



# Introduction to **Audio Content Analysis**

module 7.6: chord detection

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# introduction

## overview

### corresponding textbook section

#### section 7.6

#### ■ lecture content

- musical chords and harmony
- baseline chord detection
- Hidden Markov Models (HMMs) and the Viterbi algorithm

#### ■ learning objectives

- name basic chords and describe the concept of chord inversions
- discuss commonalities and differences between chord & key detection
- discuss the usefulness of HMMs for chord detection
- explain the Viterbi algorithm with an example



# introduction

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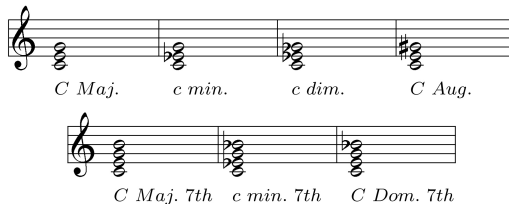
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# musical pitch

## chords

- simultaneous use of several pitches  $\Rightarrow$  **chords**
- usually constructed of (major/minor) thirds

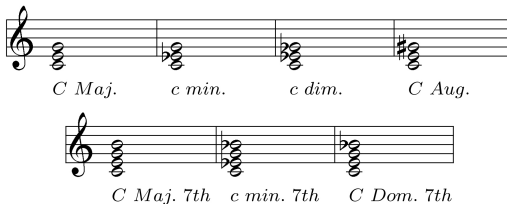


- note:
  - chord type independent of pitch doubling, pitch order
  - same label for keys and chords

# musical pitch

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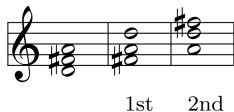


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# musical pitch

## chord inversion

- most common: root note is lowest note
- otherwise: chord inversion



# musical pitch

## harmony

- key and tonal context define chord's *harmonic function*
- examples:
  - **tonic:**  
chord on 1st scale degree (tonal center)
  - **dominant:**  
chord on 5th scale degree (often moves to tonic)
  - **subdominant:**  
chord on 4th scale degree
  - ...

# chord detection

## introduction: key vs. chord detection

### ■ commonalities

- chords are octave independent  $\Rightarrow$  pitch chroma sufficient
- process flow: pitch chroma extraction + classification

### ■ differences

- time frame for pitch chroma calculation
- templates
- number of templates/chords
- many results per song (time series)



# chord detection

## introduction: key vs. chord detection

### ■ commonalities

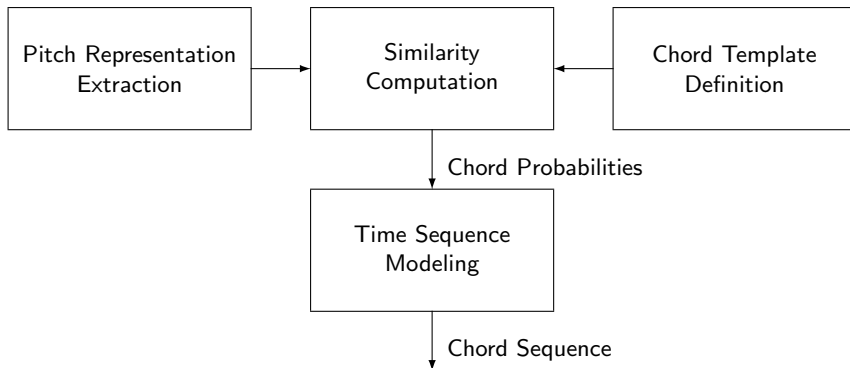
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# chord detection

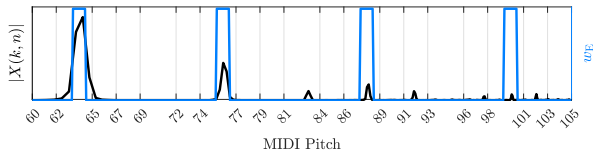
## introduction: overview



# pitch chroma

## introduction

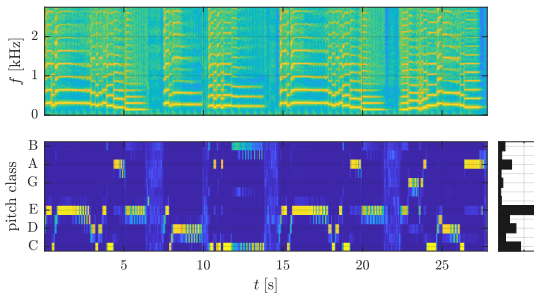
- pitch class distribution: 12-dimensional vector
- map all pitch class bands in all octaves to one



# pitch chroma

## introduction

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# pitch chroma

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### pitch chroma properties

- **no** octave information
  - no differentiation between prime and octave
  - no info on inversion
- robust, timbre-independent representation

# chord detection

## chord template

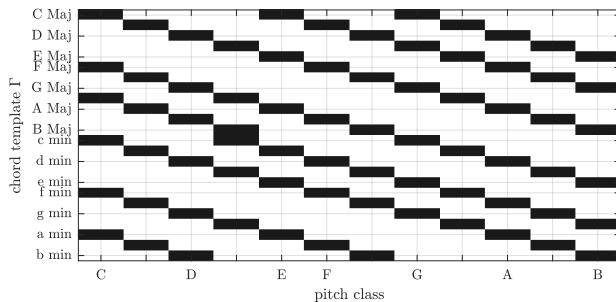
### ■ compare extracted pitch chroma with template

- simplest possible template and distance: linear transformation  
example — C major:

$$\Gamma(0, j) = [1/3, 0, 0, 0, 1/3, 0, 0, 1/3,$$

⇒ instantaneous chord likelihood:

$$\psi(c, n) = \sum_{j=0}^{11} \Gamma(c, j) \cdot \nu(j, n)$$



# chord detection

## chord progression 1/2

apply **musical knowledge** to increase the result's robustness and accuracy:

- different probabilities for different chord progressions (similar to key modulations), e.g.
  - cadences: I-IV-V-I
  - sequences: circle progression

⇒ model for *chord progression probabilities*

### 1 *analytical model* based on music theory

- circle of fifths (!?)
- key profile correlation (!?)

### 2 *empirical model* based on data

- annotate audio
- symbolic score

# chord detection

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# chord detection

## chord progression 2/2

**what properties do chord progression probabilities depend on**



# chord detection

## chord progression 2/2

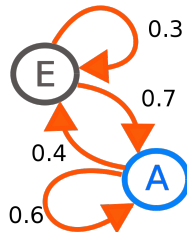


**what properties do chord progression probabilities depend on**

- musical key
- larger musical context (model order)
- style
- tempo/length??

# chord detection

## markov chain



- two possible states E, A
- transition probabilities to other state(s) and to self
- sum of transition probabilities equals 1

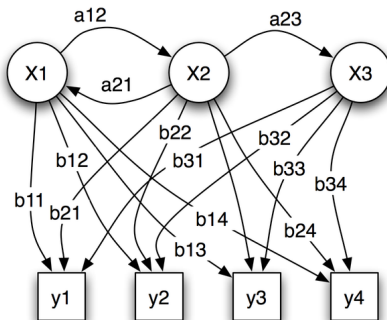
# chord detection

## hidden markov model: variables

- **states:**  
unknown/hidden
- **transition probability:**  
probability of transitioning from one state to the other
- **observations:**  
measureable time series
- **emission probability:**  
probability of an observation given a state
- **start probability:**  
probability of the initial state

# chord detection

## hidden markov model: variables



- $X$ : states
- $y$ : possible observations
- $a$ : state transition probabilities
- $b$ : emission probabilities

# chord detection

## hidden markov model: example (WP) 1/2

### ■ scenario

- doctor diagnoses fever by how patients feel
- patient may feel normal, dizzy, or cold
- patient visits multiple days in a row

**what are the states and observations in this case**



# chord detection

## hidden markov model: example (WP) 1/2

### ■ scenario

- doctor diagnoses fever by how patients feel
- patient may feel normal, dizzy, or cold
- patient visits multiple days in a row

what are the states and observations in this case

### ■ states

- *healthy*
- *fever*

### ■ observations:

- *normal*
- *cold*
- *dizzy*





# chord detection

## hidden markov model: example (WP) 2/2

### ■ start probabilities (initial state assumption)

- *healthy*: 0.6
- *fever*: 0.4

### ■ emission probabilities (prob of obs given state)

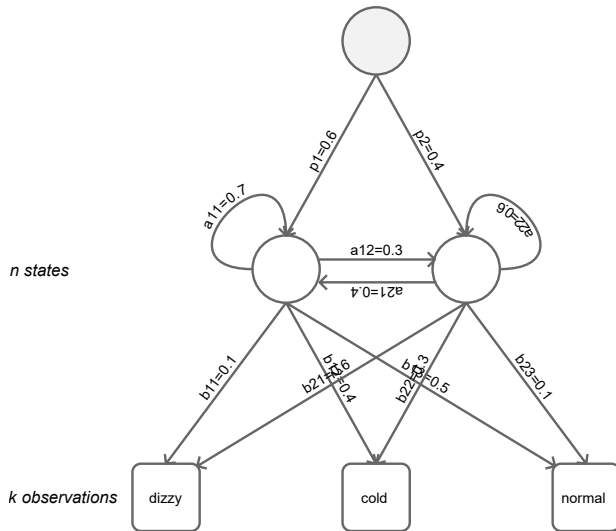
- *healthy*: normal 0.5, cold 0.4, dizzy 0.1
- *fever*: : normal 0.1, cold 0.3, dizzy 0.6

### ■ transition probabilities

- *healthy*: healthy 0.7, fever 0.3
- *fever*: : healthy 0.4, fever 0.6

# chord detection

## hidden markov model: example (WP) 2/2



start probabilities

$$\sum_n p_n = 1$$

transition probabilities

$$\sum_n a_{1,n} = 1$$

emission probabilities

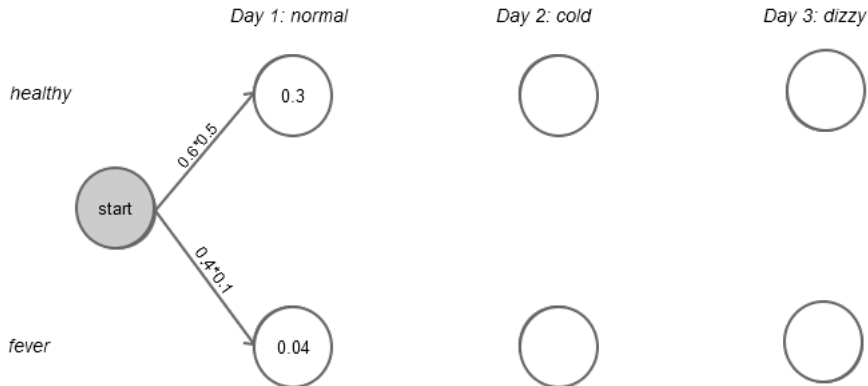
$$\sum_k b_{1,k} = 1$$

# chord detection

## hidden markov model: example (WP) 2/2

### three observations:

day 1 *normal* → day 2 *cold* → day 3 *dizzy*

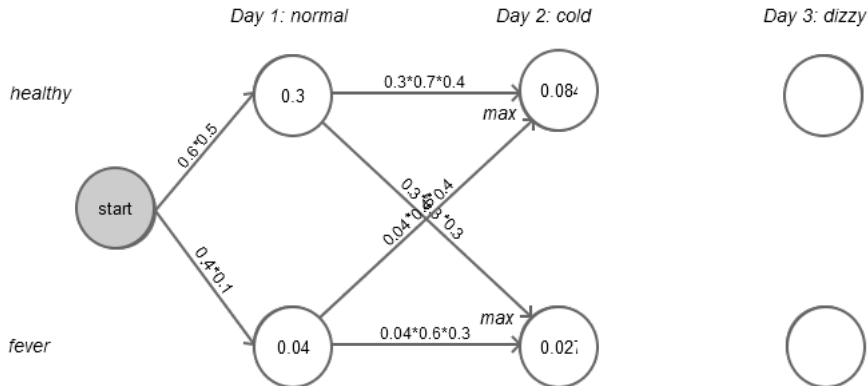


# chord detection

hidden markov model: example (WP) 2/2

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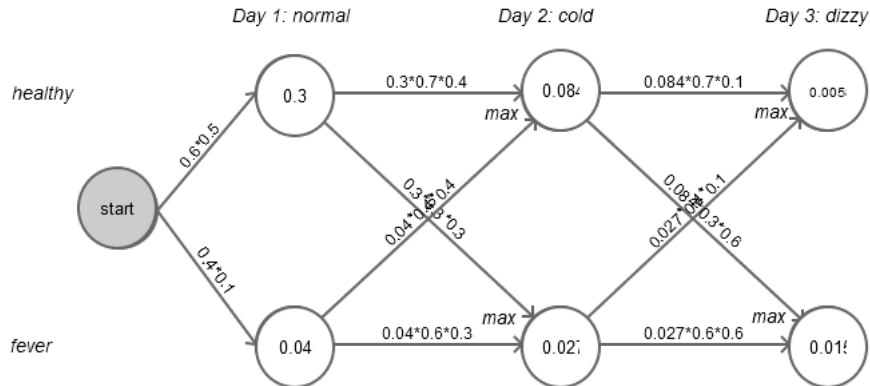


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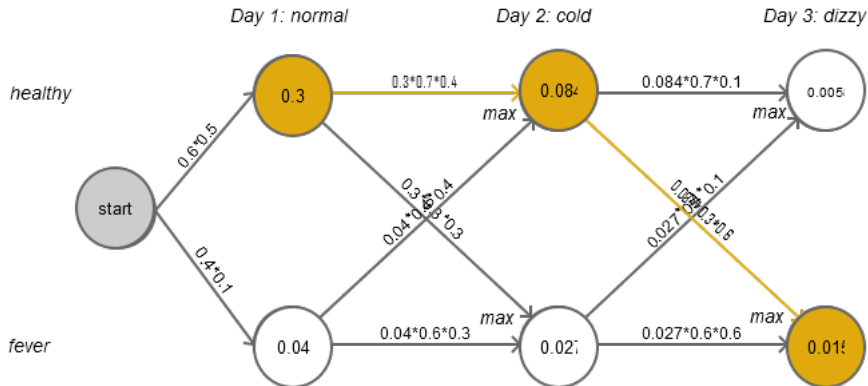


# chord detection

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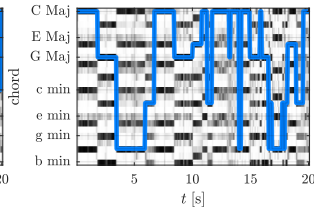
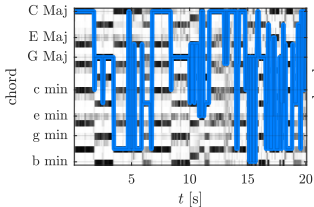
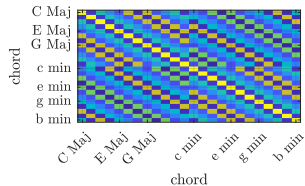
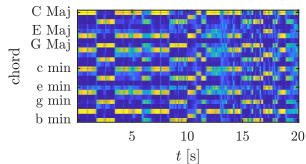
# chord detection

## HMMs for chord detection

- states → chords
- observations → pitch chroma
- emission probability → trained with pitch chroma
- transition probability → trained from dataset
- start probability → chord statistics (style dependent?)

# chord detection

## chord detection example





# summary

## lecture content

### ■ chords

- combination of three or more pitches
- usually stacked thirds
- can be inverted

### ■ chord detection

- processing steps
  - ▶ pitch chroma extraction
  - ▶ template matching
  - ▶ chord transition model

### ■ Viterbi algorithm

- find globally optimal path through state space
- estimate state sequence with
  - ▶ emission probabilities
  - ▶ transition probabilities

