# INTRODUCTION TO GRAPHS, MAPS, AND VISUALIZATION



SIC PARVIS MAGNA

IAA 2021 JULY 20, 2021

CHRISTOPHER G. HEALEY INSTITUTE FOR ADVANCED ANALYTICS DEPARTMENT OF COMPUTER SCIENCE NORTH CAROLINA STATE UNIVERSITY

HEALEY@NCSU.EDU HTTP://WWW.CSC.NCSU.EDU/FACULTY/HEALEY



- 1. Present an overview of graphs and maps
  - + graphs and guidelines on usage
  - thematic maps and guidelines on usage
- 2. Discuss perceptual foundations that underlie some of these methods
  - + color, texture, motion
  - visual attention
  - visual memory
- 3. Describe methods in the context of application domains similar to those participating in the proposal
  - marine biology, astrophysics, elections



Traditional method for comparing data attributes

- + E.g., line chart, bar chart, scatterplot, histogram
- Different graphs are used for different tasks:
  - + tracking changes (line graph)
  - + correlations, relationships (X-Y plot)
  - + correlations, clustering (scatterplot)
  - category comparison (bar chart)
  - distributions (pie chart)
  - + uniqueness and overlap (Venn diagram)

• Graph elements can represent multiple attribute values

# LINE CHART



**U.S. UNEMPLOYMENT LINE CHART** 

U5: UNEMPLOYED, DISCOURAGED, MARGINALLY ATTACHED U6: UNEMPLOYED, DISCOURAGED, MARGINALLY ATTACHED, PART TIME SEEKING FULL TIME

# LINE CHART

#### States with Unemployment Rate above Certain Levels



http://www.calculatedriskblog.com/

LINE CHART OF NUMBER OF STATES ABOVE 2006 UNEMPLOYMENT LEVEL BY QUARTER

# **BAR CHART**

#### State Unemployment Rate: Current Rate and Max for 2007 Recession

Current Recession Max Lowest since 1976



STACKED BAR CHART OF DECEMBER 2015 UNEMPLOYMENT BY STATE

# HISTOGRAM



Data source: http://www.census.gov/hhes/www/cpstables/032011/hhinc/new06\_000.htm

HISTOGRAM OF 2013 US HOUSEHOLD INCOME BY \$5000 BINS

# CUMULATIVE HISTOGRAM

2017 Budget Expedictures Cumulative Histogram



CUMULATIVE HISTOGRAM OF 2017 FEDERAL BUDGET EXPENDITURES

## SCATTERPLOTS

IRIS PLANT DATABASE PETAL LENGTH  $\rightarrow$  X, PETAL WIDTH  $\rightarrow$  Y



## SCATTERPLOTS

IRIS PLANT DATABASE

Petal Length  $\rightarrow$  X, Petal Width  $\rightarrow$  Y, Sepal Width  $\rightarrow$  colour, sepal length  $\rightarrow$  size, class  $\rightarrow$  shape



(NUMBER OF SEPALS ON A FLOWER IS ITS MEROSITY)

# **GRAPH SELECTION**



## MAPS

- Traditional method for presenting geographic and geospatial data
  - + E.g., topographic, planimetric, base
- Different maps are used for different tasks:
  - choropleth (charting value distributed by region)
  - isarithmic (contour lines)
  - proportional symbol (point location data)
  - + dot (presence or absence of a feature)
- Maps can be extended to visualize multidimensional data



Topographic map from Indiana Jones and the Last Crusade

### NAPOLEAN'S MARCH ON RUSSIA

Map representing the losses over time of French army troops during the Russian campaign, 1812-1813. Constructed by Charles Joseph Minard, Inspector General of Public Works retired. Paris, 20 November 1869

The number of men present at any given time is represented by the width of the grey line; one mm. indicates ten thousand men. Figures are also written besides the lines. Grey designates men moving into Russia; black, for those leaving. Sources for the data are the works of messrs. Thiers, Segur, Fezensac, Chambray and the unpublished diary of Jacob. who became an Army Pharmacist on 28 October. In order to visualize the army's losses more clearly, I have drawn this as if the units under prince Jerome and Marshall Davoust (temporarily seperated from the main body to go to Minsk and Mikilow, which then joined up with the main army again), had stayed with the army throughout.



CHARLES JOSEPH MINARD, 1869, FLOW MAP OF NAPOLEAN'S MARCH ON RUSSIA

## HANNIBAL'S MARCH ON ROME



CHARLES JOSEPH MINARD, 1869, FLOW MAP OF HANNIBAL'S MARCH ON ROME

## 2010 CENSUS VACANCY RATE CHANGE



DATA COURTESY UK DAILY MAIL

HTTP://WWW.DAILYMAIL.CO.UK/NEWS/ARTICLE-2176433/REVEALED-THE-10-EMPTIEST-U-S-CITIES.HTML

## 2007-2014 HOUSEHOLD INCOME CHANGE



#### DATA COURTESY REBOOT ILLINOIS

HTTP://WWW.REBOOTILLINOIS.COM/2016/03/10/WHATS-HOT/KEVIN-HOFFMANREBOOTILLINOIS-COM/TOP-30-COUNTIES-WITH-THE-LARGEST-DECLINE-IN-MEDIAN-HOUSEHOLD-INCOME-IN-ILLINOIS-FROM-2000-2014/53994/

# MULTIDIMENSIONAL GLYPHS

- Method to visualize high dimensional data
  - Data samples represented as a geometric glyphs
  - Samples' attribute values used to vary their glyphs' appearance
- Human visual perception used to select "salient" properties of colour, texture, and motion
- Harness visual system's ability to rapidly, accurately, and effortlessly perform high-level analysis tasks



California voting patterns for President, Senate, House, and Governor by Congressional district

#### JANUARY MONTHLY AVERAGE TEMPERATURE

# 



-			 	 				-	 			-		 	-								-
				 					 					 					•••			••••	
			 	 	 	-			 			 •••		 	•								
				 	 			•						 	•								
•			 	 	 				 					 	•								
		•		 	 				 														
				 	 				 									•					
•				 	 				 														
				 	 							 			2 a -						22		- 11
			 	 	 							 										]	2.21
			 	 	 							 											2.21
				 	 •••				 			 											•
			 	 	 ••						••	 		 									•
			 	 	 				 			 		 									•
			 	 	 							 		 								•	
			 	 	 				 			 		 						•			
			 	 -	 												-						
			 	 	 				 223		22	 		 									
			 	 	 				 223		22	 		 		22.							
												 		 		•							
	_			 					 														
																		•					
																		•					
												 											•
					<b>TT</b>																		
		···																					
		++++																					
					+++								. 73										
									223														
					+++				223					_									
		╉┿╉┦			+++																		
					+++		HH																
					$\mathbf{H}$										_								
		+++++			+++		+++			_													
					$ \rightarrow  $		$\mathbf{H}$																
				_																			



DATA COURTESY CLIMATIC RESEARCH UNIT, UNIVERSITY OF EAST ANGLIA

		-																		-	-		-				-			-	-	-			-	-					_
																	_								_	_										•					÷ .
			••	•••	•••	• •	•••	•••			•••		•	••	••			••		••	•••	•••			•	•••				•••		•••	• •		•						
	•	••	* *		**									• •				• •	۰.	••												•••	• •					• • •	•••		
			* *	* *		•				:								• •												• •	- C	• •	٠.					• • •			
				* *															* *	9 H													a (*	•							4. 16
																			• •																						
																																									1.2
12		-								_	11			12	22	2.2		12	22	22	2.2	111	12.2	122		Ξ.					- 12	2.2	2.2	2.2	Ξ						с т.
		•		11											2.2											•••							•••	•••	•						
	••	••						•										•••	**	••	•	•••											• •	••		•••		•			
	* *	* *	* *										1																				•	••	• •			• • •	•		
													•						- 18																						
																																							•		
	22	22	22	22			1.1							12.	22			12	22	22	22						111					11	2.2	11	11	11	11	22.			12
1222	22	22	11	22										22	22			12	22	22	2.2						2.2.2					22	22	2.2			2.2	223			2.7
															••	•••			• •	•••	•••								• • •			•••	•••	••	•••	•••	•••	•••	••••		٠.
				۰.																											* *				* *	**	• •		• • •		
		**																																							•
																																	* *	* *	* *					1	
	44																																								
		22						**						12	22	22		12	22	22	22						223					22	11	11	11	11					- T
			22		44	**	t t	**	44			44					-			22							1.1.1					2.2		5.5	5.5						
						44			44																						•••	••	••	••	••						
			**		1.1	1.1							. 🗰 1		**	• •																	••	۰.							
	**	**	**	**											**				**	**											. 🛸 🛋		* *								
	**		11			111							1		**					**													۰.								
	44	àà	44	44		**		F.F.	$\mathbf{rr}$						44																										
1111	22	22	22	22	÷÷	**	**	**	++	44	-			11	22			12	11	22	22		1.1				223				12.2	22									
	**	22			**	**	**	**	**		-	44	44			-	44		11	22	22	2.2					223					27									
	77	77	77			**	2.4	44	44		-	44	44				-																								
	**	÷÷	÷.		1.1.	2.2		Ξ.	44						**				**								**					٠									
	÷÷	**	<b>4</b> 6		1.1	5.5		1.1	2.2						**					**																					
	66		••	44		10			111					**	**			**	**	**							**1					**	**	۰.							
	44	44	44	44	-	144		11							**					**																					
						11		1.1	117					14	44	1		14	ā ā	44																					
****					••	**	**	**	**	**		-	**		22		**	44	22	22			ee									55	22	22		22					
					••	**	**	**	**	++	-	++	**	44		**	**	44			ын	e e	**	**	ee	- 14				••		22	22	22	11			11.			
***					••	••		••	**		-		-	44	22		**	44	22	22			**		**									22		11					
					• •	••		••	**				~~		**	2.2	44	<i>.</i>					2.2		44					24											<u>.</u>
					11	22		22	22							21	2.2																			**					
						<b>H</b> H			24			-	-		**		1.1		**	**	**						**1					**	**	**	**	**					
						ĸн			H H			-	-	-		-	141			**																				19.1	15
			68												éé		14	-	44	44				144																1.1	1.
					• •	••		••							àð	4.	1	14	àå	44	44		1									44		44							1.0
* * * *				• • •	• •	• •	***	••	++						LX	1.1	**	1.	11	11	1.1	1		**		1.1	2.4	1.		1	1.1	11	22	44.	11	22	11.	1.1	1.1	**	1.1
			• • •	• • •	••	••	+ + -	• •	٠٠	**		••			XX		••	1	11	XX	1.1	1		***	**	<b>.</b>	11.				<b>64</b> 24	11	11	11	11	11	11	12		44	12
	• • •				• •	• •		• •	++			••			X X	1		1	XY	11	1.1						1.1	44	÷.				1.1		11					44	
					• •	• •		• •					100	1	11	1.1	4.4	1				1.4																		44	
															**	-	24	20	**	**	-						**					**			**	**	**			1.1	
						1.1		1.1	1.1						••		HН			**	-		-									**	**	**	**	**				19.9	10
							1.1								<b>.</b>	-	H.		66	**	-	-	44		14							-								111	10
		1			• •	* *	* *	• •	* *		•••				٨Ă	4.4		14	àà					44	14		44			1		àà	44		44	44	44	·		1.1	10
	• • •	-	1	• •	• •	* *		• •		••	* *	**	••		1.1	• •	**	1	XX	XX			**		**	1.1	1.1	$\mathbf{+}\mathbf{+}$		**	1.1	Χ.	2.2	11	11	11	11	240		**	1
	**		<b>~</b>		• •	٠٠							٠٠	••		••	**	•	XX	XX					**		1.1					X.		11	11	22	11	1.1		**	3
			1		• •	* *													1.1	XY.					44		2.2.1					77		2.2	11		¥7			~	-
		-		1																29		1.1	1.1		1		**					÷.			÷÷	**	**	•			
													1.1				1.1			••	-0-0		-94	-	-		**					**	**		**	**	•				
																					-0-0			14.4		-	-	144	144	44	-	44	66	-	**	•		-			
				•									* *				* *										44		1		4.4	44	àà	44	44	44		-			
																• •	++	• •	<b>A X</b>	<b>A X</b>												11	11	11	X	11	44			-	1
				• •										+ +	• • •	• •	++			1.1	• • •	••	••	••	••	***		**	**	••	•••	XX	XX	XX	XX	XX	XX	***	++	• •	~
								1.1															~ ~	~~	~	~				~		~	YY	~	~						



#### JANUARY MONTHLY AVERAGES

																			-																						
									**	**		-																													
																											1														
												-																													
			- 7						-					22	22																							- 73			
															22									Ξ.,																	
										- 12																Ξ.				-											
		2														22					12.2				1				. 23	Z											
			22			22		-												۰.													22					- 2.			
													_																				Ξ.								
						22						-		_																	_										
														•												_		_													
						•••																	-					_													
++++					•						++					_																									
		_						_																													•••				
										-																															•
																				_																	•••			•	
											-								_																						
111									п	п	п							ш	ш		-																				
										ы	11							-		-			11													•					
									п	п	п						п	п			11																				
	ГΓ								п	п	п						п	п	л	л			11											•							
	ГГ								п	п							п	т	т	11	т		т																		
								п	п	т	П	Т.					п	т		т.	TT		11																		
TT										П	П						TT	тт	т	тт	T	T	$\mathbf{T}$																		
	$\mathbf{T}$						П	П	П	П	тт	П					гт	тт	тт	тт			1.1																		
TT								П	П	Π	П	П				TT	Г		т			т							111												
++++	Ħ	н		Т			H	H	TT	π	TT	П	т			F	ТΤ	TŤ	тт	TT	тт	TT	т		т						1.										
TT	H	н					H	T	TT	TT	$\mathbf{T}$					ΓT	тт	тт	П	П	т	т	П						11		TT		TT								
++++	H	HH			==	ΗF	H	H	Ħ	Ħ	Ħ	T				H	Ħ	Ħ	TT	TT	TT	TT	т						т		TT	TT	TT	TT							
ttt	H-	H	н	ㅋㅋ		HF	H	H	Ħ	Ħ	++	11				H	tt	Ħ	TT	Ħ	T	Ħ	-						-		TT	TT	TT	TT							
	tt	H	11				H	H	Ħ	Ħ	Ħ	++	н			H	Ħ	Ħ	Ħ	Ħ	Ħ	Ħ	T						77	77	TT	T	H	TT							
++++	t-1-	-1-				-	H	H	Ħ	Ħ	++	++				H	Ħ	11	<b>††</b>	Ħ	tt	TT	++	-	11				T		Ħ	tt	Ħ	TT	11	-	-				
+++	tt		-1-1	11			++	++	++	++	++	H			ΗH	H	H	Ħ	++	++	Ħ	Ħ	Ħ	H				-11	-	++	Ħ	Ħ	Ħ	Ħ	**		- 1			ē	
***			11			-	H	Ħ	Ħ	++	++	H			HH	H	H	Ħ	++	++	++	Ħ	11	11	11				T		Ħ	Ħ	Ħ	Ħ	**		-		11	-	
ht-t-		-1-1		11		-	H	H	++	Ħ	++	++				H-	Ħ	Ħ	Ħ	Ħ	Ħ	Ħ	Ħ	-++				-11	11	ŦŦ	Ħ	Ħ	Ħ	Ħ			-				
	11				77	-	1-1-	++	Ħ	tt	++	++				H	Ħ	Ħ	Ħ	Ħ	Ħ	Ħ	++		-11			-1-1	11		Ħ	H	H	Ħ	11	11	11		11	-++	
	t-t-1	-1-1	11	-	11	+	++	t+	++	$\mathbf{t}$	++	++				H+	H	++	++	++	Ħ	Ħ	Ħ		++					tt	Ħ	Ħ	H	Ħ			11		11	11	-
111	P P I	11		-	77	+	++	tt	++	++	++	++				H+	H	Ħ	Ħ	+	++	Ħ	H		H						Ħ	Ħ	Ħ	Ħ	11	11			++		
	P 💼	t i t	-1-1		-		(+)	t +	tt	++	++	++				H	Ħ	++	++	++	++	++	++	++	Ħ						Ħ	Ħ	Ħ	tt	$\mathbf{t}$	11	11		Ħ	$\mathbf{t}$	
***	* ***		-1-1		4	+	- ÷-		1	tt	++	++				H	Ħ	Ħ	++	++	Ħ	++	++		++						Ħ	Ħ	H	Ħ	++	++			++		++
	• • •			-1-			dende i	• •	* *		++	H				H	Ħ	++	++	++	++	++	++	++	$\mathbf{t}$			11	11	111	tt	H+	H	++	$\mathbf{t}$	++	++	11	++	++	++-
6.* * ·			-++		-1-	4	1+ I	* *	**	++	++	++				H	Ħ	++	++	++	++	++	++	++	++				++	++	Ħ	H	H	Ħ	++	++	++		H		++
111.0			-	-	7-		1-4-	• •	* *	**	++	++				++	H	++	++	++	++	++	++	++	++				11		H	H	H	++	++	++	++		++	-++	++-
11117					-+-	-4-	- 1 -	• •	••		++	++	++			+	++	++	++	++	++	+	++	++	++			++	++			H	H	H	++	++	++	++	++	++	++-
100		1							• •	**	++	++	++			++	H	++	++	++	++	++	++	++	++				++	++	Ħ	Ħ	H	++	++	++	++		1	++	++-
4444	1.9	4421	1							* *	++	++	-+-			$\vdash$	++	++	++		++	++	++	++	++			++	++	++	++		+	++	++	++	++			++	++-
		111		100	• •						1-1	++	-+-			++-	+-+-	++	+	++	++	++	++	++	++			++	++	++	H		H	┿	++	++	++	++	++		++
		****	# 1	1									-+-+			++	++-	++	++		++	++	++	++	++	++		++	++	++	++	++-	++	++	++	++	++				
		11	il.	1														++	++	++	++	++	++	++	++		- +		++	++	++	++	++	++	$^{++}$	++	++				
		1																	++	++	++	++	++	++	++			++	++	++	++	++-	++	++	++				-		
		- 44															+++		++	++	++	++	++	++	++	-+-+		++	++	++	++-	┿┿	⊷	++-	++			-			-
																	<u>}</u>			++	++	++	+	++	$\rightarrow$				++	++	++	++	++	₩	++	++		++	+		
				1.4.4																	++	++	++	++	++			++	++	++	++-	++-	++	++-	++			++	$\rightarrow$	-+-+	-
				1.4																									11	_		1.1.									

#### APRIL MONTHLY AVERAGES

					•
┼┼┼┼┼┼┼┽┽┥┥┥					
┼┼┼┼┼┼┼┼┼┼┼┼					
┼╌┼╌┼╶┼╶┼╌╄╌╉╌╉╼╉╼╉	****************				
<del>````</del>					
************				*********	
***********					
***********					
**************					
**************		*************		*************	*********
*************	*****************				
		*************	***************		
22272 2222 22222 2 2 2 2 2 2 2 2 2 2 2					
****************					
4441111 HILL	<del>╎╎┫┥┥┥┥╡╡╡╡</del> ╪┼┽┥┼┥┼╴				
1115	┪╍╋┲┥┲┥┎┥┍┥┍┥┍╋╍╋╍╋╍╋╍╋╍╋╍╋╍╋			+++++++++++++++++++++++++++++++++++++++	
	<u>┥╴┼┼┼┼┼┼┼┼┼┼┼</u> ┧╌┟╴┧╴┟╴┨╶┝╶┨╴┨╌┨╼┠╼				
the second s			┟╾╅╼╋╼╉╼╋╼╉╼╉╼┥╾┥╼┥╼┥╼┥╌┥╌┥		
·····			┢╌╆╍╋╍╋╍╋╼╋╼╋╼╋╼╋╼╋╼╉┍┤╹╵╵╵╵		
ARRENT AND A DESCRIPTION OF A DESCRIPTIO					
a sea a state a sea a		the set was not the set of the last we was not the	and we and we and set we are use the day of the local set	THE REPORT OF A DESIGN OF A DE	the same and, and the same and

#### MAY MONTHLY AVERAGES



#### AUGUST MONTHLY AVERAGES



#### **OCTOBER MONTHLY AVERAGES**



#### DECEMBER MONTHLY AVERAGES

																							•					
																	•											
			••													•				•								
					·								. • •								•							
								_													•••						•	_
								_											-								•	•
						+++				_						_	_											
	⊷⊷					+++																						
						+++	+++																					
+++++	⊷⊷					+++		⊷																		222		
					++++	+++		+++			+++																	
++++	++++	H		+++	++++	+++	⊷	H			+++										222					111		
++++	++++	++++		+++	+++	+++	+++	Ht	+++		+++																	
++++	╋╋╋╋	++++	++++		++++	+++	+++	+++	H		H			H													- C	
	╋╋	++++		++++	++++	+++		+++			HH			HH		H-1												
++++	****	++++		+++	HH	+++	HH	HH	HH		HH	H		нн		HH												
+++++	++++	++++	+++	++++	HH	+++		<del>HH</del>	HH		HH	ΗH		HH		H		H										
	++++	HH		+++-	HH	+++			111		HT	TH		H				m										
		HH		+++	HH				H		HT	H		H		н		TT T					-					
	++++	HH		+++-	HH	$\mathbf{T}$			H		HT							TT										
	++++	HH		$\mathbf{H}$	HH	$\mathbf{t}$	HT	HT	H		HT			П		$\mathbf{T}$		TT										
	$\mathbf{H}$	HH		$\mathbf{T}$	$\mathbf{H}\mathbf{H}$	$\mathbf{T}$	$\mathbf{H}$	HT	ш		HT					$\mathbf{TT}$		TT T	<b>T T T</b>			1						
	TTT			TTT	пп		пт	пт	П									ггг				۱						
	ППТ																	п	гт			гп	•					
					ГПТ			п			ш							ГГГ				ТΠ						
																		ш										
				+++-		+++			444			+++																
┟┾┾┾╸	┢┝┢┢┢	++++	+++	┿┿┿	┶┷┷	+++			+++		+++	+++									H+-					_		
╅╼╅╼┩╌		++++	+++	+++		+++	+++-	+++	+++		₩	+++		+++	-+	нн		+++				+++		+++	++-			+++-
<b>∳</b> ₋∳₋∳₋∮…	┥╌┥╌┥╌┥╌	++++	+++	┿┿╄╸	┝┼┽┽	++++		+++	+++		+++	+++	++-	+++	++-	HH		+++			+++	+++		⊷	+++		+++	╋╋╋
station of the state of the sta	<u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u></u>	****	+++	+++	┝┼┾╋	++++		+++	+++		+++	+++	++-	+++		нн		+++			+++	+++		+++	+++	+++		++++
<ul> <li>•••</li> <li>•••</li> </ul>	┢╌┝╌┢╌╋╍	++++	+++	+++	++++	++++		+++	+++		+++	+++		+++				+++			⊷	+++		+++	+++		+++	++++
****	****	++++	+++	+++	++++	++++		+++	+++		+++	+++		+++			+++				HH	HH		+++	H			+++
• • • • •		$\cdot \cdot \cdot \cdot$		+++	++++	+++	+++	+++	+++		+++	+++		HH		HH		-			+++	+++		+++	+++			++++
	* the state	111	+++	***	++++	+++	+++-	+++	+++		+++	+++		H		H	H	ΗT			Ht	HH		HH	H	HH	Ht	++++
	• • • • • • • •					Ht		+++	H		HT	+++		HH		HT		HT	fП			H		HT	H			
		1111				H										пп		ΠT	T			т		$\mathbf{m}$				
						HT.			тп							пт		TT	$\mathbf{T}$			т		ΠT				
																		пт										
11114	0 A																							ПТ				
1		1111																										
	1991	100					1.1.1		111					$\square$		$\square$												
										_						11							44					
		111111																									_	
	200	11111								-+		+++	++-			+++		+++			+ + -			+++		-		-
									+++	-+	+++	+++				+++		$\mapsto$	+++			+++		+++	-			and so in the
									╌┧╼┝═┪			+++	-+-+-	+++-				+++	┿┿┥	-+-+-	+++-		-+	+++	++		L++	
							i .	<u>L I I</u>																				

# "PREATTENTIVE" FEATURES

- Certain basic visual features are detected by our low-level visual system
  - + detection is rapid, usually in one "glance" of 100-250 msec
  - + can determine presence or absence, possibly amount
  - + unique features can capture our focus of attention

Initially proposed as an automatic, bottom-up phenomena

- Treisman's feature map theory
- Feature hierarchies

Combined bottom-up and top-down models also exist

- Wolfe's guided search
- Huang et. al's boolean maps

# HUE TARGET



ABSENT

PRESENT

# HUE TARGET



PRESENT

ABSENT

# CURVATURE TARGET



ABSENT

PRESENT

# CONJUNCTION TARGET



PRESENT

ABSENT

# CONJUNCTION TARGET



PRESENT

ABSENT

# PREATTENTIVE FEATURES


#### PREATTENTIVE FEATURES



INTERSECTION

TERMINATORS



#### **PREATTENTIVE FEATURES**



**DIRECTION OF LIGHTING** 



## FEATURE INTEGRATION

#### BOTTOM-UP MODEL



#### GUIDED SEARCH

#### BOTTOM-UP AND TOP-DOWN MODEL



## BOOLEAN MAPS

SEARCH FOR A BLUE HORIZONTAL TARGET



PRESENT

ABSENT

## BOOLEAN MAPS

SEARCH FOR A RED VERTICAL TARGET



ABSENT

PRESENT

#### FEATURE HIERARCHY

**IDENTIFY ORIENTATION OF BOUNDARY** 



HUE BOUNDARY

SHAPE BOUNDARY

#### ENSEMBLE CODING

#### IDENTIFY WHICH COLOR HAS LARGER AVERAGE SIZE



ALL GREEN CIRCLES > ALL BLUE CIRCLES

MORE LARGE BLUE CIRCLES

#### **PERCEPTUAL GUIDELINES**

 Choice of data-feature mapping guided by knowledge of human visual perception

- Color is subdivided into hue, saturation, luminance, and/or chromaticity (hue + saturation)
- Texture is subdivided into size, orientation, density, regularity of placement
- + Motion is subdivided into flicker, phase, direction, and velocity
- Feature "hierarchies" control order of data-feature mapping
- Luminance dominates hue, color dominates texture, regularity is perceptually weak, so:
  - + most important data attributes are assigned to luminance,
  - + then hue or chroma,

## **POSTATTENTIVE AMNESIA**

- If viewers are allowed to preview a scene, will they be faster to answer questions about the details of the scene?
- Intuition suggest they will
  - Implies viewers have the ability to extract detail throughout a scene, access it rapidly on demand
- Various experiments have shown that human vision does not work in this manner
  - Vision is not a camera that can "snapshot" a full-detail representation of a scene
  - Results suggest that detail is only available at the most recent focus of attention



Priming image

## **POSTATTENTIVE AMNESIA**

- If viewers are allowed to preview a scene, will they be faster to answer questions about the details of the scene?
- Intuition suggest they will
  - Implies viewers have the ability to extract detail throughout a scene, access it rapidly on demand
- Various experiments have shown that human vision does not work in this manner
  - Vision is not a camera that can "snapshot" a full-detail representation of a scene
  - Results suggest that detail is only available at the most recent focus of attention



# SEARCH WITH NO PRIMING

#### GREEN VERTICAL

#### SEARCH WITH NO PRIMING



PRESENT

#### PRIMED SEARCH



#### PRIMED SEARCH



ABSENT

• Visual system has limited memory for detail, often restricted to focus of attention

- Visual disruption (e.g., eye saccade) can render us "blind" to changes in a scene
- Common example: newspaper game, find differences between two images
- Original experiments conducted at Nissan's Cambridge Basic Research



Find four differences between the two images

# FIND FIVE DIFFERENCES



# FIND FIVE DIFFERENCES





DATA COURTESY RON RENSINK, DEPARTMENT OF PSYCHOLOGY, UBC



DATA COURTESY RON RENSINK, DEPARTMENT OF PSYCHOLOGY, UBC



DATA COURTESY RON RENSINK, DEPARTMENT OF PSYCHOLOGY, UBC

# CHANGE BLINDNESS MODELS

#### Overwriting

- current image overwritten by new one
- First impression
  - + initial view abstracted
- Nothing is stored
  - scene abstracted with no details
- Feature combination
  - previous and new views combined



Main actor changes across movie cut

- Everything is stored, nothing is compared
  - + details cannot be accessed without external stimulus

#### DETERMINE ARM ORIENTATION

Determine the orientation of the longer arm of the cross:

# + +

horizontal or vertical

#### INATTENTIONAL BLINDNESS

Determine the orientation of the longer arm of the cross:



# GREY SQUARE IN FRAME



#### **INATTENTIONAL BLINDNESS**

- During an attention-demanding task, viewers are "blind" to significant change in a scene
- These same change is easily identified when scene is viewed without any task
- Hypothesis: visual system has a limited amount of "visual attention" it can deploy over a scene
- Classic example, counting basketball passes
  - Two teams, black and white, viewer asked to count passes for one of the teams
  - + During the passing, a woman in a gorilla suit walks through the scene
  - More than half the viewers did not notice the gorilla

# SALMON MIGRATIONS

• Track salmon migration patterns in the Northern Pacific

- Migration patterns affected by:
  - + sea surface temperature
  - plankton density
  - ocean current direction and velocity
- Approach determines which strait holds the bulk of the salmon run
- Estimations critical to setting



Migration occurs north through Strait of Georgia or south through Juan de Fuca Strait

http://www.csc.ncsu.edu/faculty/healey/HTML\_papers/plankton/plankton.html

#### **KNOWN PLANKTON DENSITIES**



**PLANKTON DENSITY**  $\rightarrow$  **LUMINANCE** 

#### INTERPOLATED PLANKTON DENSITIES



PLANKTON DENSITY → LUMINANCE

#### DATA MINED PLANKTON DENSITIES



JANUARY

PLANKTON DENSITY → LUMINANCE

#### MIGRATION FACTORS VISUALIZATIONS

FEBRUARY

PLANKTON DENSITY  $\rightarrow$  BLUE...GREEN...BROWN...RED...PURPLE, CURRENT STRENGTH  $\rightarrow$  HEIGHT, SEA SURFACE TEMPERATURE  $\rightarrow$  DENSITY

#### MIGRATION FACTORS VISUALIZATIONS

JUNE



#### MIGRATION FACTORS VISUALIZATIONS

OCTOBER

PLANKTON DENSITY  $\rightarrow$  BLUE...GREEN...BROWN...RED...PURPLE, CURRENT STRENGTH  $\rightarrow$  HEIGHT, SEA SURFACE TEMPERATURE  $\rightarrow$  DENSITY

# **PAINTERLY VISUALIZATIONS**

• Can we build aesthetically beautiful visualizations?

#### Orientation versus engagement

- + Engage a viewer, promote increased recall for detail
- Motivate a more detailed examination of images
- + Highlight important properties of a dataset
- Enhance a visualization
  - highlight important data properties
  - remove extraneous detail
  - harness artistic techniques to convey difficult-to-visualize details



Original hurricane image



Boundaries enhanced

Case Study on Visualizing Hurricanes Using Illustration-Inspired Techniques, 2009. Alark Joshi, Jesus Caban, Penny Rheingans, Lynn Sparling, IEEE Transactions on Visualization and Computer Graphics 15, 5, pp 709-718.

# SUPERNOVA SIMULATION



FLOW DIRECTION  $\rightarrow$  ORIENTATION, MAGNITUDE  $\rightarrow$  COLOUR, DENSITY  $\rightarrow$  SIZE

DATA COURTESY JOHN BLONDIN, DEPARTMENT OF PHYSICS, NC STATE UNIVERSITY

## SUPERNOVA SIMULATION



FLOW DIRECTION  $\rightarrow$  ORIENTATION, MAGNITUDE  $\rightarrow$  COLOUR, DENSITY  $\rightarrow$  SIZE, PRESSURE  $\rightarrow$  ASPECT RATIO

DATA COURTESY JOHN BLONDIN, DEPARTMENT OF PHYSICS, NC STATE UNIVERSITY
#### **NONPHOTOREALISM RESULTS**

- Nonphotorealistic visualizations have capabilities similar to glyph-based visualizations
- Visual complexity can be varied to systematically change perceived aesthetic

• In terms of enhancement:

- more aesthetic visualizations produce improved memory for detail
- the most aesthetic visualizations have similar memory for detail to glyph-based visualizations



Wind Speed  $\rightarrow$  Hue, Minimum Temperature  $\rightarrow$  Luminance, Radiation  $\rightarrow$  size, Precipitation  $\rightarrow$  Orientation

Data courtesy Climatic Research Unit, University of East Anglia

### **U.S. ELECTION PATTERNS**

- "Red" versus "Blue" states
- Visualize election patterns throughout the country
- How do participants vote for different elected offices?
  - President
  - + U.S. Senate
  - + U.S. House
  - Governor
- Subdivide country into congressional districts



#### 2008 double-ended red-blue Presidential map



2008 continuous red-bluePresidential map















# NC 3D DISTRICT MAP



#### UNITED STATES



HTTP://WWW.CSC.NCSU.EDU/FACULTY/HEALEY/US ELECTION

#### EARMARKS



MAJORITY EARMARK PARTY  $\rightarrow$  HUE, DOLLARS PER PERSON  $\rightarrow$  SATURATION, ABSOLUTE DOLLARS  $\rightarrow$  HEIGHT

HTTP://WWW.CSC.NCSU.EDU/FACULTY/HEALEY/US ELECTION

#### **CONTACT INFORMATION**

HEALEY@CSC.NCSU.EDU HTTP://WWW.CSC.NCSU.EDU/FACULTY/HEALEY

> SPECIAL THANKS TO: JAMES ENNS (PSYCHOLOGY, UBC), ROBERT ST. AMANT (CS, NCSU), RUSS TAYLOR (CS, UNC-CHAPEL HILL)

JOE HSIAO, SARAT KOCHERLAKOTA, GENIVA LIU, MARK REMPLE, LAURA TATEOSIAN

SUPPORTED BY: NSF-PHY-0941373, NSF-IIS-9988507, NSF-ACI-008342, NSF-ACI-0092308