## Sequences

## October 5, 2010

## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

Definition
$A$ seqeunce is a function $f: N \rightarrow A$.

## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

## Definition

$A$ seqeunce is a function $f: N \rightarrow A$.

- A common notaion for a sequence is $a_{1}, a_{2}, \ldots a_{n}, \ldots$.


## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

## Definition

$A$ seqeunce is a function $f: N \rightarrow A$.

- A common notaion for a sequence is $a_{1}, a_{2}, \ldots a_{n}, \ldots$.
- $a_{n}$ is usually called the general term


## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

## Definition

$A$ seqeunce is a function $f: N \rightarrow A$.

- A common notaion for a sequence is $a_{1}, a_{2}, \ldots a_{n}, \ldots$.
- $a_{n}$ is usually called the general term
- Sequences do not necessarily start with $a_{1}$. They may start with any other number.


## Basics

Sequences are used in many areas in mathematics, computer science, economics and almost all sciences.

## Definition

$A$ seqeunce is a function $f: N \rightarrow A$.

- A common notaion for a sequence is $a_{1}, a_{2}, \ldots a_{n}, \ldots$.
- $a_{n}$ is usually called the general term
- Sequences do not necessarily start with $a_{1}$. They may start with any other number.
- A sequence may be finite or infinite.


## Describing sequences

There are three common ways to describe sequences:

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(3) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule"'.

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule"'.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule"'.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer:


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule" '.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule"'.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."
(2) $a_{n}$ is the number of different ways to write $n$ as a sum of no more than $\lfloor\operatorname{sqrt}(n)\rfloor$ positive integers


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule" '.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."
(2) $a_{n}$ is the number of different ways to write $n$ as a sum of no more than $\lfloor\operatorname{sqrt}(n)\rfloor$ positive integers
(3) Recursively


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule" '.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."
(2) $a_{n}$ is the number of different ways to write $n$ as a sum of no more than $\lfloor\operatorname{sqrt}(n)\rfloor$ positive integers
(3) Recursively
(1) $1,2,3,5,8, \ldots, \quad a_{n+2}=a_{n+1}+a_{n}$


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule" '.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."
(2) $a_{n}$ is the number of different ways to write $n$ as a sum of no more than $\lfloor\operatorname{sqrt}(n)\rfloor$ positive integers
(3) Recursively
(1) $1,2,3,5,8, \ldots, \quad a_{n+2}=a_{n+1}+a_{n}$
(2) $a_{n, k}=a_{n-1, k-1}+a_{n-k, k}, \quad a_{n, 0}=0, a_{n, n}=a_{n, 1}=1 n \geq k$


## Describing sequences

There are three common ways to describe sequences:
(1) Explicitely
(1) $1,3,5,7, \ldots,(2 n-1), \ldots$
(2) $2,4,7,11,15, \ldots,\binom{n+1}{2} \ldots$
(3) $0,3,8,15, \ldots$ Can you suggest an explicit expression?
(2) By a "rule" '.
(1) $2,3,5,6,7,8,10,11,12,13,14,15,17, \ldots a_{n}=$ ?

- Answer: $a_{n}$ is "The $n^{\text {th }}$ non perfect square."
(2) $a_{n}$ is the number of different ways to write $n$ as a sum of no more than $\lfloor\operatorname{sqrt}(n)\rfloor$ positive integers
(3) Recursively
(1) $1,2,3,5,8, \ldots, \quad a_{n+2}=a_{n+1}+a_{n}$
(2) $a_{n, k}=a_{n-1, k-1}+a_{n-k, k}, \quad a_{n, 0}=0, a_{n, n}=a_{n, 1}=1 n \geq k$
(3) $a_{n}=(n-1)\left(a_{n-1}+a_{n-2}\right), \quad a_{1}=0, a_{2}=1$.


## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.
(3) Another goal is to build sequences that will help solve problems.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.
(3) Another goal is to build sequences that will help solve problems.
(9) For instance calculating integrals is based on building sequences and finding their limit.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.
(3) Another goal is to build sequences that will help solve problems.
(9) For instance calculating integrals is based on building sequences and finding their limit.
(3) Calculating the number of rabbits starting with one pair is done using the Fibonacci sequence.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.
(3) Another goal is to build sequences that will help solve problems.
(9) For instance calculating integrals is based on building sequences and finding their limit.
(5) Calculating the number of rabbits starting with one pair is done using the Fibonacci sequence.
(0. There are many other "named sequences'." We shall study some of them.

## Goals

(1) Throughout this class and in many other classes you will be using sequences to model and solve problems.
(2) One major goal is to find "simple" rules for given sequences.
(3) Another goal is to build sequences that will help solve problems.
(1) For instance calculating integrals is based on building sequences and finding their limit.
(3) Calculating the number of rabbits starting with one pair is done using the Fibonacci sequence.
(0) There are many other "named sequences'." We shall study some of them.
(1) We shall start by examining a number of examples.

## Examples

For the following sequnces try to find a "simple" explicit rule:

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) 1.0.1.0.1.0... $a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) 1.0.1.0.1.0... $a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) 1.0.1.0.1.0... $a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(c) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(9) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(3) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(9) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(0) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(1) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(1) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots \quad a_{n}=$ ?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(0) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(1) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots a_{n}=$ ?

## Remark

Consider the last example. It was not too difficult to see that $a_{n}=3^{n}-2^{n}$

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(1) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots a_{n}=$ ?

## Remark

Consider the last example. It was not too difficult to see that $a_{n}=3^{n}-2^{n}$
You are probably still struggling with the sequence preceding it.

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(5) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(1) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots a_{n}=$ ?

## Remark

Consider the last example. It was not too difficult to see that $a_{n}=3^{n}-2^{n}$
You are probably still struggling with the sequence preceding it. Do you see any relation between it and the last sequence?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(3) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(3) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots a_{n}=$ ?

## Remark

Consider the last example. It was not too difficult to see that $a_{n}=3^{n}-2^{n}$
You are probably still struggling with the sequence preceding it.
Do you see any relation between it and the last sequence?
Can you see it now once your attention was called to it?

## Examples

For the following sequnces try to find a "simple" explicit rule:
(1) $1.0 .1 .0 .1 .0 \ldots \quad a_{n}=$ ?
(2) $1,0,1,1,0,0,1,1,1,0,0,0, \ldots \quad a_{n}=$ ?
(3) $3,6,11,18,27,38,51, \ldots \quad a_{n}=$ ?
(1) $2,4,16,256,65536,4294967296, \ldots \quad a_{n}=$ ?
(3) $1,2,2,3,3,3,4,4,4,4,5,5,5,5,5, \ldots a_{n}=$ ?
(6) $1,2,4,8,14,25,45,79,138,240, \ldots \quad a_{n}=$ ?
(3) $1,5,19,65,211,665,2059,6305,19171,58025 \ldots a_{n}=$ ?

## Remark

Consider the last example. It was not too difficult to see that $a_{n}=3^{n}-2^{n}$
You are probably still struggling with the sequence preceding it.
Do you see any relation between it and the last sequence?
Can you see it now once your attention was called to it?

