



۰.

الحديد الجار

ς.

~

MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDAUS 10057

.

. .

.

REPORT DOCUMENTATION				N PAGE			Form Approved OM8 No 0704-0188		
Ta REPORT SECURITY CLASSIFICATION					16 RESTRICTIVE MARKINGS				
Unclassi	fied								<u></u>
	• • •	01	400	·	Approved	for public	F REPORT	a. die	
Αυ		91	455		unlimite	d	161699	c, u12	50110001
4 PERFORMING	ORGANIZAT	IUN KEPU		:#(5)	5. MONITORING	ORGANIZATION R	EPORT NU	MBER(S)	
					R&D 4314	-CC-01			
6a. NAME OF PI	ERFORMING	ORGANIZ.	ATION	6b. OFFICE SYMBOL	7a. NAME OF M	IONITORING ORGA	NIZATION		
The Weizmann Institute of (If applicable)					USARDSG-	UK			
SCIENCE	ty, State. an	d ZIP Coa	e)	L	76. ADDRESS (C	ity, State, and ZIP	Code)		
Pohomot 76100					Box 65				
Israel	, 0100				FPO NY O	9510-1500			
83. NAME OF FI	UNDING / SPC	ONSORING		86. OFFICE SYMBOL	9. PROCUREMEN	IT INSTRUMENT IC	ENTIFICAT	ION NUN	MBER
ORGANIZAT	ION			(If applicable)	DATA45-	84-0-0040			
USARDSG-	UK	ARO-E		<u> </u>		SUNDING NUMARE			
Sc. ADDRESS (CA	ty, State, and	I ZIP Code	•)	•	PROGRAM	PROJECT	TASK		WORK UN
Box 65	9510-150	1 A	•		ELEMENT NO.	NO.	NO.	1	ACCESSION
					OTTOER	TETOTTOZEN.	1		
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN	AUTHOR(S) or Zohar EPORT	Manna 1 TION	36. TIME C	OVERED 4.85 TO <u>31.3.8</u> 7	14 DATE OF REP	ORT (Year, Month	, Day) 15	. PAGE (COUNT 3
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN	AUTHOR(S) OF Zohar EPORT TARY NOTA	Manna 1 TION	35. TIME C	OVERED <u>4.85</u> TO <u>31.3.8</u> 7	14 DATE OF REP	ORT (Year, Month	, Day) 15	. PAGE (COUNT 3
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17	AUTHOR(S) DT Zohar EPORT TARY NOTA COSATI	<u>Маппа</u> 1 ТІОN СОДЕS	36. TIME C FROM <u>1</u> .	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS	14 DATE OF REPO	ORT (Year, Month	, Day) 15 Ind identify	. PAGE (COUNT 3
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD	AUTHOR(S) DE ZOHAE EPORT TARY NOTA COSATI GROUP	Manna TION CODES SUB-	36. TIME C FROM <u>1</u> . GROUP	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS	(Continue on rever	ORT (Year, Month	, Day) 15	PAGE C	COUNT 3 Umber)
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17	AUTHOR(S) DE Zohar EPORT TARY NOTA COSATI GROUP 05	Manna 1 TION CODES SUB-	35. TIME C FROM <u>1</u> . GROUP	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS	14 DATE OF REPO	ORT (Year, Month	d iden ify	PAGE (COUNT 3 (umber) TE
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 19 JABSTRACT (AUTHOR(S) DT Zohar EPORT TARY NOTA COSATI GROUP 05 Continue on	Manna 1 TION CODES SUB- COVES	3b. TIME C FROM <u>1</u> . GROUP	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block	(Continue on rever	ORT (Year, Month	d identify	PAGE ()y voc EC	COUNT 3 TE 1988
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 14 JABSTRACT (Research	COSATI GROUP 05 Continue on Concent	Manna TION CODES SUB- reverse r trated	3b. TIME C FROM <u>1</u> . GROUP	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics:	(Continue on rever	ORT (Year, Month	d ider ify	PAGE ()7 1000 _EC R 1.5	COUNT 3 TE 10988
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 TQUABSTRACT (Research 1. De	COSATI GROUP 05 Continue on concent eductive	Manna TION CODES SUB- reverse r trated synthe	3b. TIME C FROM <u>1</u> . GROUP of necessary on threesis of	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo	(Continue on rever number)	ORT (Year, Month	, Day) 15 d iden ity E I AP	PAGE C Jy Tool LEC R 1.5 ca E	COUNT 3 TE 1988
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 19 ABSTRACT (Research 1. De 2. B1 3. Th	COSATI GROUP 05 Continue on Concent concent concent concent concent concent concent	Manna TION CODES SUB- reverse r trated synthe arch al plans.	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithm	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo	(Continue on rever number)	ORT (Year, Month	d iden ify E I AP	PAGE ()y foce E R 1.5 e E	COUNT 3 TE 1988
12. PERSONAL A Professo 13a. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 TQABSTRACT (Research 1. De 2. Bi 3. Th In the f	COSATI GROUP 05 Continue on concent ductive inary-sea leory of first are	Manna TION CODES SUB- reverse of crated synthe arch al plans. ea, a m	3b. TIME C FROM 1. GROUP on threessary on threess of lgorithm. method c	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive sym-	(Continue on rever number) orks,	ORT (Year, Month rse if necessary and	, Day) 15 d iden ify EI AP	PAGE C LEC R 1 5 CA E ks wa	s develo
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 19 JABSTRACT (Research 1. De 2. Bi 3. Th In the f	COSATI GROUP 05 Continue on a concent ductive nary-sea heory of irst are second ar	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, ge	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithmethod control the	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo ans, of deductive symplements of binary-search so	(Continue on rever number) orks, hthesis of de	ORT (Year, Month rse if necessary and eterministic enstructed a	networ nd spec	PAGE ()y Voc EC EC E E ks wa ializ	s develo
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 FIELD 12 17 FIELD 12 17 FIELD 12 17 FIELD 13 FIELD 14 ABSTRACT (Research 1. De 2. Bi 3. Th In the final In the sparticul explicit	COSATI GROUP 05 Continue on a concent ductive inary-sea heory of first are second ar lar appli	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, get cation s was d	3b. TIME C FROM <u>1</u> . GROUP of necessary on threesis of lgorithm method co eneral the ns. Fir	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive symplications binary-search second second binary-search second second binary a variant ced into the pr	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	ORT (Year, Month rse if necessary and eterministic constructed a onal logic i hesis resear	networ n which	PAGE () EC R 15 C R 15 C	s devel ed for s are
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 19 ABSTRACT (Research 1. De 2. Bi 3. Th In the f In the s particul explicit	COSATI GROUP 05 Continue on a concent ductive lary-sea leory of first are second ar lar appli cobjects	Manna TION CODES SUB- reverse r reverse r trated synthe arch al plans. ea, a m tea, get cation s was b	3b. TIME C FROM <u>1</u> . GROUP of necessary on threesis of lgorithmo- method co eneral the s. Fir introduce	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo nas, of deductive symplements binary-search search search hally, a variant ced into the pro-	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	ORT (Year, Month rse if necessary and constructed a onal logic i hesis resear	networ n which	PAGE (PAGE (E E E E E E E E E E E	s develo s develo s are
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 FIELD 12 17 TAJABSTRACT (Research 1. De 2. Bi 3. Th In the f In the s particul explicit	COSATI GROUP 05 Continue on a concent ductive inary-sea heory of first are second ar lar appli cobjects	Manna TION CODES SUB- reverse r rated synthe arch al plans. a, a m rea, ge cation s was b	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithm method c eneral b ns. Fir introduc	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive symplications binary-search similarly, a variant ced into the pro-	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	ORT (Year, Month rse if necessary an ecerministic constructed a onal logic i hesis resear	networ n which ch.	PAGE C PAGE C E E E E E E E E E E E E E E E	s develo ed for s are
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 19 JABSTRACT (Research 1. De 2. Bi 3. Th In the f In the s particul explicit	COSATI GROUP 05 Continue on a concent ductive inary of irst are second ar lar appli objects	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, get cation s was b	3b. TIME C FROM <u>1</u> . GROUP of necessary on threesis of lgorithm method c eneral b ns. Fir introduc	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive symplications binary-search so hally, a variant ted into the pro-	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	ORT (Year, Month rse if necessary and constructed a onal logic i hésis resear	networ n which	PAGE (PAGE (E E E C E C E C E C E C E C E C E C E	s develo ed for s are
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 12 17 TABSTRACT (Research 1. De 2. Bi 3. Th In the f In the s particul explicit	COSATI GROUP 05 Continue on a concent ductive inary-sea heory of first are second ar lar appli cobjects	Manna TION CODES SUB- reverse r rated synthe arch al plans. a, a m rea, ge cation s was b	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithm method c eneral b ns. Fir introduc	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive symplications binary-search similarly, a variant ced into the pro-	(Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	ORT (Year, Month rse if necessary and ecerministic constructed a onal logic i hésis resear	networ n which ch.	PAGE C PAGE C E E E E E E E E E E E E E E E	s develo ed for s are
12. PERSONAL A Professon 13a TYPE OF R Final 16. SUPPLEMEN 17. FIELD 12. 14. 14. 14. 15. 14. 14. 15. 14. 14. 14. 14. 15. 14. 14. 14. 14. 14. 14. 14. 14	COSATI GROUP 05 Continue on Concent ductive inary-sea leory of first are second ar lar appli cobjects	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, get cation was b	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithm method c eneral b ins. Fir introduc	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo binary-search so hally, a variant ted into the pro-	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth	eterministic eterministic enstructed a onal logic i hesis resear	networ n which cATION	PAGE ()y Voc EC R 15 CA E Sks wa ca E Sks wa ca E Sks wa ca E	s develo ed for s are
12. PERSONAL A Professo 13. TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 FIELD 1 12 17 TALABSTRACT (Research 1. De 2. Bi 3. Th In the f In the f In the s particul explicit 20 DISTRIBUTION SUNCLASSI 12. NAME OF	COSATI GROUP 05 Continue on a concent ductive inary-sea heory of first are second an lar appli cobjects	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, get cation s was b BILITY OF TED X E INDIVIO	3b. TIME C FROM <u>1</u> . GROUP on threessary on threesis of lgorithm method co eneral the s. Fir introduce ABSTRACT SAME AS	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo as, of deductive symplications binary-search sub- hally, a variant ced into the pro- pro- PT IN DTIC USER	(Continue on rever (Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth 21 ABSTRACT S Unclass 225 TELEPHONE	ORT (Year, Month rse if necessary and constructed a onal logic i hesis resear SECURITY CLASSIFI ified E (Include Area Coo	networ no which ch.	PAGE (Pr Joc R 15 R 15 C E E Sks wa ializ i plan	s develo ed for s are
12. PERSONAL A Professo 13a TYPE OF R Final 16. SUPPLEMEN 17 FIELD 1 12 17 FIELD 1 12 17 FIELD 1 2 17 FIELD 1 2 FIELD 1	COSATI GROUP 05 Continue on a concent ductive inary-sea leory of first are second an lar appli cobjects DN/AVAILAB FIED/UNLIMI RESPONSIBLI a M. Zava	Manna TION CODES SUB- reverse r rated synthe arch al plans. ea, a m rea, get cation swas d BILITY OF TED XI E INDIVIO ada	3b. TIME C FROM <u>1</u> . GROUP on threesis of lgorithmomethod co eneral b introduce ABSTRACT SAME AS	OVERED <u>4.85</u> TO <u>31.3.8</u> 18. SUBJECT TERMS and identify by block the topics: data flow netwo and, search so binary-search so binary-search so ally, a varian ced into the pro-	(Continue on rever number) orks, hthesis of de chema were co t of situatio ogram - synth 21 ABSTRACT S Unclass 225 TELEPHONE 01-409	ORT (Year, Month rse if necessary and constructed a onal logic i hesis resear SECURITY CLASSIF ified E (Include Area Con 4423	networ nd spec n which ch. CATION	PAGE ()y Voc EC E E E E E E E E E E E E E E E E E E	s develo ed for s are

INTERACTIVE SYNTHESIS OF COMPUTER PROGRAMS

by

Zohar Manna Professor of Computer Science Weizmann Institute of Science Rehovot 76100, Israel

Final Report: United States Army Research Contract DAJA-45-84-C-0040 April 1, 1985 – March 31, 1987

Acce	ssien For	
NTIS	GRA&I	· · · · · · · · · · · · · · · · · · ·
DTIC	Тав	
Unan	nounced	ñ
Just	fication_	
Avai	lability (odes
Avai Dist	lability (Avail and Special	odes /or
A-1		

38 2 1

3

TECHNICAL SUMMARY

Our research concentrated on the following three topics. For each topic a copy of a published paper is enclosed.

• Deductive Synthesis of Dataflow Networks

Jonsson, B., Z. Manna, and R. Waldinger, "Towards deductive synthesis of data-flow networks," *First Symposium on Logic of Computer Science*. Cambridge, MA, June 1986, pp. 26-37.

The synthesis of concurrent programs is much more complicated than the synthesis of sequential programs. In general, a concurrent program does not have a single input value and a single output value, but receives several inputs and sends several outputs during its execution. If we consider *sequences* of input and output values, then we can specify a concurrent program by giving a relation between the sequence of input values and the sequence of output values. This specification method is natural especially for networks of deterministic processes that communicate asynchronously by sending messages over buffered channels. Deterministic data flow networks fall into this category.

We have developed a method for the deductive synthesis of deterministic dataflow networks. which are specified by a relation between sequences of input values and sequences of output values.

Our synthesis method consists of two stages. The first stage, the deductive-synthesis stage, starts from a specification of the network. Using the deductive-tableau techniques of Manna and Waldinger, a system of recursive equations is synthesized. This system can be regarded as an applicative program that satisfies the specification for the network, but it does not directly represent any structure or parallelism of a network. In the second stage, the system of recursive equations is transformed into a dataflow network.

1

• Binary-Search Algorithms

Manna, Z., and R. Waldinger, "The origin of the binary-search paradigm," 9th International Joint Conference on Artificial Intelligence, Los Angeles, August 1985, pp. 222-224. Also in Science of Computer Programming Journal, Vol. 9, No. 1 (August 1987), pp. 37-83.

Some of the most efficient numerical algorithms rely on a *binary-search* strategy; according to this strategy, the interval in which the desired output is sought is divided roughly in half at each iteration. This technique is so useful that some authors (e.g., Dershowitz and Manna, Smith) have proposed that a general binary-search paradigm or schema be built into program synthesis systems and then specialized as required for particular applications.

It is certainly valuable to store such schemata if they are of general application and difficult to discover. This approach, however, leaves open the question of how schemata are discovered in the first place. We have found that the concept of binary search appears quite naturally and easily in the derivations of some numerical programs. The concept arises as the result of a single resolution step, between a goal and itself, using our deductive-synthesis techniques.

The programs we have produced in this way (e.g., real-number quotient and square root, integer quotient and square root, and array searching) are quite simple and reasonably efficient, but are bizarre in appearance and different from what we would have constructed by informal means. For example, we have developed by our synthesis techniques the following real-number square-root program $sqrt(r, \mathcal{E})$:

 $sqrt(r, \epsilon) \Leftarrow \begin{cases} if \ max(r, 1) < \epsilon \\ then \ 0 \\ else \ if \ [sqrt(r, 2\epsilon) + \epsilon]^2 \le r \\ then \ sqrt(r, 2\epsilon) + \epsilon \\ else \ sqrt(r, 2\epsilon). \end{cases}$

The program tests if the error tolerance ϵ is sufficiently large; if so, 0 is a close enough approximation. Otherwise, the program finds recursively an approximation within 2ϵ less than the exact square root of r. It then tries to refine this estimate, increasing it by ϵ if the exact square root is large enough and leaving it the same otherwise.

This program was surprising to us in that it doubles a number rather than halving it as the classical binary-search program does. Nevertheless, if the repeated occurrences of the recursive call $sqrt(r, 2\epsilon)$ are combined by common-subexpression elimination, this program is as efficient as the familiar one and somewhat simpler.

• A Theory of Plans

Manna, Z., and R. Waldinger, "How to clear a block: A theory of plans," in *Reasoning About Actions and Plans: Proceedings of the 1986 Workshop*, Timberline, Oregon, July 1986, Morgan and Kaufmann (M.P. Georgeff and A.L. Lansky, eds.), pp. 11-45. Also in the *Journal of Automated Reasoning*, Vol. 3, No. 4 (December 1987), pp. 343-377.

Problems in commonsense and robot planning were approached by methods adapted from our program-synthesis research; planning is regarded as an application of automated deduction. To support this approach, we introduced a variant of situational logic, called *plan theory*, in which plans are explicit objects. A machine-oriented deductive-tableau inference system is adapted to

2

plan theory. Equations and equivalences of the theory are built into a unification algorithm for the system. Frame axioms are built into the resolution rule.

Special attention was paid to the derivation of conditional and recursive plans. Inductive proofs of theorems for even the simplest planning problems, such as clearing a block, have been found to require challenging generalizations.

SCIENTIFIC COLLABORATION

The research was conducted in full collaboration with Dr. Richard Waldinger (Artificial Intelligence Center, SRI International), Eric Muller (programmer), and the following Ph.D. students of the Computer Science Department at Stanford University: Yoni Malachi (graduated 1986), Bengt Jonsson, Tomas Feder, Jon Traugott, Alex Bronstein, David Kashtan, and Marianne Baudinet.

Invited lectures and seminars, on the research reported here, were given in the following countries: Austarlia, China, England, India, Israel, Italy, Japan, Thailand, and in the USA.

