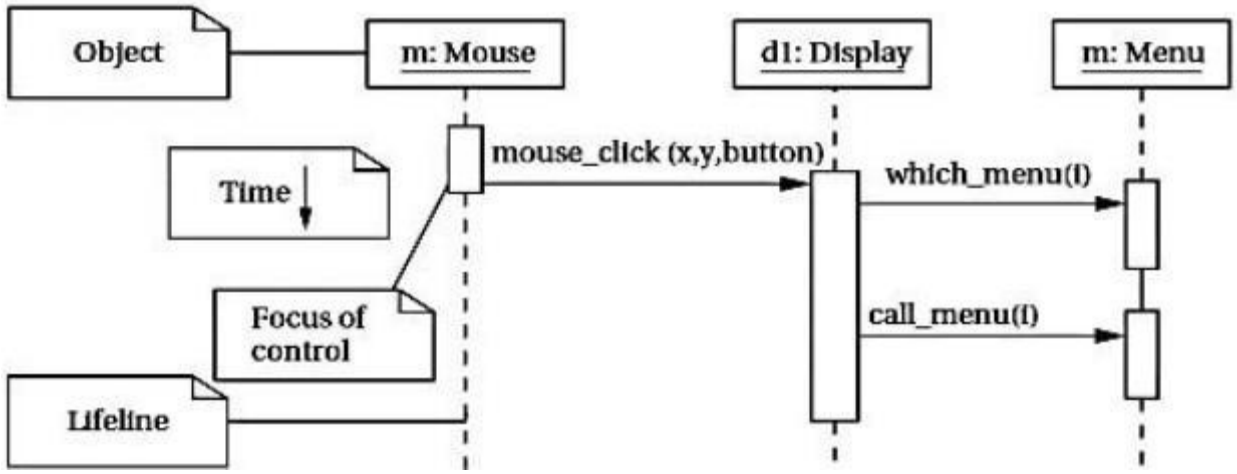


Fig1.4.5A stateandtransitioninUML.

- These state machines will not rely on the operation of a clock, as in hardware; rather, changes from one statetoanother aretriggered by the occurrenceof events.
- Aneventissometypeofaction.Wehavethreetypesofeventsdefinedby UML,asillustratedinFigure1.4.6

.

➢ Asignalisanasynchronousoccurrence.ItisdefinedinUMLbyanobjectthatislabeledasa<<signal>>. Theobjectinthediagramservesasadeclarationoftheevent'sexistence.Asignalmayhaveparametersthatarepassed to thesignal'sreceiver.

➢ Acalleventfollowsthe modelofaprocedurecallina programminglanguage.

➢ Atime-outeventcausesthemachine toleaveastateafteracertainamountoftime.

➢ The labeltm(time-value)ontheedgegivestheamountoftimeafterwhichthetransitionoccurs.Atime-outis generally implemented with an external timer.

Sequencediagram:

- It issometimes usefultoshow thesequence of operations over time, particularlywhen severalobjectsareinvolved.
- Asequencediagramissomewhatsimilartoahardwaretimingdiagram,althoughthetime flowsverticallyina sequencediagram and horizontally in a timing diagram.
- Thesequencediagramisdesignedtoshowaparticularchoiceofeventsanditisnotconvenientforshowinganu mberof mutually exclusivepossibilities.

3. With an example in consumer electronics, explain the embedded system design with computing platform.

CONSUMERELECTRONICSARCHITECTURE:

- Notalldeviceshaveallfeatures,depending onthe waythe deviceisto beused,butmost devicesselectfeaturesfroma common menu.
- Similarly,thereisnosingleplatformfor consumerelectronicsdevices,butthearchitecturesinuse areorganizedaroundsomecommon themes.
- Thisconvergenceispossiblebecausethesedevices implementafew basictypesof functionsinvariouscombinations:multimedia, communications, anddata storageand management.
- The style of multimedia or communications may vary, and different devices may use different formats, but thiscausesvariations inhardware andsoftwarecomponentswithin thebasic architectural templates.

FUNCTIONALREQUIREMENTS:

- Consumerelectronicsdevicesprovideseveraltypesofservicesindifferentcombinations:
- *Multimedia:*
  - Themediamaybe audio,stillimages,or video(whichincludesboth motionpicturesandaudio).
  - Thesemultimediaobjectsaregenerallystoredincompressedformandmustbeuncompressedtobeplayed(audio playback, video viewing, etc.).
  - Alargeand growingnumberof standardshavebeen developedfor multimediacompression: MP3,DolbyDigital(TM),etc. for audio;JPEGforstillimages;MPEG-2, MPEG-4,H.264, etc. for video.

Datastorageandmanagement:

- Because people want to select what multimedia objects they save or play, data storage goes hand-in-hand withmultimediacaptureand display.
- ManydevicesprovidePC-compatiblefilesystemsso thatdata canbesharedmoreeasily.

Communications:

- Communicationsmaybe relativelysimple,such asaUSB interfacetoa hostcomputer.
- Thecommunications link may alsobe moresophisticated, suchasan Ethernet port oracellulartelephonelink.

NON-FUNCTIONALREQUIREMENTS:

1.Manydevicesarebattery-operatedmeans,whichthattheymustoperateunderstrictenergybudgets.

2.Atypicalbattery foraportabledeviceprovidesonly about75mW, whichmust supportnotonly theprocessorsanddigital electronics but also thedisplay, radio, etc.

3.Consumerelectronicsmustalsobe veryinexpensive.

4.Thesedevicesmustalsoprovideveryhighperformance;sophisticatednetworkingandmultimediacompressionrequire hugeamounts ofcomputation.

USECASES:

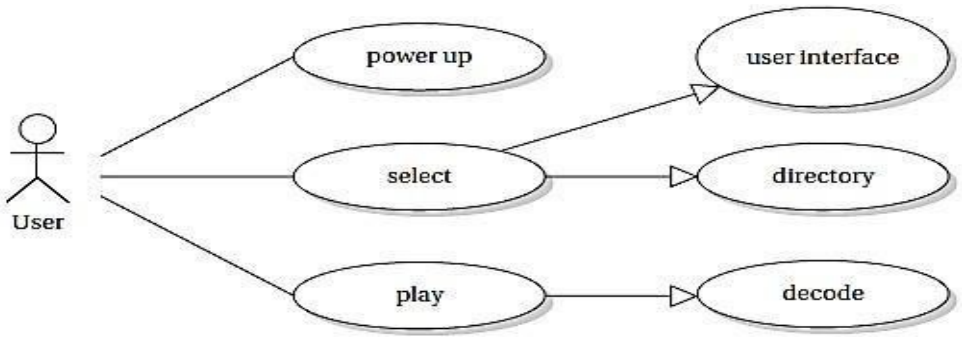


Fig2.12 Usecaseforplaying multimedia

- Fig2.12shows ausecaseforselectingand playingamultimediaobject (anaudio clip,apicture,etc.).
- Selectinganobjectmakes useofboth theuserinterfaceand the filesystem.
- Playingalsomakesuse ofthefilesystem aswellas thedecodingsubsystemandI/Osubsystem.

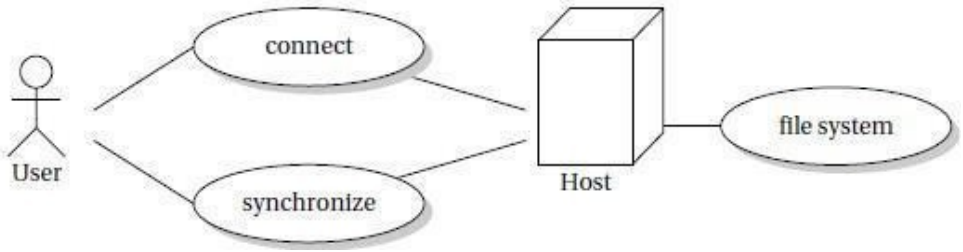


Fig2.12.1Usecaseof synchronizingwith ahostsystem

- Fig2.12.1shows ause caseforconnectingto a client.
- Theconnectionmay beeitherover alocalconnection likeUSBor overtheInternet.
- Whilesomeoperationsmay beperformedlocally on theclient device,most of thework is doneon thehostsystemwhilethe connection is established.

PlatformsandOperatingSystems:

- Giventhesetypes ofusagescenarios, wecandeduceafewbasiccharacteristics ofthe underlyingarchitectureofthesedevices.
- Thestoragesystemprovides bulk, permanentstorageas shownin fig 2.12.2.
- ThenetworkinterfacemayprovideasimpleUSBconnectionorafull-blownInternetconnection.
- Multiprocessorarchitecturesarecommoninmanyconsumermultimediadevices.
- Fig2.12.2shows,two-processorarchitecture;if morecomputationisrequired,moreDSPs andCPUsmaybeadded.
- TheRISCCPUrunsthe operatingsystem,runstheuserinterface,maintainsthefilesystem,etc.
- TheDSP performssignalprocessing.
- TheDSP may beprogrammable insomesystems; inother cases,itmay beoneormorehardwiredaccelerators.

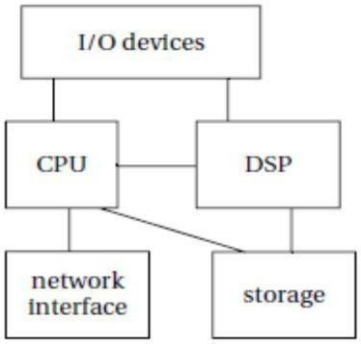


Fig 2.12.2 Hardware architecture of a generic consumer electronics

deviceOperatingSystem:

- Theoperatingsystemthat runsonthe CPUmustmaintain processes andthe filesystem.
- Processes are necessary to provide concurrency—for example, the user wants to be able to push a button whilethe deviceisplaying back audio.
- Dependingonthecomplexityofthedevice,theoperating systemmay notneedto createtasksdynamically.
- Ifalltaskscanbecreated usinginitializationcode,theoperatingsystemcanbemadesmaller andsimpler.

FILESYSTEMS:DOS

Filesystem:

- DOSfileallocationtable (FAT)filesystemsrefertothefilesystemdevelopedbyMicrosoftfor earlyversionsof theDOS operating system.
- FAT can be implemented on flash storage devices as well as magnetic disks, wear-leveling algorithms forflashmemory canbeimplemented withoutdisturbing thebasicoperation ofthefilesystem.
- FATcanbeimplemented ina relativelysmallamountofcode.

Flashmemory:

- Manyconsumer electronicsdevicesuse**flashmemoryformassstorage.**
- Flashmemoryisa typeofsemiconductor memory that,unlikeDRAMorSRAM,provides permanentstorage.
- Valuesarestoredin theflashmemory cellas electricchargeusing aspecialized capacitor thatcan storethechargeforyears.

- Fig2.12.1shows ause caseforconnectingto a client.
- Theconnectionmay beeitherover alocalconnection likeUSBor overtheInternet.
- Whilesomeoperationsmay beperformedlocally on theclient device,most of thework is doneon thehostsystemwhilethe connection is established.

PlatformsandOperatingSystems:

- Giventhesetypes ofusagescenarios, wecandeduceafewbasiccharacteristics ofthe underlyingarchitectureofthesedevices.
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beadded.

TheRISCCPUrunsthe operatingsystem,runstheuserinterface,maintainsthefilesystem,etc.

- TheDSP performssignalprocessing.
- TheDSP may beprogrammable insomesystems; inother cases,itmay beoneormorehardwiredaccelerators.
- Theflashmemory cell doesnotrequirean externalpowersupply tomaintainitsvalue.
- Furthermore, the memory can be written electrically and, unlike previous generations of electrically-erasablesemiconductormemory,canbewrittenusingstandardpowersupplyvoltagesandsodoesnotneedtobedisconnectedduring programming.

Flash fileSystems:

- Flashmemoryhasoneimportantlimitationthatmust betakenintoaccount.
- Writingaflashmemorycellcausesmechanicalstressthateventuallywearsoutthecell.
- Today'sflashmemoriescanreliablybewrittenamilliontimesbutatsomepointtheywillfail.
- While a million write cycles may sound like enough to ensure that the memory will never wear out, creating asingle file may require many write operations, particularly to the part of the memory that stores the directoryinformation.
- Awear-levelingflashfilesystemmanagestheuseofflashmemorylocations toequalizewearwhilemaintainingcompatibility with existing filesystems.
- A simple model of a standard file system has two layers: **the bottom layer handles physical reads andwriteson the storagedevice;thetop layerprovides alogical viewof the filesystem.**
- A flash file system imposes an **intermediate layer that allows the logical-to-physical mapping of files tobechanged.**
- This layer keeps track of how frequently different sections of the flash memory have been written andallocatesdata toequalizewear.
- Itmayalsomovethelocationofthedirectorystructurewhilethe filesystemisoperating.
- Because the directory system receives the most wear, keeping it in one place may cause part of the memory towearout beforetherest,unnecessarilyreducing theuseful lifeof thememory device.
- Severalflashfilesystemshavebeendeveloped,suchas**YetAnotherFlashFilingSystem(YAFFS).**

4.Elaborate in detail about the various quality assurance techniques used for evaluating the embedded system design.

QUALITYASSURANCETECHNIQUES:

- The **International Standards Organization (ISO)** has created a set of quality standards known as ISO9000.
- ISO 9000 was created to apply to a broad range of industries, including but not limited to embeddedhardwareand software.
- The processes used to satisfy ISO 9000 affect the entire organization as well as the individual steps takenduringdesign and manufacturing.
- Wecan,however,makethefollowingobservationsaboutqualitymanagementbasedonISO9000:

Processiscrucial:

- Knowing what steps are to be followed to create a high quality product is essential to ensuring that all thenecessarysteps arein fact followed.

Documentationisimportant:

Thecreationofthedocumentsdescribingprocesseshelpsthoseinvolvedunderstandtheprocesses.

- Documentation helps internal quality monitoring groups to ensure that the requiredprocesses areactuallybeingfollowed and
- Italsohelpsoutsidegroupstounderstandthe processesandhowtheyarebeingimplemented.

Communicationisimportant:

- Qualityultimatelyreliesonpeople.
- Gooddocumentationisanaidforhelpingpeopletounderstandthetotal qualityprocess.
- The people in the organization should understand not only their specific tasks but also how their jobscanaffect overall systemquality.

- Metrics are used in quality control process to know the levels of quality, the execution speed of programsorthecoverageof test patterns and the rateat which bugsare found.

Roleof ISO 9000:

- To help organizations to study their total process, not just particular segments that may appear to beimportantat aparticular time.
- Onewell-knownwayofmeasuringthequalityofanorganization'ssoftwaredevelopmentprocessisthe

CapabilityMaturityModel(CMM).

- TheCMM provides amodelfor **judging an organization.**

- Itdefinesthefollowingfivelevelsofmaturity:

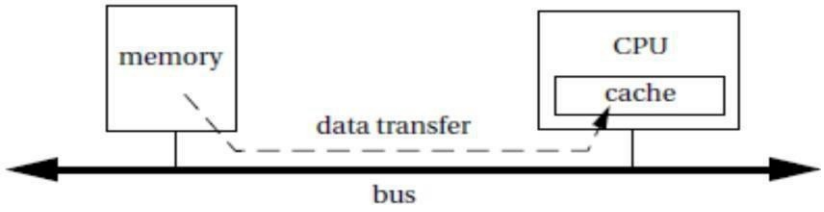
1. **Initial:** A **poorly organized process**, with very few well-defined processes.Success of a project dependsonthe efforts of individuals, not theorganization itself.
2. **Repeatable:** This level provides **basic tracking mechanisms** that allow management to understand cost,scheduling,and how well the systems underdevelopment meet their goals.
3. **Defined:** The management and engineering processes are **documented and standardized**. All projectsmakeuseof documentedand approved standard methods.
4. **Managed:**Thisphasemakes **detailed measurementsofthedevelopmentprocess**andproductquality.
5. **Optimizing: At the highest level, feedback from detailed measurements** isused to continually improvetheorganization's processes.

5. Enumerate on platform level performance analysis of embedded computing system design.

PLATFORM-LEVELPERFORMANCEANALYSIS:

- Bus-basedsystemsaddanotherlayerofcomplicationtoperformanceanalysis.
- Platform-levelperformanceinvolvesmuch morethantheCPU.
- We often focus on the CPU because it processes instructions, but any part of the system can affect totalsystemperformance.
- Moreprecisely,theCPUprovidesan upperboundonperformance,but any otherpartofthe systemcanslowdown theCPU.
- Merelycountinginstruction executiontimesis notenough.

Fig2.13Systemleveldataflowsandperformance.



- Considerthesimplesystem ofFig 2.13.Wewantto movedata from memoryto theCPU toprocessit.
- Toget thedatafrom memory to the CPU wemust:
  - Readfromthememory;
  - Transferoverthebusto thecache;and
  - Transferfromthecacheto theCPU
- Thetimerequiredtotransfer fromthecachetotheCPUisincludedinthe instructionexecutiontime,but theothertwo times arenot.

Bandwidthasperformance:

- Bandwidth:Therate atwhichwecanmovedata.
- Ultimately,ifweareinterestedin real-timeperformance,measuredinseconds.
- Butoftenthesimplestway tomeasureperformanceisin unitsof clockcycles.
- However,differentpartsofthesystemwillrunatdifferentclockrates.

BusBandwidth:

- Whenwearetransferringlargeblocksofdata,considerthebandwidth providedby onlyonesystemcomponent, thebus.
- Consideran imageof 320 $\times$240pixels, witheachpixelcomposed of3bytes ofdata.
- Thisgives agrand total of230, 400 bytesofdata.
- Iftheseimagesarevideoframes, wewant to checkif wecan pushoneframe throughthe system withinthe1/30secthat wehavetoprocess aframe beforethenext onearrives.
- Letusassumethatwe cantransfer onebyte ofdata everymicrosecond,whichimplies abus speedof 1MHz.
- Inthiscase, wewould require230, 400s =0.23secto transferoneframe.
- Thatismorethan the0.033secallotted tothedata transfer.
- Wewould havetoincreasethetransfer rate by7$\times$to satisfyourperformancerequirement.
- **We can increase bandwidth in two ways:** We can increase the clock rate of the bus or we can increase theamountof data transferred per clockcycle.
- Forexample,ifweincreasedthebus tocarryfour bytes or32bits pertransfer,wewould reducethe transfertimeto 0.058 sec.
- Ifwe couldalso increase the busclock rateto 2MHz, thenwewouldreducethetransfer timeto 0.029sec,whichis within ourtimebudget forthe transfer.

Busbandwidthcharacteristics:

- Howdo weknow how longit takes totransfer oneunitof data?Todeterminethat,wehavetolook at thedatasheetforthe bus.
- Abustransfer generallytakesmorethanonebuscycle.

- Bursttransfers,whichmovetocontiguouslocations, maybemoreefficientperbyte.
- Wealso needto knowthe widthof thebus, how many bytesper transfer.
- Finally,weneedto knowthebus clock period,which in generalwill bedifferent from theCPU clock period.

Busbandwidthformulas:

- Let'sassumethebusclockperiodPandthebus widthW.
- Writethebasic formulasinunitsof buscyclesT , thenconvert thosebuscycle countstorealtimetusingthebusclock period P:

$$\mathbf{t = TP} \qquad \ldots(1)$$

- Asshown in Fig 2.13.1,abasicbus transfer transfers aW-widesetof bytes.

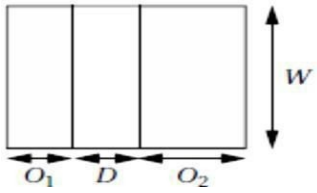


Fig2.13.1Timesanddatavolumesin abasicbustransfer

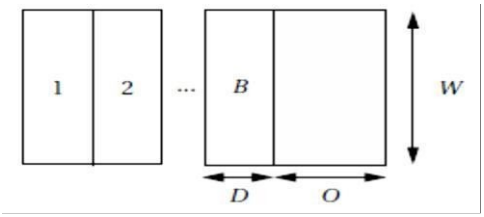


Fig2.13.2Timesanddatavolumesin aburstbustransfer.

- Thedata transferitselftakesD clockcycles. (Ideally,D =1, but amemorythatintroduces waitstates isoneexampleof atransfer thatcould require D >1 cycles.)
- Addresses, handshaking, and other activities constitute overhead that may occur before (O_1) or after (O_2) thedata.
- Forsimplicity, wewill lump theoverhead into$O=O_1+O_2$.

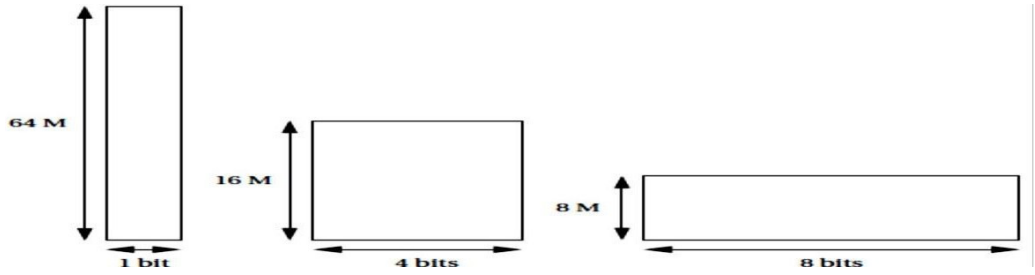
ComponentBandwidth:

- Thewidth ofamemorydetermines thenumber of bits wecan readfrom thememory inone cycle.
- Thatis aform ofdatabandwidth.
- Wecan changethe typesofmemory componentsweusetochangethememory bandwidth; wemay alsobeableto changethe format of ourdata to accommodate thememory components.

Memoryaspectratios:

- Asinglememorychip isnot solelyspecified by thenumber ofbits itcan hold.

Fig2.13.3Memoryaspectratios



- Asshownin Fig2.13.3,memories ofthe samesizecan havedifferent**aspectratios.**

- Forexample,a64-MBmemory thatis 1-bit-wide willpresent 64million addressesof1-bitdata.
- The same size memory in a 4-bit-wide format will have 16 distinct addresses and an 8-bit-wide memorywillhave8 million distinct addresses.
- Memory chips do not come in extremely wide aspect ratios but we can build wider memories by usingseveralmemories in parallel.
- Ratherthanbuy memory chips individually,wemaybuymemory asSIMMs orDIMMs.
- Thesememories arewidebutgenerally onlycomein fairlystandardwidths.
- Which aspect ratio is preferable for the overall memory system depends in part on the format of the datathatwewanttostoreinthememoryandthespeedwithwhichitmustbeaccessed,givingrisetobandwidthanalysis.

MemoryaccesstimesandBandwidth:

- Wealsohaveto consider thetimerequiredtoreador writeamemory.
- Onceagain, werefer to thecomponent datasheets to findthesevalues.
- Accesstimesdepend quiteabit onthe typeofmemory chipused.
- Pagemodesoperatesimilarlytoburstmodesinbuses.
- Ifthememory isnotsynchronous, wecan stillreferthetimesbetween eventsbackto thebus clock cycletodeterminethe number of clock cycles required for an access.
- Thebasicform oftheequation formemorytransfer timeis thatofEqu(3),where Oisdetermined bythepagemodeoverhead and D isthe timebetween successive transfers.
- However, the situation is slightly more complex if the data types do not fit naturally into the width of thememory.
- Let'ssaythatwewanttostorecolorvideopixelsin ourmemory.
- Astandardpixelisthree**8-bit**colorvalues(red, green,blue, forexample).
- A**24-bit-widememory** wouldallowus toreadorwriteanentirepixelvaluein oneaccess.
- An**8-bit-widememory**, incontrast, wouldrequirethree accesses forthepixel.
- If we have a **32-bit-wide memory**, we have two main choices: We could waste one byte of each transfer orusethat byte to storeunrelated data, or wecould pack the pixels.
- Inthelattercase,thefirstreadwouldgetallofthefirstpixelandonebyteofthesecondpixel;thesecondtransfer would getthelasttwo bytes ofthesecondpixel andthefirst twobytes ofthe third pixel;andsoforth.

6.Assuming the design of model train controller,draw a state diagram for a behavior that sends the command bits on the track.The machine should generate the address,generate the correct message type,include the parameters and generate the error correcting code(ECC).

DESIGN:MODELTRAINCONTROLLER

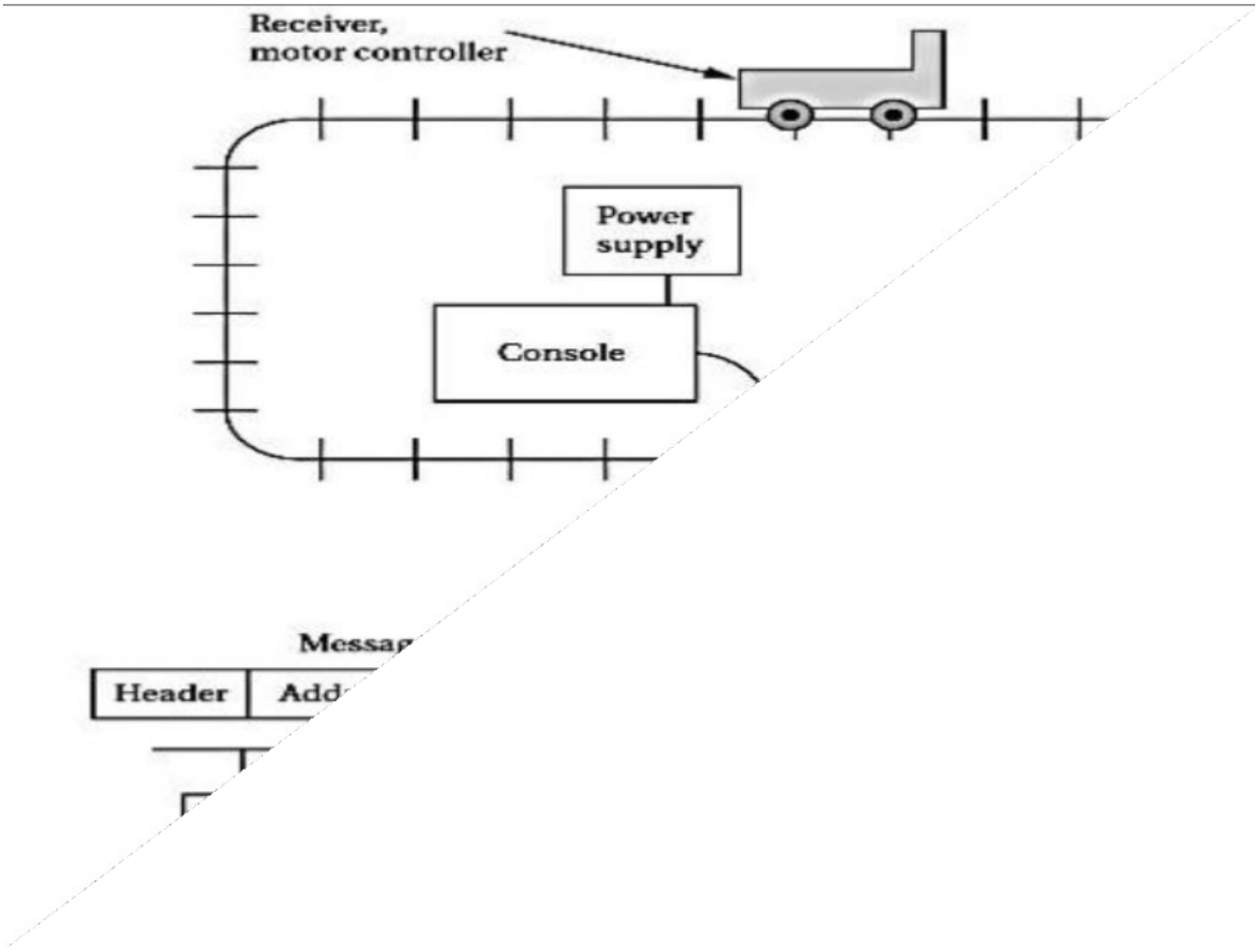


Fig1.5Amodeltrain controlsystem

- InordertolearnhowtouseUMLtomodelsystems,wewillspecifyasimplesystem,amodeltrain controllerin Fig1.5.
- Theusersends messagestothetrain withacontrolboxattachedto thetracks.
- Thecontrolbox mayhavefamiliarcontrols suchas athrottle, emergencystop button,and soon.
- Thetrainreceivesitselectricalpowerfromthetworailsofthetrack,thecontrolboxcansendsignalstothetrainovert he tracks bymodulating the power supply voltage.
- Asshownin thefig 1.5,thecontrolpanelsendpackets overthe tracksto thereceiver onthetrain.
- Thetrainincludesanalogelectronicstosensethebitsbeingtransmittedandacontrolsystemtosetthetrainmotor's speed and direction based on thosecommands.
- Eachpacketincludesanaddresssothattheconsolecancontrolseveraltrainsonthesametrack;thepacketalsoinclu des an errorcorrection code(ECC) toguard against transmissionerrors.
- Thisisaone-waycommunicationsystemthemodeltraincannotsendcommandsbacktotheuser.

Requirements:

Thebasic setofrequirementsforthesystem:

- Theconsoleshallbeabletocontrolupto eighttrains ona singletrack.
- Thespeedofeachtrainshallbecontrollablebyathrottletoatleast63differentlevelsineachdirection(forwardandreverse).
- Thereshallbeanemergency stopbutton.
- Anerrordetectionschemewillbeusedtotransmitmessages.
- Thereshallbeaninertiacontrolthatshallallowtheusertoadjusttheresponsivenessofthetraintocommandedchanges in speed.
- Wecanputtherequirementsintoourchartformat:

Name	Modeltraincontroller
Purpose	Controlspeed ofup toeight modeltrains
Inputs	Throttle,inertiasetting, emergencystop, trainnumber
Outputs	Traincontrolsignals
Functions	Setenginespeedbasedupon inertiasettings;respondtoemergencystop
Performance	Canupdatetrainspeedatleast10timespersecond
Manufacturingcost	$50
Power	10W(plugs intowall)
Physicalsizeandweight	Consoleshouldbecomfortablefortwo hands,approximatesizeof standard keyboard;weight<2pounds

DIGITALCOMMAND CONTROL(DCC):

- The DCC standard was created by the National Model RailroadAssociation to support interoperable digitally-controlledmodel trains.
- DCCwascreatedtoprovideastandardthatcouldbebuiltbyanymanufacturersothathobbyistscouldmixandmatch components from multiplevendors.
- TheDCC standardis given intwo documents:
  - StandardS-9.1,theDCCElectricalStandard,defineshowbitsareencodedontherailsfortransmission.
  - StandardS-9.2,theDCCCommunicationStandard,definesthepacketsthatcarryinformation.
- AnyDCC-conformingdevicemustmeetthese specifications.
- TheDCCstandarddoesnot specifymanyaspectsof aDCCtrainsystem.
- Itdoesn'tdefinethecontrolpanel,thetypeofmicroprocessorused,theprogramminglanguagetobeused,ormanyother aspects of areal model train system.
- Theencodingstandardmustbe carefullydesignedbecausethemainfunctionofthe trackistocarrypowertothe locomotives.
- Thesignalencoding systemshouldnotinterferewithpowertransmissioneithertoDCCornon-DCClocomotives.
- Thedata signalshould not changethe DC valueof therails.
- Thedatasignalswingsbetweentwovoltagesaroundthepowersupplyvoltagesuchas0and1asshowninFig1.5.1.

Thestandardalsodescribesotherelectricalpropertiesofthesystem,suchasallowabletransitiontimesforsignals.

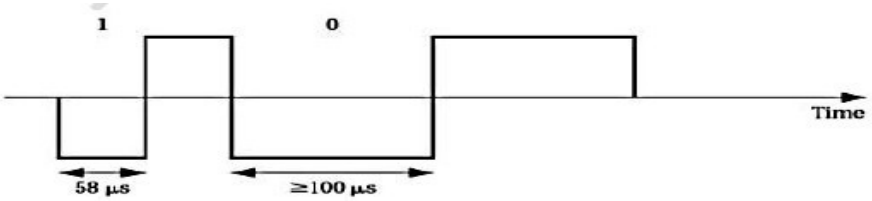


Fig1.5.1BitencodinginDCC.

- TheDCCCommunicationStandarddescribeshowbitsarecombinedintopacketsandthemeaningofsomeimportantpackets.

- Wecanwritethebasicpacketformatasaregular expression:

PSA(SD)+E …… (1)Where

- Pisthepreamble,whichisasequenceof at least10 1bits.
- Sisthepacket start bit.It isa0bit.
- A is an address data byte that gives the address of the unit, with the most significant bit of the addresstransmitted first. An address is eight bits long. The addresses 00000000,11111110, and 11111111 arereserved.
- Sisthe databyte start bit,whichlikethe packet startbitis a0.
- D is the data byte, which includes eight bits. A data byte may contain an address,instruction,data,or errorcorrectioninformation.
- Eisapacketendbit,whichis a 1bit.

- Apacketincludes oneormoredatabytestartbit/data bytecombinations.

Baselinepacket:

- AbaselinepacketistheminimumpacketthatmustbeacceptedbyallDCCimplementations.
- Morecomplexpackets aregiven inaRecommended Practicedocument.
- Abaselinepacket hasthreedatabytes:
  - Addressdatabytethatgivestheintendedreceiverofthepacket;
  - Instructiondatabyteprovidesabasicinstruction;
  - Errorcorrectiondatabyteisusedtodetectandcorrecttransmissionerrors.
- Theinstructiondatabyte carriesseveralpiecesofinformationsuchas
  - Bits0-3providea4-bitspeedvalue.
  - Bit4hasanadditional speedbit.
  - Bit 5givesdirection,with 1forforwardand0forreverse.
  - Bits7-8areset at01toindicatethatthisinstructionprovidesspeedanddirection.

ConceptualSpecification

- DigitalCommandControlspecifiessomeimportantaspectsofthesystem,butitdoesnotspecifyeverythingabouta model train control system.
- Solutionforthe aboveproblemis conceptualspecification.It allowsusto understandthesystembetter.
- Atraincontrolsystem turnscommandsintopackets.
- Acommandcomes fromthe commandunitwhile apacket istransmittedover therails.
- Commandsandpacketsmaynotbegeneratedina1-to-1ratio.
- Inthe DCCstandardcommandunitsshouldresendpackets incaseapacketisdroppedduringtransmission.

1. Commandunitand
2. Train-boardcomponentas shownin Figure1.5.2.

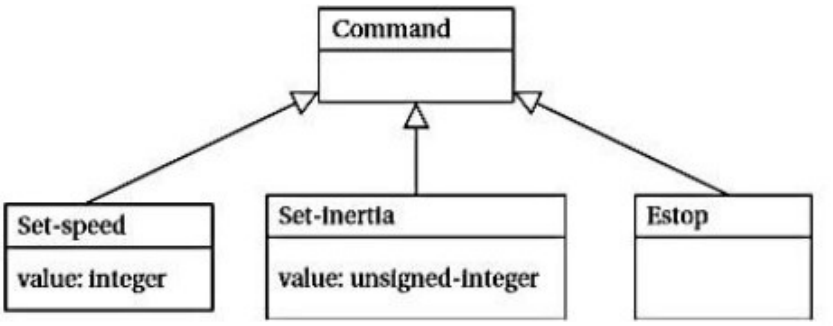


Fig1.5.2Class diagramforthetrain controllermessages.

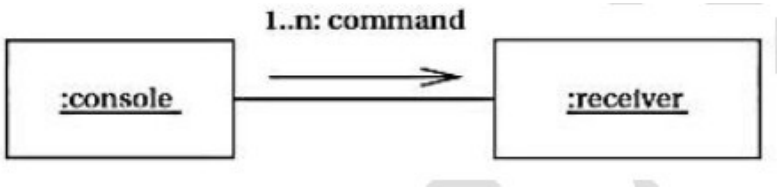


Fig1.5.3UMLcollaborationdiagramformajorsubsystemsofthetrain controllersystem.

Nowwewilldiscussaboutclassdiagramoftrainsubsystemsandfunctionsofeachelementpresentedinthediagram.

- Theconsoleneedstoperformthreefunctions:
  - Readthestateofthefrontpanelonthecommand unit,
  - Formatmessages,and
  - Transmitmessages.

- Thetrainreceivermustalso performthreemajorfunctions:
  - Receivethe message,
  - Interpretthemessage
  - Control themotor

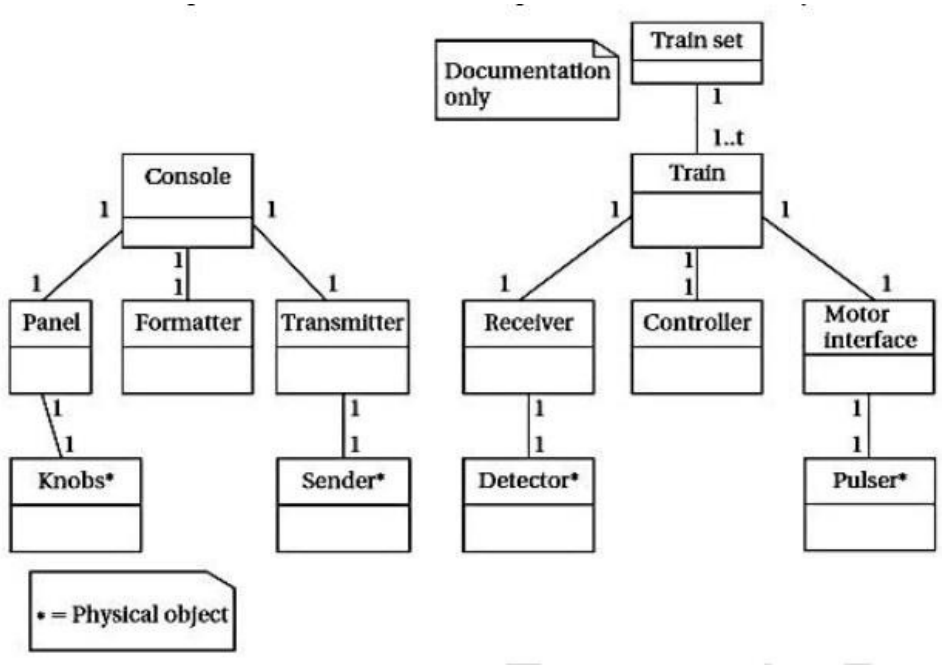
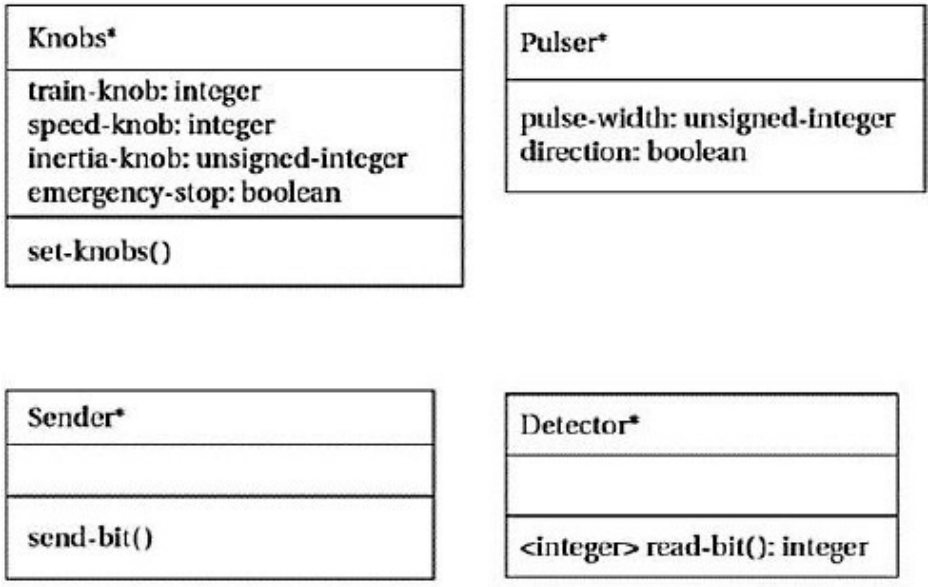


Fig1.5.4AUMLclassdiagramforthetrain controllershowingthe composition ofthesubsystems.

DetailedSpecification:



Basiccharacteristicsof classes in UMLdiagram:

- The**Console**classdescribesthecommandunit'sfrontpanel,whichcontainstheanalogknobsandhardwareto interfaceto thedigital parts ofthe system.
- The**Formatter**classincludesbehaviorsthatknowhowtoreadthepanelknobsandcreatesabitstreamforthe required message.
- The**Transmitter**classinterfaces toanalogelectronicsto sendthemessagealongthetrack.
- Intheclassdiagramsomespecialclassesthatrepresentanalogcomponentsanditisendingthenameofeachwit h anasterisk:

➢ **Knobs***describestheactualanalogknobs,buttons,andleversonthe control panel.
➢ **Sender*** describes the analog electronics that send bits along the

track.Likewise,the trainmakes useofthreeother classes

thatdefineitscomponents:

1. The**Receiver**classknowshow toturn theanalogsignalson thetrack intodigital form.
2. The**Controller**classincludesbehaviorsthatinterpretthecommandsandfiguresouthowtocontrolthemotor.
3. The**Motorinterface**classdefineshowtogeneratetheanalogsignals requiredtocontrol themotor.

Classestorepresentanalogcomponents:

- **Detector***detectsanalogsignalsonthetrackandconvertsthemintodigitalform.
- **Pulser***turnsdigitalcommandsintotheanalogsignalsrequiredtocontrolthemotorspeed.

Wehavealso definedaspecialclass, Trainset, tohelpus rememberthat thesystem canhandlemultiple trains.

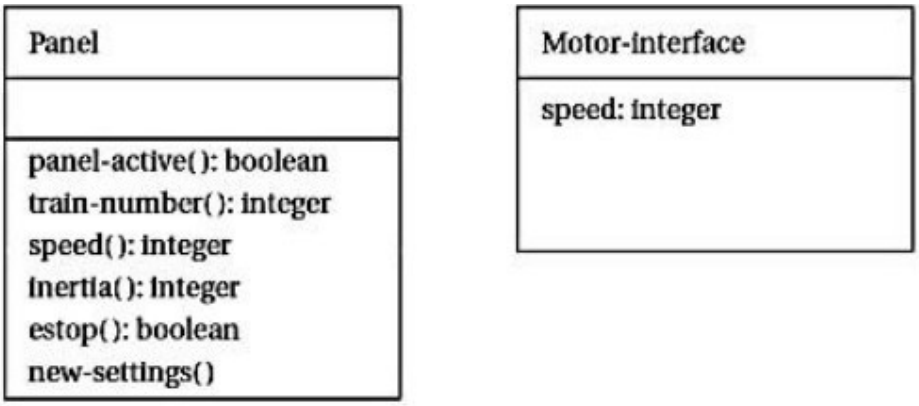


Fig1.5.5 Class diagramforthe Paneland Motorinterface.

☐ Weneedtodefinetheanalogcomponentsinalittlemoredetailbecausetheircharacteristicswillstronglyinfluencet heFormatter and Controller.

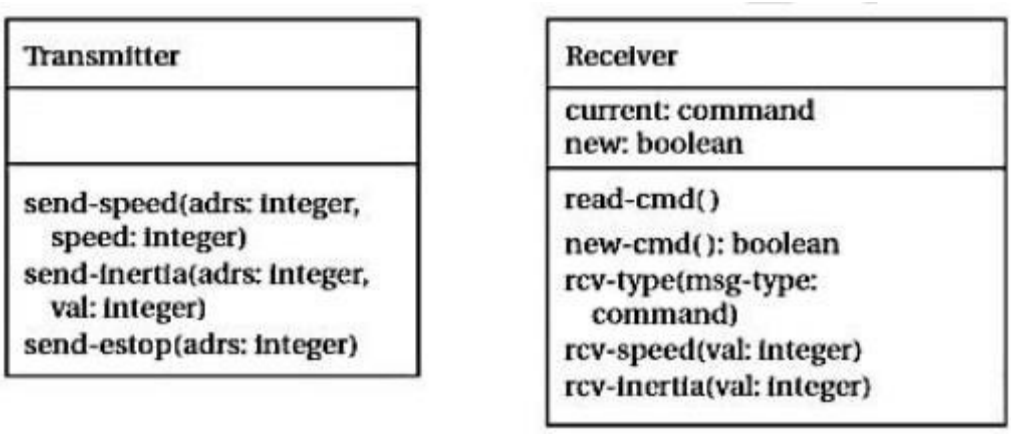
☐ Fig1.5.5Classesdescribinganalogphysicalobjectsinthetraincontrol system.Now wewillconcentrate oneachanalog componentsandits functions indetailed manner withits classdiagram.

☐ ThePanel has threeKnobs:

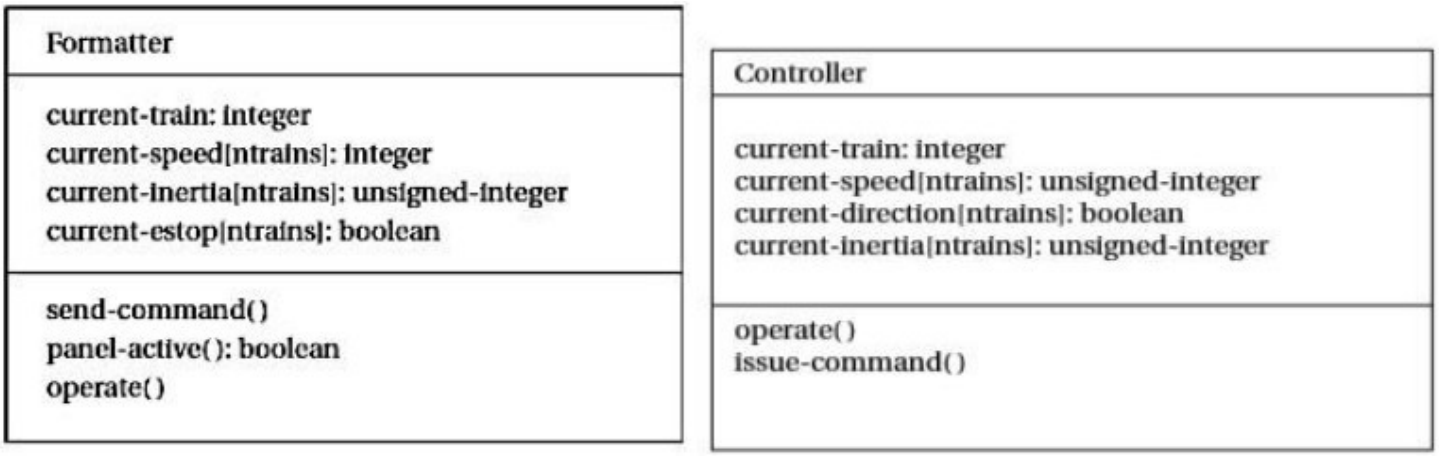
1. Trainnumber
2. Speedand

3. Inertia.

- Italsohasonebuttonforemergency-stop.



ClassdiagramfortheTransmitterandReceiver.



Classdiagramforformatterand controllerclass.

☐Theseclassesspecifythedetailedfunctionsofeachandeverycomponents.Thepulsewillcontrolthetrainspeedusing pulsewidth modulation.

☐ Inthe traincontrolsystemwehave twomorecomponentssuchasformatterandcontroller.Nowwewillseetheclass diagram ofits gives the detailedoperation performed bythe particularcomponent.

☐ Operatebehavioranyclassalsoimportantbehaviorofclassesisdefinedinstatediagramforexamplewecanseethe state diagram forformatterandcontrollerclass.

Classdiagramsandstatediagramswillgivemoredetailedinformationandwhatkindofoperationseachclassgoingto perform everythingwill bepresented.

Howoneclass isgoing tocommunicate orinterfacewith otherclass toperform differentkind ofoperations.

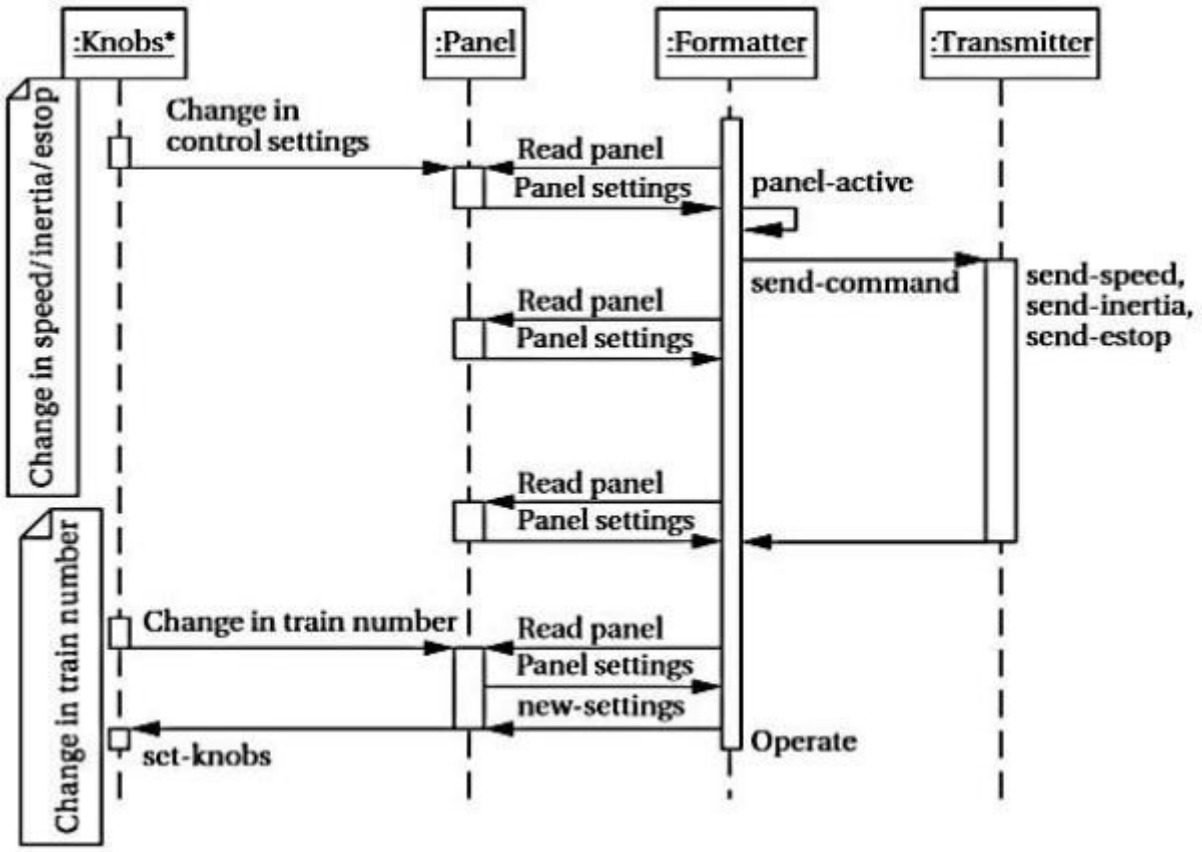


Fig1.5.10Sequencesdiagram fortransmittingacontrolinput.

- Sequencediagramwillspecifiestheinterfacebetweenmorethanoneclassesanditsdetailedoperatio nsandwhat ways its going to operate.
- Forexamplewe cantake sequencediagramortransmitting acontrolinput.

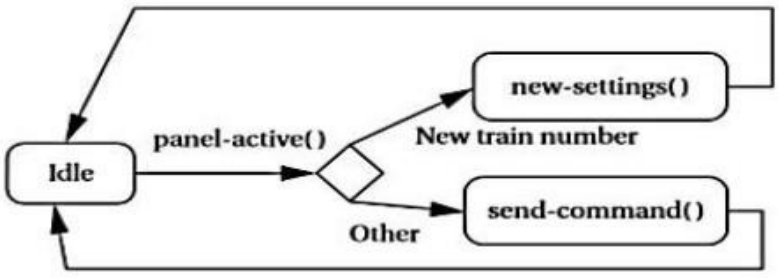


Fig1.5.11 Statediagram fortheformatteroperatebehavior.