



internal server

stethoscope

Fuel(x2).play

K

running

-> default

record >

Avg CPU: 4.8 %

Peak CPU: 10.9 %

IGens: 270

Synths: 21

Groups: 20

SynthDefs: 75

0

0

2

, Scale.egyptian

, 0.2, 0.15], inf)+Prand([0, 0.5, 2].stutte

Challenges:

Part I: A computer-generated composition which respects the rules of Western music.

Part II: A drum machine which takes 2D ASCII arrays and transforms them into sound.

-or-

An instrument that communicates in the MIDI protocol.

-or-

A set of sound envelope profiles and a program to play them.

Programming VI: Sound Synthesis

What is sound?

Western Music Basics

- Note Frequencies

- Scales and Chords

- Chord Progressions

Project Ideas

- Automatic Composition

- Arpeggiator

- Drum Machine

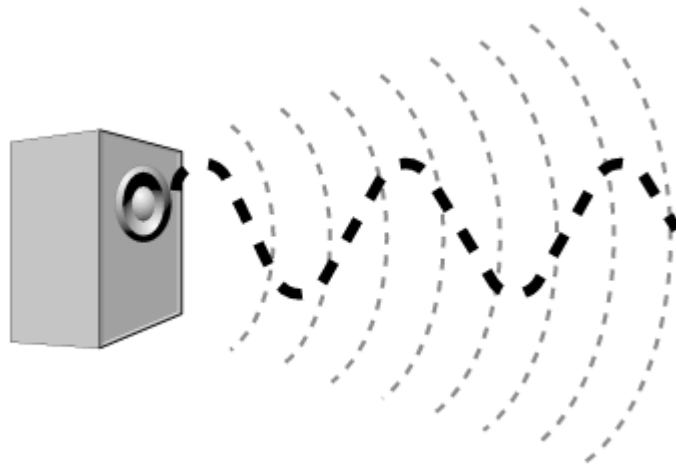
- Sampler

- Midi Device

- Sound Envelope Editor

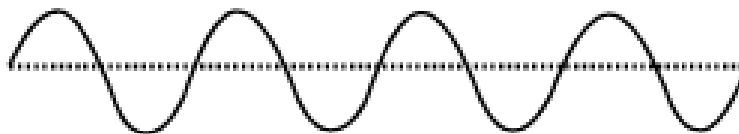
Inspiration

Sound is Vibration

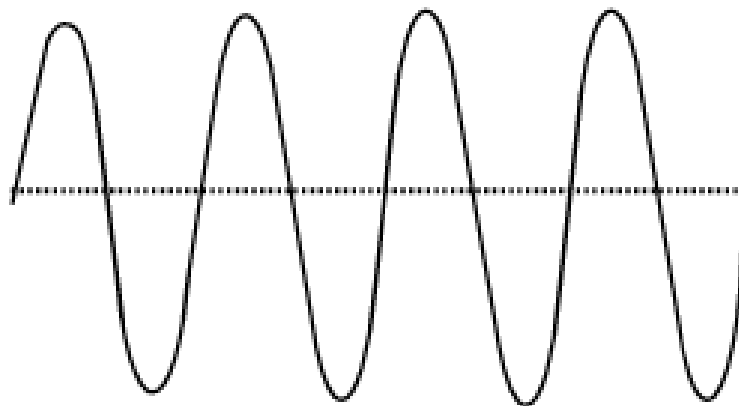


Volume (Amplitude)

Low Volume
(less air pressure)



High Volume
(more air pressure)

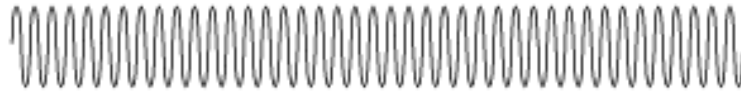


Frequency

10–18 kHz
"Treble"



5–10 kHz



2–5 kHz



800–2000 kHz
"Mid-range"



200–800 kHz



100–200 kHz



40–100 Hz
"Bass"



Frequency

Frequency is measured in units of **hertz** (Hz) which is equal to **one occurrence of a repeating event per second**.

The relation between the frequency and the period, T , of a repeating event or oscillation is given by:

$$f = \frac{1}{T}$$

Standard Tuning Frequencies

Middle C \approx 262 Hz

Higher frequency

40	c' 1-line octave	C4 Middle C	261.626
39	b	B3	246.942
38	a#/b♭	A#3/B♭3	233.082
37	a	A3	220.000
36	g#/a♭	G#3/A♭3	207.652
35	g	G3	195.998
34	f#/g♭	F#3/G♭3	184.997
33	f	F3	174.614
32	e	E3	164.814
31	d#/e♭	D#3/E♭3	155.563
30	d	D3	146.832
29	c#/d♭	C#3/D♭3	138.591
28	c small octave	C3 Low C	130.813

Octave = 2x freq

Lower frequency

Tone ()

Syntax:

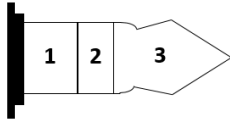
```
tone(pin, frequency)  
tone(pin, frequency, duration)
```

Parameters:

pin: the Arduino pin on which to generate the tone.
frequency: the frequency of the tone in hertz. Allowed data types: unsigned int.
duration: the duration of the tone in milliseconds (optional). Allowed data types: unsigned long.

Making Sound with Arduino

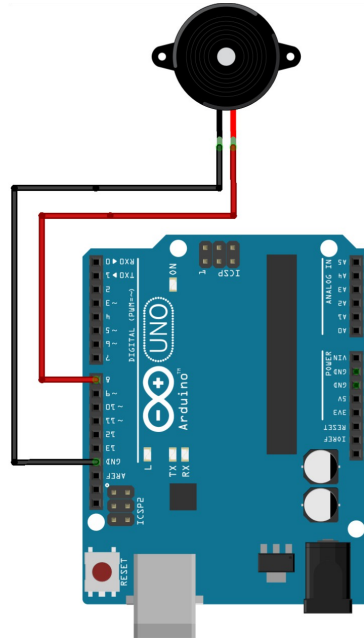
1. Use an amp



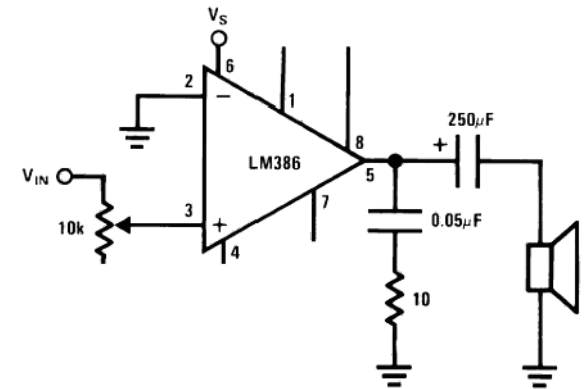
Pin	Description
1	Ground
2	Right
3	Left



2. Use a piezo



3. Use an op-amp & 8ohm speaker



440 Hz Standard Tuning Frequencies

```
#define NOTE_B0 31
#define NOTE_C1 33
#define NOTE_CS1 35
#define NOTE_D1 37
#define NOTE_DS1 39
#define NOTE_E1 41
#define NOTE_F1 44
#define NOTE_FS1 46
#define NOTE_G1 49
#define NOTE_GS1 52
#define NOTE_A1 55
#define NOTE_AS1 58
#define NOTE_B1 62
#define NOTE_C2 65
#define NOTE_CS2 69
#define NOTE_D2 73
#define NOTE_DS2 78
#define NOTE_E2 82
#define NOTE_F2 87
#define NOTE_FS2 93
#define NOTE_G2 98
#define NOTE_GS2 104
#define NOTE_A2 110
#define NOTE_AS2 117
#define NOTE_B2 123
#define NOTE_C3 131
#define NOTE_CS3 139
#define NOTE_D3 147
#define NOTE_DS3 156
#define NOTE_E3 165
#define NOTE_F3 175
#define NOTE_FS3 185
#define NOTE_G3 196
#define NOTE_GS3 208
#define NOTE_A3 220
#define NOTE_AS3 233
#define NOTE_B3 247
#define NOTE_C4 262
#define NOTE_CS4 277
#define NOTE_D4 294
#define NOTE_DS4 311
#define NOTE_E4 330
#define NOTE_F4 349
#define NOTE_FS4 370
#define NOTE_G4 392
#define NOTE_GS4 415
#define NOTE_A4 440
#define NOTE_AS4 466
#define NOTE_B4 494
#define NOTE_C5 523
```

Key number	Helmholtz name	Scientific name	Frequency (Hz)	Corresponding Open Strings				
				Violin	Viola	Cello	Bass	Guitar
66	c ¹ 5-line octave	C5 Eighth octave	4186.01					
67	b ¹	B5	3651.07					
68	a ¹ 1b ¹	A5/7B:7	3729.31					
69	a ¹	A5	3520.00					
70	g ¹ 1a ¹	G5/7A:7	3322.44					
71	g ¹	G5	3185.96					
72	f ¹ 1g ¹	F5/7G:7	2959.96					
73	f ¹	F5	2793.83					
74	e ¹	E5	2637.02					
75	d ¹ 1e ¹	D5/7E:7	2489.02					
76	d ¹	D5	2349.32					
77	c ¹ 1d ¹	C5/7D:7	2217.46					
78	c ¹ 4-line octave	C7 Double high C	2093.00					
79	b ¹	B6	1975.53					
80	a ¹ 1b ¹	A6/8B:6	1864.66					
81	a ¹	A6	1760.00					
82	g ¹ 1a ¹	G6/9A:6	1661.22					
83	g ¹	G6	1567.96					
84	f ¹ 1g ¹	F6/9G:6	1479.98					
85	f ¹	F6	1396.91					
86	e ¹	E6	1318.51					High E (24th Fret)
87	d ¹ 1e ¹	D6/8E:6	1244.51					
88	d ¹	D6	1174.65					
89	c ¹ 1d ¹	C6/10D:6	1108.73					
90	c ¹ 5-line octave	C6 Soprano C (high C)	1046.50					
91	b ¹	B5	987.767					
92	a ¹ 1b ¹	A5/5B:5	932.328					
93	a ¹	A5	880.000					
94	g ¹ 1a ¹	G5/5A:5	830.609					
95	g ¹	G5	783.991					
96	f ¹ 1g ¹	F5/5G:5	739.989					
97	f ¹	F5	698.456					
98	e ¹	E5	659.255					
99	d ¹ 1e ¹	D5/5E:5	622.254					
100	d ¹	D5	587.330					
101	c ¹ 1d ¹	C5/5D:5	554.365					
102	c ¹ 2-line octave	C5 Tenor C	523.251					
103	b ¹	B4	493.883					
104	a ¹ 1b ¹	A4/6B:4	465.163					
105	a ¹	A4 A440	440.000	A	A			High A (Optional)
106	g ¹ 1a ¹	G4/4A:4	415.305					
107	g ¹	G4	391.995					
108	f ¹ 1g ¹	F4/4G:4	369.994					
109	f ¹	F4	349.228					
110	e ¹	E4	329.628					High E
111	d ¹ 1e ¹	D4/4E:4	311.127					
112	d ¹	D4	293.665	D	D			
113	c ¹ 1d ¹	C4/4D:4	277.183					
114	c ¹ 1-line octave	C4 Middle C	261.626					
115	b ¹	B3	246.942					B
116	a ¹ 1b ¹	A3/3B:3	233.082					
117	a ¹	A3	220.000			A		
118	g ¹ 1a ¹	G3/3A:3	207.652					
119	g ¹	G3	195.996	G	G			G
120	f ¹ 1g ¹	F3/3G:3	184.997					
121	f ¹	F3	174.614					F (7 string)
122	e ¹	E3	164.814					
123	d ¹ 1e ¹	D3/3E:3	155.563					
124	d ¹	D3	146.832			D		D
125	c ¹ 1d ¹	C3/3D:3	138.591					
126	c ¹ small octave	C3 Low C	130.813	C (5 string)	C	C (6 string)		
127	b ¹	B2	123.471					
128	a ¹ 1b ¹	A2/2B:2	116.541					
129	a ¹	A2	110.000					A
130	g ¹ 1a ¹	G2/2A:2	103.826					
131	g ¹	G2	97.9989			G	G	
132	f ¹ 1g ¹	F2/2G:2	92.4906					
133	f ¹	F2	87.3071	F (6 string)				

The twelve notes

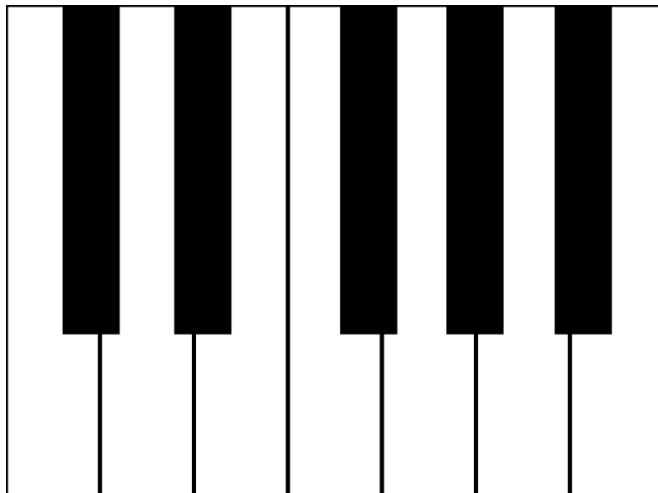
The octave itself is subdivided in 12 notes, which we've named:

A, A#, B, C, C#, D, D#, E, F, F#, G, G#



A diagram showing two vertical red lines with a red double-headed arrow between them, representing a semi-tone interval.

Semi-tone
(half-tone)



The Heptatonic Diatonic Scales

Root
note

(Major)	→	Ionian (I)	W	W	H	W	W	W	H								
		Dorian (II)	W	H	W	W	W	H	W								
		Phrygian (III)		H	W	W	W	H	W	W							
		Lydian (IV)			W	W	W	H	W	W	H						
		Mixolydian (V)				W	W	H	W	W	H	W					
(Minor)	→	Aeolian (VI)					W	H	W	W	H	W	W				
		Locrian (VII)						H	W	W	H	W	W	W			

W = 2 semi-tones

H = 1 semi-tone

The Heptatonic Diatonic Scales

Name	Mode	D'Arezzo	Fulda	Espinosa	Example chant
Dorian	I	serious	any feeling	happy, taming the passions	<i>Veni sancte spiritus</i> ▶ 0:00 CC 🔊 MENU
Hypodorian	II	sad	sad	serious and tearful	<i>Iesu dulcis amor meus</i> ▶ 0:00 CC 🔊 MENU
Phrygian	III	mystic	vehement	inciting anger	<i>Kyrie, fons bonitatis</i> ▶ 0:00 CC 🔊 MENU
Hypophrygian	IV	harmonious	tender	inciting delights, tempering fierceness	<i>Conditor alme siderum</i> ▶ 0:00 CC 🔊 MENU
Lydian	V	happy	happy	happy	<i>Salve Regina</i> ▶ 0:00 CC 🔊 MENU
Hypolydian	VI	devout	pious	tearful and pious	<i>Ubi caritas</i> ▶ 0:00 CC 🔊 MENU
Mixolydian	VII	angelical	of youth	uniting pleasure and sadness	<i>Introibo</i> ▶ 0:00 CC 🔊 MENU
Hypomixolydian	VIII	perfect	of knowledge	very happy	<i>Ad cenam agni providi</i> ▶ 0:00 CC 🔊 MENU

Finding the notes in a scale

1. Pick the Scale
2. Pick a root note

Finding the notes in a scale

1. Pick the Scale
2. Pick a root note

C

C C#, D D#, E F F#, G G#, A A#, B C

Finding the notes in a scale

1. Pick the Scale
2. Pick a root note

C Ionian

	W		W		H		W		W		W		H	
C		D		E	F		G		A		B		C	

Finding the notes in a scale

1. Pick the Scale
2. Pick a root note

C Ionian

	W		W		H		W		W		W		H	
	C		D		E	F		G		A		B	C	

*A melody for a song in this key
can play any note in this scale!

Constructing Chords

In tonal Western classical music (music with a tonic key or "home key"), the most frequently encountered chords are triads, so called because they consist of three distinct notes: **the root** note, and intervals of a **third** and a **fifth** above the root note.

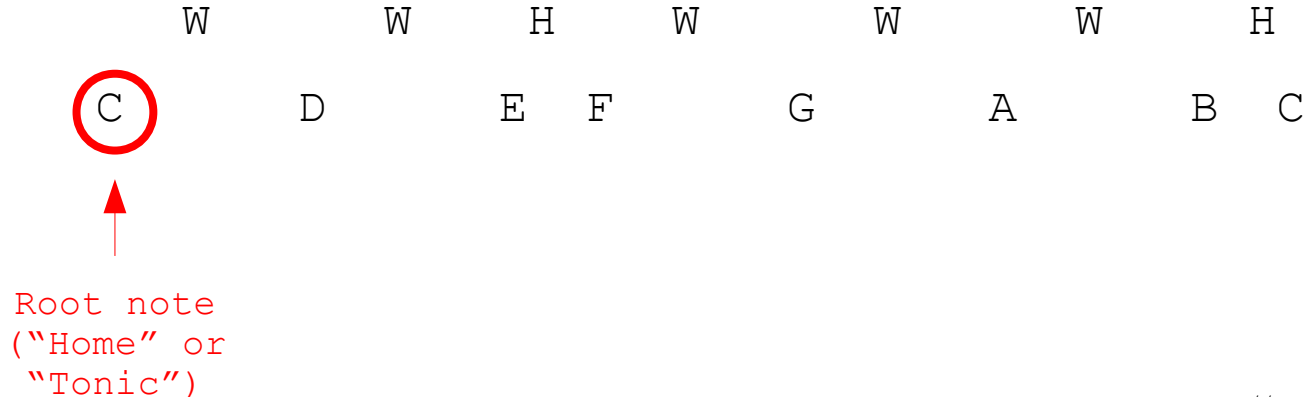
C Ionian

	W		W		H		W		W		W		H
C		D		E	F		G		A		B		C

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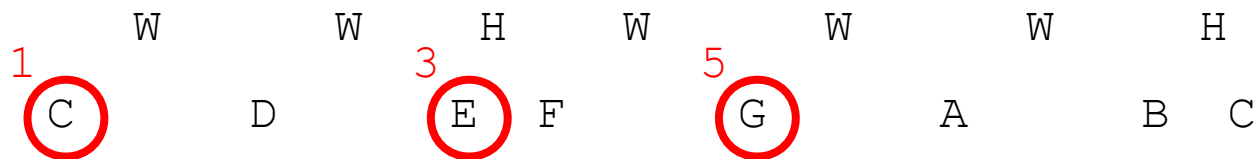
C Ionian



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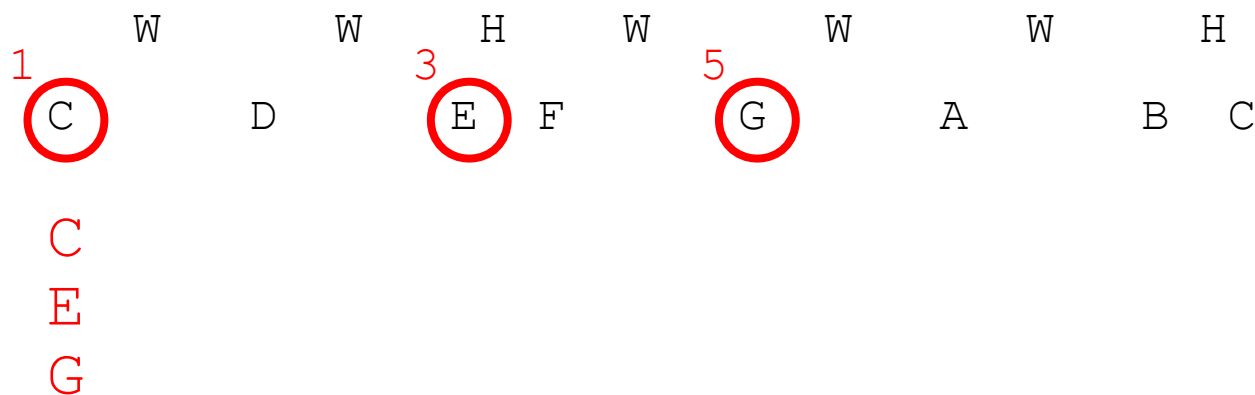
C Ionian



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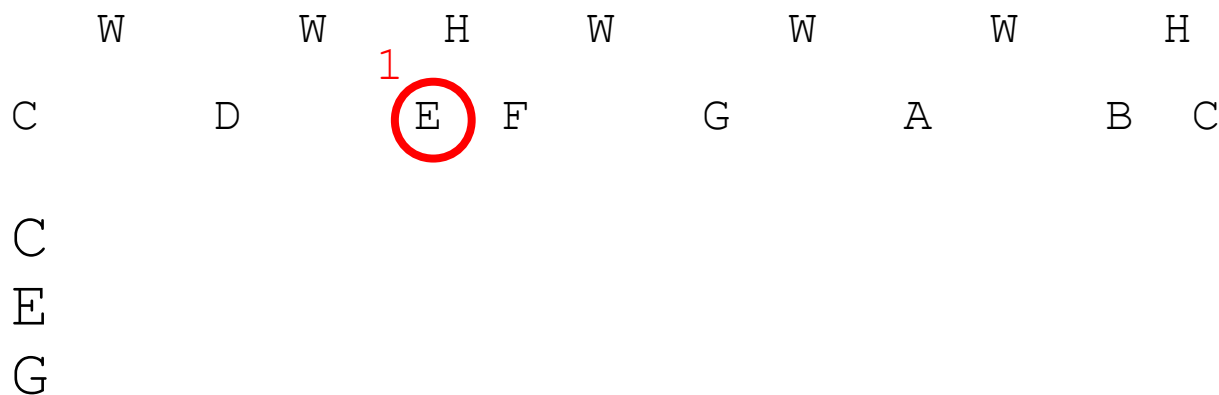
C Ionian



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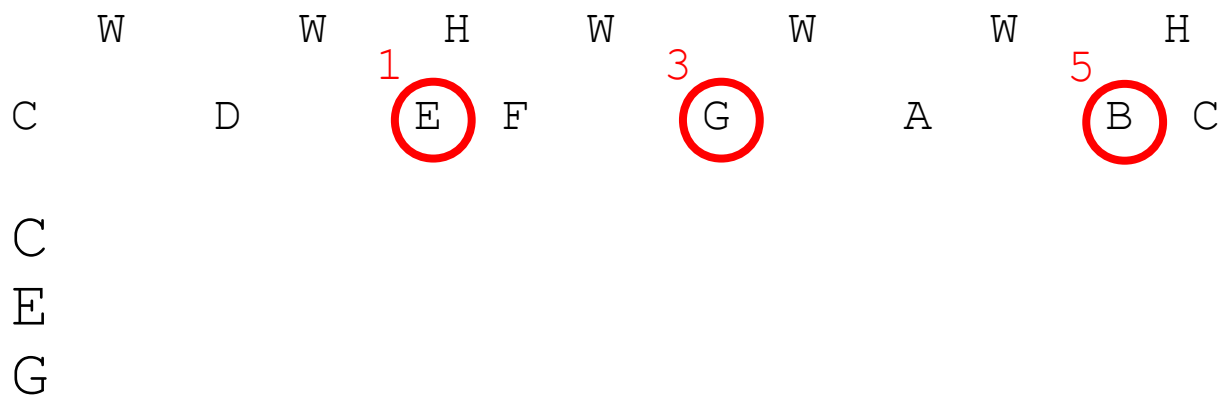
C Ionian



Constructing Chords

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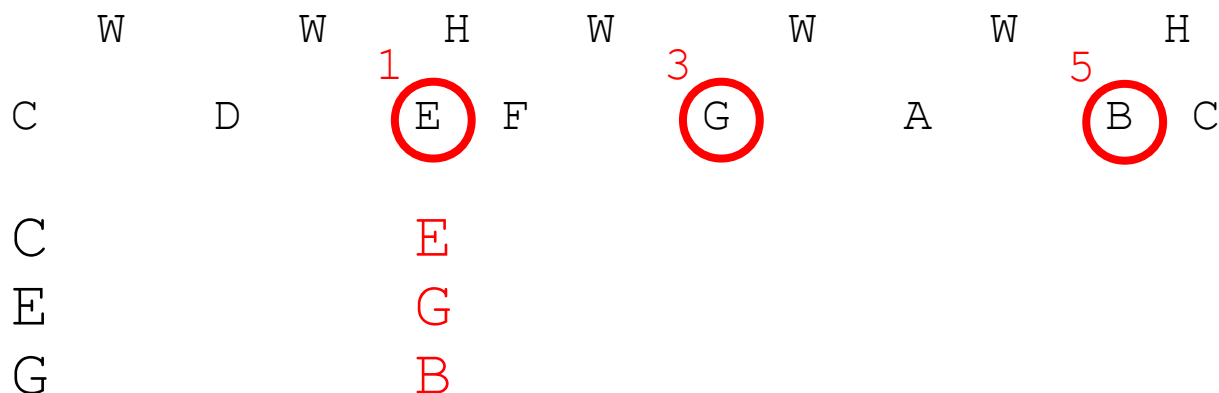
C Ionian



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C Ionian



Constructing Chords

In tonal Western classical music (music with a tonic key or "home key"), the most frequently encountered chords are triads, so called because they consist of three distinct notes: **the root** note, and intervals of a **third** and a **fifth** above the root note.

C Ionian

	W		W		H		W		W		W		H
	C		D		E	F		G		A		B	C
	C		D		E	F		G		A		B	
	E		F		G	A		B		C		D	
	G		A		B	C		D		E		F	

All the triads
that are part
of this scale:

Typical Chord Progressions

I-IV-V-V

I-I-IV-V

I-IV-I-V

I-IV-V-IV

Typical Chord Progressions

I-IV-V-V

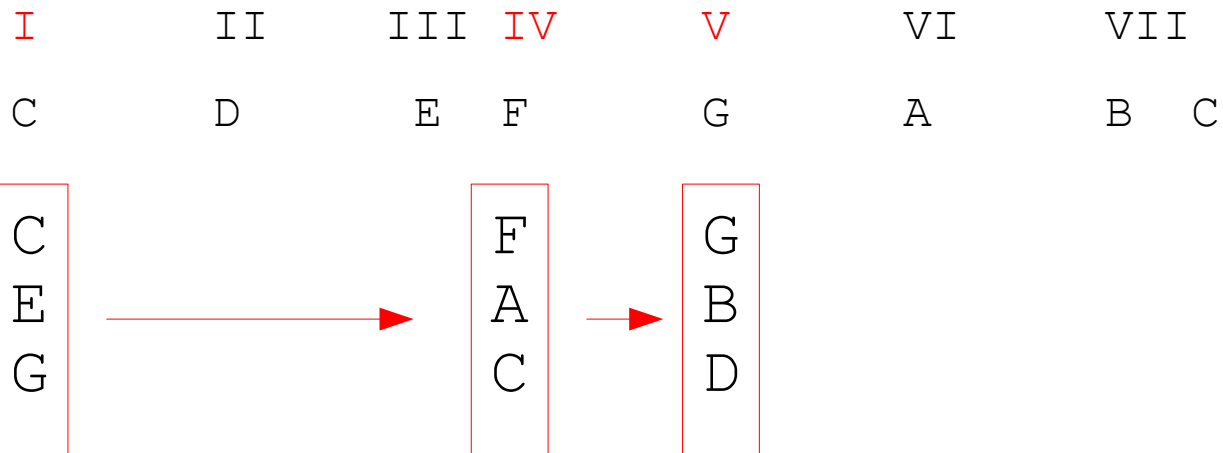
C Ionian

I	II	III	IV	V	VI	VII
C	D	E	F	G	A	B C
C E G	D F A	E G B	F A C	G B D	A C E	B D F

Typical Chord Progressions

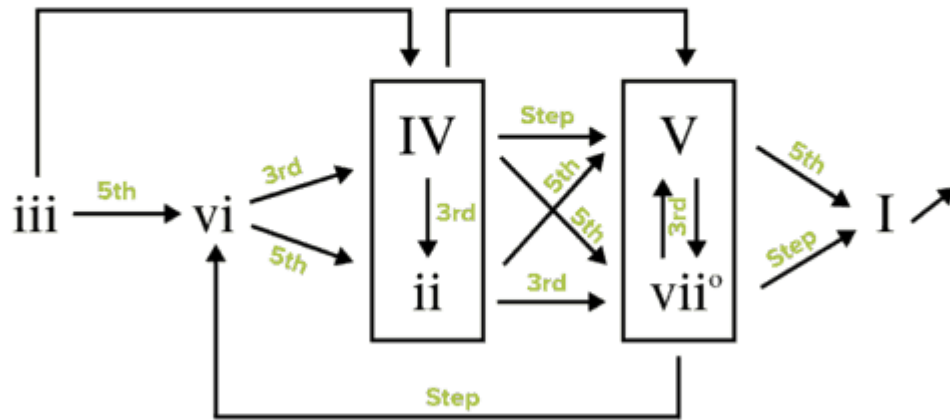
I-IV-V-V

C Ionian



Chord Progression Formulas

FORMULA FOR MAJOR KEYS



I	→	Anything
vi	→	IV, V, I, ii
IV	→	I, V, vi, iii
V	→	I, IV, vi
iii	→	vi, I, IV, ii
ii	→	V, IV, iii

Stable
↕
Unstable

Example Composition Review:

- i.) Pick root note (ex. C)
- ii.) Pick a scale (ex. Ionian)
- iii.) Construct chord triads
- iii.) Pick a chord progression or chord progression formula
- iv.) Loop a sequence of 8 or fewer chords

Tinkercad Circuits

